IB Diploma Programme Environmental Systems and Societies

Giáo trình luyện thi chuyên sâu

Song ngữ Anh–Việt

8020 ENGLISH

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Lời mở đầu · Foreword

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5/5 AP — điểm tuyệt đối	**90/100** IB Diploma
100% GV $\geq$ 8.0 IELTS / 1500 SAT	**CMU** Tiến sĩ ĐH #1 Hoa Kỳ về CS

> **Đội ngũ tiêu biểu:** Thầy Châu Cát Tường (Academic Head, ThS Western Sydney, top 1% IELTS 8.5) · TS Nguyễn Anh Huy (Carnegie Mellon, cựu kỹ sư Amazon) · TS Nguyễn Phước Trường (Toán, ĐH Klagenfurt) · cùng đội ngũ giảng viên SAT 1500–1600, IELTS 8.0–8.5.

Kết quả học viên — điểm thi thật: IELTS 8.0–9.0 · SAT 1550 / 1570 / 1590 · AP 5/5 (Calculus BC, Microeconomics) · IB 90/100 (Economics) · Duolingo 110 · PTE 90 · TOEFL 120. **Bảng vàng SAT:** Khánh Đăng 1510 · Thảo Nguyên 1520 · Tâm Anh 1530.

"Cuối cùng đã đậu vào trường top như mong muốn." — Phan Thị Thanh Hằng, IELTS Overall 8.5.

Cách dùng sách hiệu quả: mỗi Unit gồm (1) **Lý thuyết trọng tâm** tiếng Anh kèm **giải thích tiếng Việt**; (2) **Ví dụ mẫu** có lời giải; (3) **Hệ thống bài tập** kèm **lời giải chi tiết**. Hãy tự làm bài trước khi xem lời giải để đạt hiệu quả tối đa.

THÀNH TÍCH THỰC TẾ · 8020 ENGLISH

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ĐỘI NGŨ

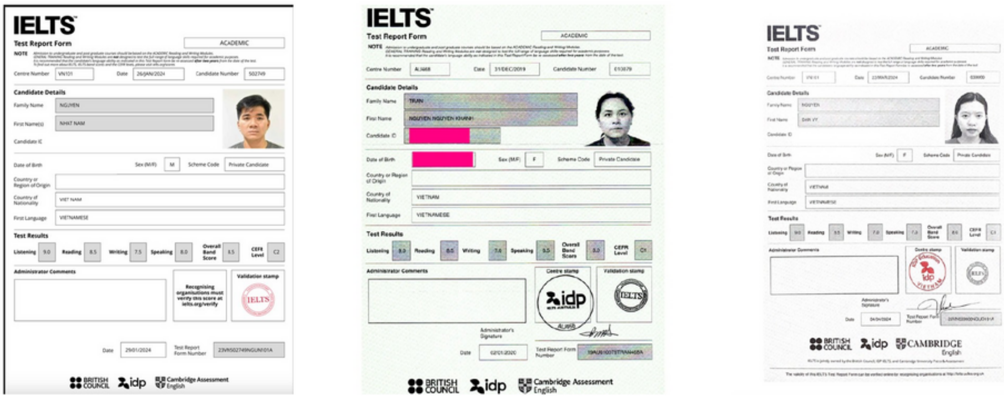
ĐỘI NGŨ GIÁO VIÊN TẬN TÂM

**Tối thiểu 8.0 IELTS Overall*


Gv. Nguyễn Nhật Nam
IELTS 8.5 Overall


Gv. Nguyễn Khanh
IELTS 8.0 Overall


Gv. Nguyễn Đan Vy
IELTS 8.0 Overall

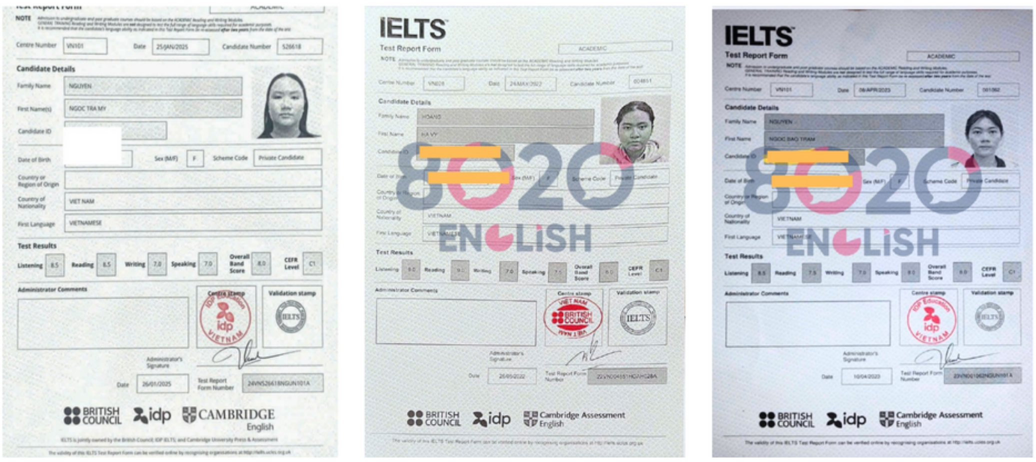


Giảng viên 8020 — IELTS 8.5 & 8.0 Overall (British Council · IDP · Cambridge)

KẾT QUẢ HỌC VIÊN

THÀNH TÍCH HỌC VIÊN

Bảng điểm thi thật – chất lượng được giám sát nghiêm ngặt. Một số học viên chỉ cần 1–2 khóa để đạt kết quả mong muốn.



Học viên 8020 — IELTS 8.0 Overall (bảng điểm thật)

ĐỘI NGŨ

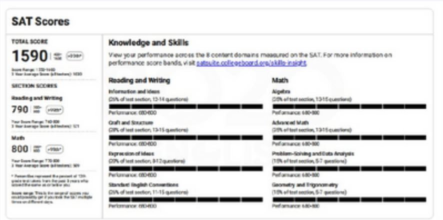
ĐỘI NGŨ GIÁO VIÊN TẬN TÂM

**Tối thiểu 1500 SAT Overall*

Thầy Quang Minh

Đại học Bách Khoa Hà Nội

SAT 1590 | IELTS 8.0



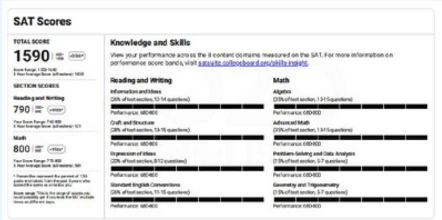
THẾ MẠNH & KINH NGHIỆM

- Học sinh đạt 1450–1560 SAT
- Dạy nhanh band 1400–1550+
- Chiến thuật làm bài & quản lý thời gian

Cô Phương Vy

Đại học Ngoại thương

SAT 1590 | IELTS 8.0



THẾ MẠNH & KINH NGHIỆM

- SAT Verbal Instructor (Springboard, QAS)
- Dạy lớp nhỏ & xây dựng tài liệu riêng
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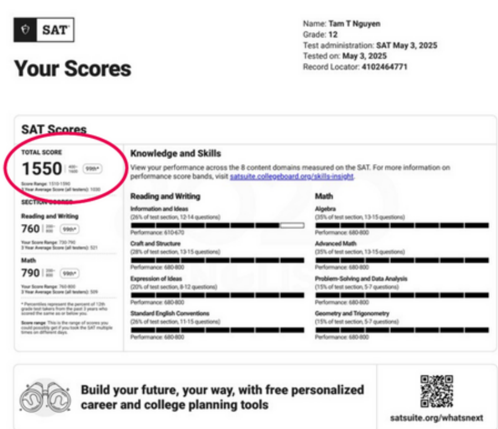
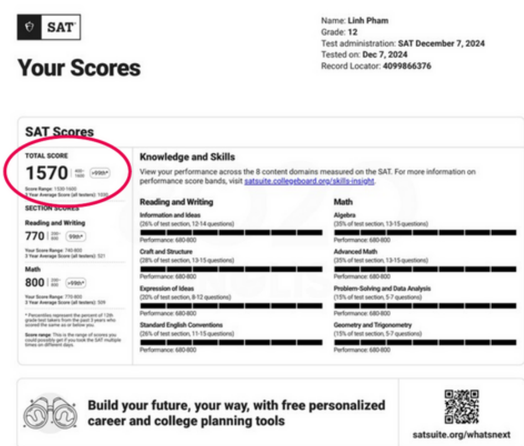
Giảng viên 8020 — SAT 1590 (ĐH Bách Khoa Hà Nội & ĐH Ngoại thương)

KẾT QUẢ HỌC VIÊN

TUTOR 1-1 – ĐIỂM SỐ ẤN TƯỢNG

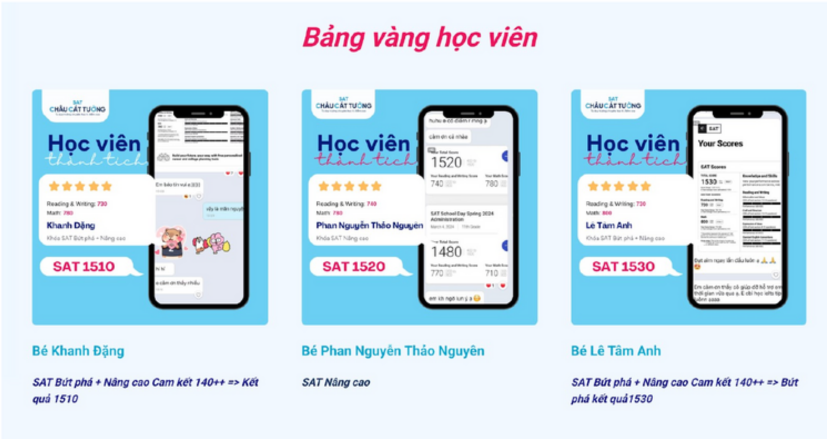




Học viên 8020 — SAT 1550 & 1570 (College Board)

KẾT QUẢ HỌC VIÊN

BẢNG VÀNG HỌC VIÊN



KHÁNH ĐẶNG – SAT 1510
"SAT Bứt phá + Nâng cao cam kết 140++ → 1510"

THẢO NGUYÊN – SAT 1520
"SAT Nâng cao → 1520"

TÂM ANH – SAT 1530
"SAT Bứt phá + Nâng cao cam kết 140++ → 1530"

Bảng vàng SAT — Học viên đạt 1510 · 1520 · 1530

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ AP

AP Biology: 4 · AP Chemistry: 4

AP Calculus AB: 5

AP Calculus BC: 5

AP Chemistry: 5

Bảng điểm AP thật của học viên – nhiều môn đạt điểm 4 & 5

Điểm AP thật — Calculus AB/BC 5/5 · Biology & Chemistry 4–5 (College Board)

Mục lục • Contents

Foundations of ESS

Mục tiêu Unit: Cách tiếp cận hệ thống (systems approach): storage–flow–transfer–transformation, input–process–output, phản hồi âm/dương, cân bằng tĩnh và cân bằng động, khả năng phục hồi (resilience) và ngưỡng (tipping point); hệ giá trị môi trường (EVS) theo phổ sinh thái trung tâm–nhân loại trung tâm–công nghệ trung tâm; định luật nhiệt động lực học áp dụng cho hệ sinh thái; vốn tự nhiên, thu nhập tự nhiên, phát triển bền vững, giới hạn hành tinh (planetary boundaries), bi kịch của tài sản chung (tragedy of the commons), đánh giá tác động môi trường (EIA); ô nhiễm, liều lượng–đáp ứng, nguyên tắc phòng ngừa, tích luỹ sinh học và khuếch đại sinh học.

1.1 Environmental value systems

1.1.1 What is an environmental value system?

Every individual, community, and government approaches environmental issues carrying a particular **worldview** — a set of assumptions and values about how humans relate to the rest of nature. The IB syllabus calls this an **environmental value system (EVS)**: a way of viewing the world and evaluating environmental issues, shaped by cultural, religious, economic, and political contexts, that influences how a person or society perceives and interacts with the environment. An EVS is not simply a scientific position; it is a lens that determines which facts are considered relevant, how risks and benefits are weighed, and what counts as an acceptable trade-off between development and conservation.

An EVS typically forms as the product of several interacting influences:

- **Personal experience** — direct exposure to nature, environmental disasters, or resource scarcity strongly shapes an individual's outlook.
- **Cultural and religious background** — many belief systems (e.g., Indigenous cosmologies, Buddhist or Daoist thought, certain interpretations of Christianity, Judaism, or Islam) contain explicit teachings about humanity's duty toward, or dominion over, the natural world.
- **Education and access to information** — scientific literacy and exposure to environmental data (e.g., climate models, biodiversity statistics) can shift a value system over time.
- **Economic circumstances** — a subsistence farmer dependent on a forest for fuel and food has different immediate incentives than a wealthy urban consumer, even if both value the forest.
- **Political ideology** — beliefs about the proper role of government regulation, free markets, and collective action feed directly into environmental policy preferences.

Because these influences differ from person to person and society to society, EVS is best understood not as a single fixed category but as a continuum, or **spectrum**, running from strongly nature-centered views at one extreme to strongly human/technology-centered views at the other.

The EVS spectrum

Ecocentrism (nature-centered) places intrinsic value on all living things and ecosystems, independent of their usefulness to humans; it argues for minimal human interference, self-restraint, and small-scale, self-sufficient communities. Its most extreme form is **deep ecology**, which holds that all organisms and ecosystems have an equal right to exist and flourish, that hu-

man population and consumption must be radically reduced, and that current economic and political structures require fundamental transformation, not mere reform.
Anthropocentrism (human-centered) is the middle of the spectrum: it accepts that humans must manage and regulate the environment to sustain resources and quality of life for people, favouring negotiated compromise, environmental regulation, taxation, and education — the classic position of the "environmental manager."
Technocentrism (technology-centered) holds that environmental problems can and should be solved through technological innovation, management, and continued economic growth, with confidence that human ingenuity will overcome resource limits. Its most extreme form is the **cornucopian** view: markets and technology will always find substitutes for depleted resources, so there are effectively no meaningful limits to growth, and minimal environmental regulation is needed.

The EVS spectrum: ecocentric ↔ anthropocentric ↔ technocentric, with deep ecology and cornucopianism as the two extreme, opposite ends.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hệ giá trị môi trường (EVS) là cách một cá nhân hay xã hội nhìn nhận và đánh giá các vấn đề môi trường, chịu ảnh hưởng bởi văn hoá, tôn giáo, kinh tế và chính trị. EVS được sắp xếp trên một **phổ (spectrum)** gồm ba vùng chính: **sinh thái trung tâm (ecocentric)** — coi tự nhiên có giá trị tự thân, cần hạn chế tối đa can thiệp của con người (cực đoan nhất là **deep ecology** — sinh thái học chiều sâu, cho rằng mọi loài đều có quyền tồn tại ngang nhau và đòi hỏi thay đổi tận gốc hệ thống kinh tế–chính trị); **nhân loại trung tâm (anthropocentric)** — con người cần quản lý và điều tiết môi trường để duy trì tài nguyên cho chính con người, thiên về thoả hiệp, quy định pháp luật và giáo dục; **công nghệ trung tâm (technocentric)** — tin rằng công nghệ và tăng trưởng kinh tế sẽ giải quyết được vấn đề môi trường (cực đoan nhất là **cornucopian** — tin rằng tài nguyên gần như vô hạn nhờ thị trường và công nghệ luôn tìm ra giải pháp thay thế).

1.1.2 Instrumental value versus intrinsic value

A closely related distinction concerns *why* something in nature is considered valuable. **Instrumental value** (also called utilitarian value) is value assigned because something is useful to humans — a forest valued for its timber, a wetland valued for flood protection, a species valued because it might yield a future medicine. **Intrinsic value** is value that something possesses simply by existing, independent of any usefulness to humans — a view that a species or ecosystem has a right to exist regardless of its utility. Ecocentric worldviews emphasize intrinsic value; technocentric worldviews rely almost entirely on instrumental value; anthropocentric worldviews typically invoke a mixture of both, often prioritizing instrumental value in practice while paying rhetorical respect to intrinsic value.

Ví dụ mẫu · Interpreting one scenario through three EVS lenses

A government proposes converting 200 hectares of old-growth rainforest into a licensed palm oil plantation, promising jobs for $3{,}000$ local residents and export revenue. An environmental review shows the forest holds several endemic species found nowhere else. Explain how an ecocentrist, an anthropocentrist acting as an environmental manager, and a cornucopian technocentrist would each most likely respond to this proposal, and why.

Ecocentric response: oppose the project outright, or oppose it unless it is abandoned entirely. The rainforest and its endemic species have intrinsic value regardless of economic return; their irreversible loss cannot be offset by jobs or revenue, and a precautionary, hands-off stance is preferred.

Anthropocentric (environmental manager) response: seek a negotiated compromise — perhaps approve a smaller plantation footprint, require a buffer zone and a biodiversity offset (protecting an equivalent area elsewhere), mandate an environmental impact assessment, and impose monitoring conditions. The manager accepts that human economic needs (jobs, revenue) are legitimate but insists they be balanced against resource protection through regulation.

Cornucopian technocentric response: approve the project with minimal restriction, trusting that economic growth and future technology (e.g., synthetic alternatives to palm oil, or ex-situ conservation such as seed banks and captive breeding) can address any biodiversity loss later, and that the immediate economic benefit should not be sacrificed for a hypothetical future cost.

This is a recurring IB exam skill: the same data set (200 ha, 3,000 jobs, endemic species) is not in dispute — what differs is which facts each worldview treats as decisive.

GIẢI THÍCH TIẾNG VIỆT

VN

Một kỹ năng thi IB hay gặp: cùng một bộ dữ liệu (200 ha rừng, 3.000 việc làm, loài đặc hữu) nhưng ba hệ giá trị sẽ đưa ra ba phản ứng khác nhau — không phải vì họ có dữ liệu khác nhau, mà vì họ đánh giá dữ liệu đó theo các ưu tiên khác nhau: người theo ecocentrism ưu tiên giá trị tự thân của rừng và loài đặc hữu; người theo anthropocentrism (environmental manager) tìm giải pháp thoả hiệp có quản lý; người theo technocentrism (cornucopian) tin công nghệ tương lai sẽ giải quyết được hậu quả.

1.1.3 Why the same evidence yields different conclusions

Because an EVS operates as an interpretive lens rather than a testable hypothesis, two observers holding different EVS positions can examine identical data — the same measurements, the same photographs, the same economic figures — and reach opposite policy conclusions, each internally consistent with their own value system. Recognizing this is an essential IB exam skill: a question that asks you to “discuss” or “evaluate” a controversial environmental issue is very often, implicitly, asking you to show how different EVS positions would interpret the same body of evidence differently, rather than asking which single interpretation is objectively correct.

Ví dụ mẫu · A second EVS scenario: a national park logging dispute

A national forestry agency releases data showing that a protected old-growth forest inside a national park contains a commercially valuable species of hardwood, now scarce elsewhere in the region after decades of logging outside the park. The agency proposes a strictly limited, scientifically managed selective harvest of 2% of mature trees per decade, arguing this rate is well below the forest’s natural regeneration rate and would fund the park’s conservation budget. Explain how a deep ecologist and an anthropocentric environmental manager would each most likely evaluate this proposal, given that — unlike the earlier palm oil example — the same regulator here is proposing a harvest rate the data suggest is sustainable.

Deep ecologist: likely to oppose the harvest even at a data-supported "sustainable" rate, because a national park is designated on the premise that its ecosystems are protected from extraction *in principle*, regardless of whether a particular rate can be shown not to reduce the timber stock. The mature trees targeted for harvest often have irreplaceable ecological roles (e.g., as habitat structures) that a regeneration-rate calculation does not capture, so the harvest is rejected on principle rather than assessed purely on the arithmetic.

Anthropocentric environmental manager: likely to evaluate the proposal on its technical merits — checking whether the 2% figure is genuinely below the regeneration rate, whether monitoring and enforcement are credible, and whether the resulting conservation funding produces a net benefit for the park as a whole — and may approve the harvest conditionally, precisely because this position accepts that regulated, monitored extraction from a protected area can be compatible with long-term conservation, provided the underlying natural capital (Section 1.4) is not depleted.

Notice that the deep ecologist's objection here is not primarily about whether the agency's arithmetic is correct — it is about whether extraction from a protected area is acceptable *at all*, a values-based objection that no additional regeneration-rate data alone can resolve.

VN GIẢI THÍCH TIẾNG VIỆT

Ở ví dụ thứ hai này, cùng một số liệu ("khai thác 2%/thập kỷ, thấp hơn tốc độ tái sinh tự nhiên") nhưng người theo **deep ecology** vẫn phản đối vì cho rằng vườn quốc gia về nguyên tắc không nên bị khai thác, bất kể tỷ lệ khai thác có được chứng minh là "bền vững" về mặt số liệu hay không; trong khi người theo **anthropocentrism (environmental manager)** sẽ đánh giá dựa trên tính khả thi kỹ thuật (tốc độ tái sinh, giám sát, lợi ích tài chính cho bảo tồn) và có thể chấp thuận có điều kiện. Điều này cho thấy bất đồng đôi khi không nằm ở số liệu mà nằm *ở nguyên tắc giá trị* — một dạng câu hỏi phân tích thường gặp trong đề thi IB.

1.2 Systems and models

1.2.1 Storages, flows, transfers, and transformations

ESS studies the environment using a **systems approach**: any system — an ecosystem, the atmosphere, a farm, a city, even a single organism — can be analyzed in terms of its **storages** (stocks of matter or energy held within the system, e.g., carbon stored in tree biomass, water stored in a lake) and the **flows** that move matter or energy into, out of, and within the system. Flows crossing the system boundary are called **inputs** (e.g., solar energy entering an ecosystem, rainfall entering a catchment) and **outputs** (e.g., heat radiated to space, water lost by evaporation).

Flows within a system are further divided into two types:

- **Transfers** — movement of matter or energy from one storage to another *without* a change in its state or form (e.g., water flowing downhill from a lake to a river, a herbivore physically moving plant matter into its gut).
- **Transformations** — a change in the state or form of matter or energy, often involving a chemical or biological process (e.g., photosynthesis transforming light energy into chemical energy stored in glucose; decomposition transforming complex organic matter into simple inorganic nutrients).

Ví dụ mẫu · Transfer or transformation?

Classify each process as a transfer or a transformation, and justify each answer.
(a) Wind carries topsoil from a bare field to a neighbouring valley.

(b) A cow digests grass and respires some of the carbon as CO_2.
(c) Water evaporates from the ocean surface into the atmosphere.
(d) A river deposits suspended sediment on its floodplain during a flood.

(a) Transfer. The soil physically relocates from one storage (the field) to another (the valley) without changing its chemical or physical form — it is still soil.
(b) Transformation. Cellular respiration chemically converts organic carbon compounds in the grass into a different chemical form, CO_2, and releases usable energy — a clear change of state, not merely relocation.
(c) Transformation. Evaporation changes the physical state of water from liquid to gas; although a change of state rather than a chemical reaction, it is still classified as a transformation because the form of the matter changes.
(d) Transfer. The sediment moves location (river channel to floodplain storage) but remains physically and chemically the same material.
The general test: ask whether the matter or energy has merely *moved* (transfer) or has *changed form* (transformation, whether physical, chemical, or biological).

Isolated, closed, and open systems

Systems are classified by what is allowed to cross their boundary:

- **Isolated system:** neither matter nor energy crosses the boundary. (No true isolated system exists in nature at a meaningful scale; it is a theoretical idealization.)
- **Closed system:** energy crosses the boundary, but matter does not. Earth as a whole is the standard example: it receives a continuous input of solar energy and radiates heat back to space, but (aside from occasional meteorite infall and minor atmospheric gas escape) exchanges essentially no matter with its surroundings.
- **Open system:** both energy and matter cross the boundary. Almost every ecosystem studied in ESS is an open system — e.g., a forest receives inputs of sunlight, rainfall, and migrating animals, and loses outputs of heat, evaporated water, and emigrating organisms.

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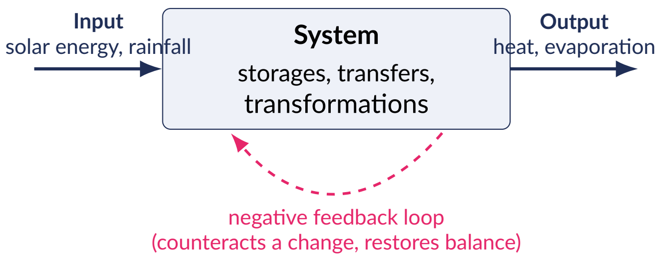
Hệ kín tuyệt đối (isolated system): không trao đổi cả vật chất lẫn năng lượng với môi trường xung quanh (chỉ là khái niệm lý thuyết, không tồn tại trong thực tế). **Hệ đóng (closed system)**: trao đổi năng lượng nhưng không trao đổi vật chất — Trái Đất là ví dụ điển hình (nhận năng lượng mặt trời, toả nhiệt ra vũ trụ, nhưng gần như không trao đổi vật chất). **Hệ mở (open system)**: trao đổi cả vật chất lẫn năng lượng — hầu hết hệ sinh thái mà ESS nghiên cứu (rừng, hồ, thành phố) đều là hệ mở. Phân biệt **transfer** (chuyển vị trí, không đổi dạng, ví dụ nước chảy từ hồ ra sông) và **transformation** (đổi dạng vật chất/năng lượng, ví dụ quang hợp biến năng lượng ánh sáng thành năng lượng hoá học).



A generic open system: inputs and outputs cross the system boundary; internal storages are linked by transfers and transformations; feedback loops (dashed) connect an output condition back to affect a future input or internal process.

1.2.2 What is a model, and why (and how) do we use one?

A **model** is a simplified representation of a real system or process, built to make that system easier to understand, predict, or communicate. Because reality is far too complex to describe in full detail, a model deliberately strips away some variables and interactions, keeping only those judged most important to the question being asked. Models take many forms in ESS: simple diagrams (e.g., the input–output system diagrams used throughout this unit), mathematical equations (e.g., the residence-time formula in Section 1.3), physical scale models, and large computer simulations (e.g., global climate models).

Models serve three main purposes:

1. **To understand** a system — by isolating key relationships, a model reveals which factors drive an outcome.
2. **To predict** future behaviour — e.g., a climate model projecting global mean temperature under different greenhouse gas emission scenarios.
3. **To communicate** complex ideas simply — e.g., a diagram of nutrient cycling communicates a process that would otherwise take pages of description.

Every model, however, has limitations. Because a model is a simplification, it necessarily rests on **assumptions** about which variables matter and how they interact; if those assumptions are wrong or incomplete, the model's output will be unreliable. Models also carry **uncertainty**, especially when they must project far into the future or when the underlying data are incomplete (e.g., cloud formation and ocean circulation feedbacks remain sources of uncertainty in climate models). A model is also only as good as the data used to build and test it, and complex real-world systems often contain feedbacks or thresholds (Section 1.3) that a simplified model may fail to capture, especially when conditions move outside the range for which the model was originally built and tested.

> A model trades completeness for clarity. It is a tool for thinking about a system, not a perfect replica of it — model outputs should always be interpreted alongside a clear statement of the assumptions and simplifications on which they rest.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mô hình (model) là một biểu diễn đơn giản hoá của một hệ thống hay quá trình thực tế, giúp con người hiểu, dự đoán hoặc truyền đạt thông tin về hệ thống đó dễ dàng hơn. Mô hình luôn phải đơn giản hoá thực tế nên luôn mang theo **giả định (assumptions)** và **độ bất định (uncertainty)** — ví dụ mô hình khí hậu toàn cầu vẫn còn nhiều bất định liên quan đến mây và hải lưu. Khi đọc kết quả của bất kỳ mô hình nào (kể cả mô hình khí hậu), học sinh IB cần luôn đặt câu hỏi: mô hình này đã đơn giản hoá điều gì, và điều đó ảnh hưởng ra sao đến độ tin cậy của kết quả?

1.2.3 Types of models used in environmental systems and societies

ESS draws on several distinct categories of model, each suited to different purposes:

- **Conceptual (diagrammatic) models** — box-and-arrow diagrams such as the input–output system diagrams used throughout this unit; useful for communicating a system's overall structure quickly, but limited in their ability to quantify how much flows where.
- **Physical (scale) models** — a physical, often miniaturized, representation of a real system, e.g., a river-basin model built in a laboratory flume to study flood behaviour; useful for visualizing spatial processes but limited by the difficulty of accurately scaling every relevant physical property (e.g., friction, viscosity) down to model size.

- **Mathematical models** — equations describing relationships between variables, e.g., the residence-time formula $\tau = M/F$ introduced in Section 1.3, or an equation describing population growth; useful for precise, quantifiable prediction, but only as reliable as the assumptions embedded in the equation.
- **Computer simulation models** — complex programs (e.g., global climate models, species distribution models) that combine many mathematical relationships and large datasets to simulate a system's behaviour over time and explore "what-if" scenarios; powerful for exploring scenarios that cannot be tested experimentally on the real system, but carry the greatest cumulative uncertainty because they combine so many individual assumptions at once.

> No single type of model is inherently superior — the appropriate choice depends on the question being asked, the scale of the system, the data available, and whether the priority is quick communication, spatial visualization, precise calculation, or long-term scenario exploration.

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Bốn loại mô hình chính trong ESS: **mô hình khái niệm/sơ đồ** (dễ truyền đạt cấu trúc tổng thể nhưng khó định lượng); **mô hình vật lý thu nhỏ** (trực quan về không gian nhưng khó thu nhỏ chính xác mọi đặc tính vật lý); **mô hình toán học** (định lượng chính xác nhưng chỉ đáng tin cậy bằng đúng các giả định trong phương trình); **mô hình mô phỏng máy tính** (mạnh nhất để khám phá kịch bản tương lai, nhưng cũng mang độ bất định lớn nhất vì kết hợp rất nhiều giả định cùng lúc). Không có loại mô hình nào "tốt nhất" tuyệt đối — lựa chọn phụ thuộc vào câu hỏi nghiên cứu, quy mô hệ thống, dữ liệu sẵn có, và mục đích sử dụng.

1.2.4 System hierarchy and the choice of boundary

Systems in ESS are typically **nested** within one another at increasing scales: a single organism is itself a system (with internal storages and flows), which exists within a population, which exists within a community of interacting populations, which exists within an ecosystem (including the non-living physical environment), which exists within the biosphere as a whole. Each level can be studied as a system in its own right, with its own boundary, storages, and flows — and a flow that counts as an "output" at one scale (e.g., an animal emigrating out of a local population) may simply be an internal **transfer** at a larger scale (e.g., the same animal moving to a different population within the same regional ecosystem).

This means that **where the boundary is drawn** is a modelling choice, not a fact about nature, and it materially affects which flows count as inputs/outputs versus internal transfers. For example, milk leaving one dairy farm for an off-site processing plant is an **output** if the system boundary is drawn around that single farm — but the very same shipment becomes an internal **transfer** if the boundary is instead drawn around the whole regional dairy industry (farm plus processing plant together). A careful systems analysis therefore always begins by stating explicitly what lies inside the system boundary and what lies outside it, since the very same real-world flow can be classified differently depending on that choice.

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Hệ thống trong ESS thường được **lồng vào nhau (nested)** theo quy mô tăng dần: cá thể → quần thể → quần xã → hệ sinh thái → sinh quyển — mỗi cấp độ đều có thể được xem là một hệ thống riêng với ranh giới, kho chứa và dòng chảy của chính nó. **Ranh giới hệ thống là một lựa chọn khi phân tích**, không phải một sự thật cố định của tự nhiên: cùng một dòng chảy có thể là "output" ở quy mô nhỏ nhưng lại chỉ là "transfer" nội bộ ở quy mô lớn hơn (ví dụ sữa rời khỏi một trang trại là "output" nếu ranh giới chỉ bao quanh trang trại đó, nhưng lại là "transfer" nội bộ nếu ranh giới bao quanh cả ngành sữa khu vực). Vì vậy, trước khi phân loại một dòng chảy, luôn cần nói rõ ranh giới hệ thống đang xét là gì.

1.2.5 Distinguishing storage (stock) and flow variables

A recurring source of error is confusing a **storage (stock) variable** with a **flow variable**. A storage variable describes an *amount present at one point in time* and is measured in absolute units (e.g., m^3 of water, tonnes of carbon, individuals in a population). A flow variable describes a *rate of movement over a time interval* and is always measured per unit time (e.g., m^3/yr, tonnes/year, births per year). The residence-time formula introduced in Section 1.3, $\tau = M/F$, only produces a result with meaningful units of time because M is a storage and F is a flow — dividing an amount by a rate always yields a quantity with units of time.

Ví dụ mẫu · Storage or flow?

Classify each quantity as a storage (stock) variable or a flow variable, and state a plausible unit for each: (a) the mass of carbon held in a forest's living biomass; (b) the rate at which a country emits CO_2 from burning fossil fuels; (c) the volume of water held in a reservoir; (d) the rate at which a river carries sediment past a monitoring point.

(a) Storage. An amount present at a given moment; a plausible unit is tonnes of carbon.
(b) Flow. A rate of release over time; a plausible unit is tonnes CO_2/year.
(c) Storage. An amount held at a given moment; a plausible unit is m^3.
(d) Flow. A rate of transport over time; a plausible unit is tonnes/day (or tonnes/year).

A simple check: if the quantity would still make sense described at a single instant ("there are currently X present"), it is a storage; if it only makes sense described over an interval of time ("X happens per year"), it is a flow.

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Một lỗi thường gặp là nhầm lẫn giữa **biến kho chứa (storage/stock)** — lượng có tại một thời điểm, đơn vị tuyệt đối (ví dụ m^3, tấn) — với **biến dòng chảy (flow)** — tốc độ biến đổi theo thời gian, luôn có đơn vị "trên một đơn vị thời gian" (ví dụ m^3/năm, tấn/năm). Công thức thời gian lưu trú $\tau = M/F$ chỉ cho kết quả có đơn vị thời gian chính xác vì M là kho chứa còn F là dòng chảy — lấy một lượng chia cho một tốc độ luôn cho ra một đơn vị thời gian.

1.3 Energy, equilibria, and resilience

1.3.1 The laws of thermodynamics in ecological systems

The behaviour of energy within environmental systems is governed by two fundamental physical laws.

The two laws of thermodynamics

First law of thermodynamics (conservation of energy): energy cannot be created or destroyed, only converted from one form to another. When a producer photosynthesizes, light energy is not lost — it is transformed into chemical energy stored in the bonds of glucose.
Second law of thermodynamics: whenever energy is converted from one form to another, the total entropy (disorder) of the universe increases; in practice, this means that every energy transformation is imperfect and releases some usable (high-quality) energy as low-quality, dispersed heat that cannot be recaptured to do further useful work in that system. No transfer of energy along a food chain is ever 100% efficient.

This second law explains directly why energy and matter behave so differently in ecosystems. Because every transformation of energy (e.g., photosynthesis, respiration, muscle contraction) loses some energy as heat that radiates away and is not recoverable by the system, energy cannot be recycled — it must be continually resupplied, ultimately from the sun, and flows through an ecosystem in **one direction only** (a one-way flow, not a cycle). Chemical elements such as carbon, nitrogen, and phosphorus, by contrast, are not degraded by these transformations — a carbon atom in a CO_2 molecule is chemically no different after being fixed by a plant, eaten by a herbivore, and respired back into the atmosphere. Because matter is conserved and not degraded in the same sense, it can be recycled indefinitely between organisms and the physical environment (Chapter 2 covers these biogeochemical cycles in detail).

> Energy flows one way through an ecosystem (continually resupplied by the sun, continually lost as heat at each transformation) because the second law of thermodynamics degrades usable energy at every step. Matter cycles because chemical elements are conserved and not degraded by these same transformations.

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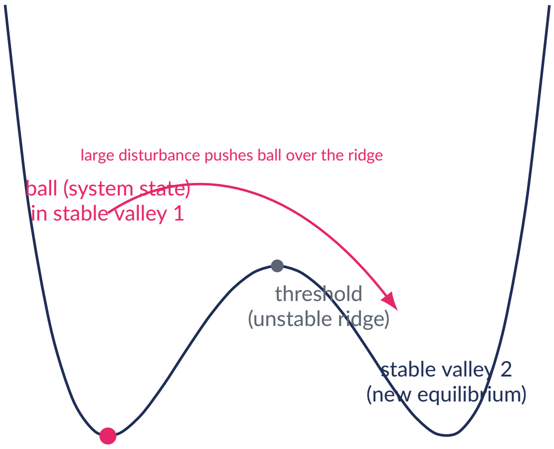
Định luật 1 nhiệt động lực học: năng lượng không tự sinh ra hay mất đi, chỉ chuyển từ dạng này sang dạng khác. **Định luật 2:** mỗi lần chuyển hoá năng lượng đều làm tăng entropy (độ hỗn loạn) của vũ trụ — nghĩa là luôn có một phần năng lượng bị "thất thoát" dưới dạng nhiệt chất lượng thấp, không thể tái sử dụng để sinh công có ích. Đây chính là lý do **năng lượng chỉ đi theo một chiều** qua hệ sinh thái (phải liên tục được mặt trời bổ sung, liên tục mất dần dưới dạng nhiệt), còn **vật chất (các nguyên tố hoá học) thì được tuần hoàn (recycle)** vô thời hạn vì không bị "xuống cấp" qua các quá trình chuyển hoá sinh học.

1.3.2 Equilibria, resilience, and tipping points

A system is in **equilibrium** when its storages and flows are, on balance, stable over time. ESS distinguishes two types:

- **Static equilibrium:** storages remain essentially unchanged and there is little or no flow of matter or energy (rare in living systems; more typical of, e.g., a sealed rock formation).
- **Steady-state equilibrium** (dynamic equilibrium): storages remain relatively stable over time, but this stability is maintained by continuous flows of matter and energy into and out of the system, with inputs approximately balancing outputs. Nearly every healthy ecosystem is in steady-state, not static, equilibrium — e.g., a stable lake continually receives and loses water, yet its water level fluctuates only within a narrow, self-correcting range.

A stable equilibrium has the property that after a disturbance, the system tends to **return** toward its original state. This capacity is called **resilience**: the ability of a system to absorb a disturbance and continue to function without a fundamental change in structure or behaviour. Resilience is not unlimited, however. Beyond a certain magnitude of disturbance, a system may cross a **threshold** (or **tipping point**) — a critical level beyond which a small additional change produces a disproportionately large, often abrupt and irreversible, shift to a new stable state, sometimes with very different characteristics from the original.



Stability landscape: a system (ball) sitting in valley 1 is resilient to small disturbances and rolls back down. A sufficiently large disturbance pushes it over the threshold (ridge), after which it settles into a different stable state, valley 2 — often not easily reversible.

Ví dụ mẫu · Resilience and threshold in a coral reef

A coral reef ecosystem experiences a moderate marine heatwave. Most corals bleach (expel their symbiotic algae, turning white) but the majority survive and recover their colour and function within two years once water temperatures return to normal. Five years later, a much more severe and prolonged heatwave causes mass coral death; the reef is subsequently dominated by fast-growing algae, and even after water temperatures return to normal, coral fails to re-establish for decades. Explain these two outcomes using the concepts of resilience and threshold.

In the first event, the disturbance (moderate heatwave) did not exceed the reef's capacity to absorb change — the system displayed **resilience**, and negative feedback processes (surviving coral regrowth, recolonization by algae-free coral larvae) returned the ecosystem to its original coral-dominated state. In the second event, the disturbance was large enough to push the system across a **threshold**: mass coral mortality removed the structural habitat and competitive advantage that coral needs to dominate, allowing algae to take over that advantage instead. The reef settled into a new, algae-dominated stable state, which persists even once the original stressor (high temperature) is removed, because the new state has its own reinforcing (positive) feedbacks — e.g., algae blocking coral larvae from settling on hard substrate.

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Cân bằng tĩnh (static equilibrium): hệ thống không thay đổi, gần như không có dòng chảy vật chất/năng lượng. **Cân bằng động/trạng thái ổn định (steady-state equilibrium)**: các kho chứa (storages) tương đối ổn định nhưng nhờ dòng vào và dòng ra liên tục cân bằng nhau — đây là dạng cân bằng phổ biến ở hầu hết hệ sinh thái khoẻ mạnh. **Khả năng phục hồi (resilience)**: khả năng một hệ thống hấp thụ nhiễu loạn (disturbance) mà không thay đổi cấu trúc/chức năng cơ bản. **Ngưỡng (threshold/tipping point)**: mức nhiễu loạn mà nếu vượt qua, hệ thống sẽ chuyển sang một trạng thái ổn định mới — thường khó hoặc không thể đảo ngược.

A system's resilience is not fixed — it is linked to measurable ecological properties. Greater **biodiversity** and species **redundancy** (multiple species capable of performing a similar ecological role) generally increase resilience, because if one species or population is lost to a disturbance, another can partly compensate for its function. Greater structural and functional diversity (e.g., varied habitat types, multiple feeding pathways) similarly spreads risk, so a disturbance affecting one part of a system is less likely to destabilize the system as a whole. Conversely, ecosystems already simplified by human activity (e.g., monoculture plantations, heavily overfished marine food webs) typically have lower resilience and are more vulnerable to being pushed past a threshold by a disturbance that a more diverse system would have absorbed.

> Biodiversity and redundancy are not only ethically relevant (Section 1.1) — they are functionally linked to a system's resilience: more diverse systems generally have more redundant pathways available to absorb a disturbance, and are therefore less likely to be pushed past a threshold into a new, often less desirable, stable state.

> VN **GIẢI THÍCH TIẾNG VIỆT**
> Khả năng phục hồi của một hệ thống không cố định mà phụ thuộc vào các đặc tính sinh thái có thể đo lường được: **đa dạng sinh học** và **tính dư thừa chức năng** (nhiều loài có thể đảm nhiệm vai trò sinh thái tương tự nhau) giúp tăng khả năng phục hồi, vì khi một loài bị mất do nhiễu loạn, loài khác có thể phần nào thay thế chức năng đó. Ngược lại, các hệ sinh thái đã bị đơn giản hoá do hoạt động của con người (độc canh, hệ sinh thái biển bị đánh bắt quá mức) thường có khả năng phục hồi thấp hơn và dễ bị đẩy qua ngưỡng hơn.

1.3.3 Negative and positive feedback

> **Negative feedback** counteracts an initial change, pushing the system back toward its original state — it is **stabilizing** and is the mechanism underlying steady-state equilibrium and resilience. Example: as a herbivore population grows, food becomes scarcer, so the population's growth rate falls, checking further growth.
> **Positive feedback** amplifies an initial change, pushing the system further away from its original state — it is **destabilizing** and is often the mechanism that pushes a system past a threshold into a new state. Example: melting Arctic sea ice exposes darker ocean water underneath; the darker surface has a lower albedo (reflectivity) and absorbs more solar radiation than the bright ice did, which warms the water further and causes still more ice to melt — reinforcing the original warming trend rather than counteracting it.

> VN **GIẢI THÍCH TIẾNG VIỆT**
> **Phản hồi âm (negative feedback)** chống lại sự thay đổi ban đầu, đưa hệ thống trở lại trạng thái cũ — có tính **ổn định hoá**, là cơ chế của cân bằng động và khả năng phục hồi. **Phản hồi dương (positive feedback)** khuếch đại sự thay đổi ban đầu, đẩy hệ thống ra xa trạng thái cũ hơn — có tính **gây mất ổn định**, thường là cơ chế đẩy hệ thống vượt qua ngưỡng để chuyển sang trạng thái mới (ví dụ băng biển Bắc Cực tan làm lộ ra mặt nước biển sẫm màu, hấp thụ nhiều bức xạ mặt trời hơn, làm ấm thêm và tan băng nhiều hơn nữa).

1.3.4 Quantitative skill: residence time

A useful quantitative tool for describing how long matter or energy typically remains within a storage before leaving it is **residence time** (also called turnover time), denoted τ:

> $$\tau = \frac{M}{F}$$
>
> where M is the quantity present in the storage at a given time, and F is the rate of outflow from that storage, with M and F expressed in consistent units (e.g., if M is in m^3 then F must be in m^3/yr for τ to come out in years).

Ví dụ mẫu · Residence time of a lake

A lake holds $M = 5.0 \times 10^6$ m^3 of water. Water leaves the lake (by outflow and evaporation combined) at a rate of $F = 2.5 \times 10^5$ m^3/yr. Calculate the residence time of water in the lake.

$$\tau = \frac{M}{F} = \frac{5.0 \times 10^6 \text{ m}^3}{2.5 \times 10^5 \text{ m}^3/\text{yr}} = 20 \text{ years.}$$

On average, a molecule of water entering this lake remains in it for about 20 years before leaving. A long residence time like this means the lake is slow to flush out a pollutant once introduced, and slow to recover its original chemistry after contamination.

(!) Lỗi thường gặp: Residence time is an *average*, not a guarantee for any single molecule or parcel of matter — some water may leave a lake within days (e.g., water entering near the outflow) while other water may remain for far longer than τ. It describes the storage's overall turnover behaviour, calculated from the ratio of the total amount stored to the total rate of outflow, assuming the storage is in (or close to) steady state (inflow $\approx$ outflow, so M is not rapidly changing).

1.3.5 Comparing residence times across environmental storages

Residence times vary enormously across different environmental storages, and this variation has a direct practical consequence: storages with short residence times respond, and recover, quickly, while storages with long residence times are slow to change and slow to recover once disturbed. Typical (order-of-magnitude) residence times include:

- **Atmospheric water vapour:** on the order of a single week — rapid turnover means local weather anomalies are short-lived.
- **A large, fast-flowing river:** days to a few weeks — a river recovers quickly once a pollution source is removed.
- **A moderately sized lake:** years to decades — a pollutant introduced into a lake may take years to flush out, as in the lake example above.
- **A confined groundwater aquifer:** decades to centuries — contamination or overextraction can take generations to reverse, as in the aquifer example in the problem bank.
- **The deep ocean:** centuries to roughly a thousand years — heat and dissolved gases absorbed by deep ocean water are extremely slow to re-equilibrate with the atmosphere.

Ví dụ mẫu · Energy conversion efficiency and the second law

A small hydroelectric turbine receives 500 MJ of potential energy from falling water each hour and converts it into 380 MJ of electrical energy in that hour. (a) Calculate the turbine's energy conversion efficiency. (b) Calculate how much energy is not converted to useful electrical output, and explain, using the second law of thermodynamics, what happens to it.

(a) Efficiency $= \dfrac{\text{useful energy output}}{\text{total energy input}} \times 100\% = \dfrac{380 \text{ MJ}}{500 \text{ MJ}} \times 100\% = 76\%.$

(b) Energy not converted to electricity: $500 - 380 = 120$ MJ. By the second law of thermodynamics, this energy is not destroyed (the first law forbids that) but is degraded into a less useful form — primarily low-grade heat, generated by friction in the turbine's moving parts and the surrounding water, which disperses into the environment and cannot be recaptured by the turbine to generate further electricity. This is why no real energy-conversion device —

whether a turbine, a muscle, or a step in a food chain — ever reaches 100% efficiency.

VN **GIẢI THÍCH TIẾNG VIỆT**

Không có hệ thống chuyển hoá năng lượng thực tế nào đạt hiệu suất 100% — một phần năng lượng luôn bị "thất thoát" dưới dạng nhiệt chất lượng thấp do ma sát và các quá trình không hoàn hảo khác, đúng theo định luật 2 nhiệt động lực học. Về thời gian lưu trú (residence time), các kho chứa khác nhau có thời gian lưu trú rất khác nhau — hơi nước khí quyển chỉ khoảng một tuần, trong khi tầng nước ngầm hay đại dương sâu có thể mất hàng thế kỷ đến hàng nghìn năm — đây là lý do ô nhiễm ở các kho chứa "chậm" (nước ngầm, đại dương sâu) khó khắc phục hơn nhiều so với ô nhiễm ở kho chứa "nhanh" (sông, hơi nước khí quyển).

1.4 Sustainability

1.4.1 Natural capital, natural income, and sustainable development

Natural capital refers to the elements of nature that produce goods and services of value to people — it is best thought of as a **stock** (e.g., a forest, a fish stock, an aquifer, a fertile soil layer). **Natural income** is the sustainable **flow** or yield that a unit of natural capital produces without depleting the underlying stock — e.g., the sustainable annual timber harvest a forest can provide indefinitely, or the sustainable annual catch a fishery can sustain while the fish population itself remains stable.

(!) Lỗi thường gặp: A common confusion is treating natural capital and natural income as the same thing. They are not: natural capital is the *stock itself* (the forest, the fishery, the aquifer), while natural income is the *sustainable flow or yield* that stock produces (the annual harvest, the annual catch, the annual safe extraction rate). Harvesting at a rate equal to or below natural income leaves the stock (natural capital) intact indefinitely; harvesting faster than natural income is produced draws down the underlying stock itself — this is unsustainable, since it is equivalent to spending capital rather than living off the flow of income it generates.

This capital/income distinction is the foundation of the most widely cited definition of sustainable development, from the **Brundtland Report** (*Our Common Future*, 1987):

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

VN **GIẢI THÍCH TIẾNG VIỆT**

Vốn tự nhiên (natural capital) là phần "gốc" — chính bản thân tài nguyên (khu rừng, quần thể cá, tầng nước ngầm). **Thu nhập tự nhiên (natural income)** là phần "lãi" — lượng khai thác bền vững mà vốn đó có thể tạo ra hằng năm mà không làm giảm vốn gốc. Khai thác vượt quá thu nhập tự nhiên đồng nghĩa với việc "ăn vào vốn" — không bền vững về lâu dài. **Báo cáo Brundtland (1987)** định nghĩa **phát triển bền vững** là sự phát triển đáp ứng nhu cầu hiện tại mà không làm tổn hại đến khả năng đáp ứng nhu cầu của các thế hệ tương lai.

1.4.2 The planetary boundaries framework

The **planetary boundaries framework** identifies nine critical Earth-system processes that together regulate the stability and resilience of the planet as a whole. For each process, scientists estimate a boundary — a level that should not be transgressed if humanity wishes to remain within a safe operating space resembling the relatively stable conditions of the last several thousand years. The nine boundaries include: **climate change**, **biosphere integrity** (biodiversity loss/extinction rate),

land-system change, **freshwater use**, **biogeochemical flows** (nitrogen and phosphorus cycles), **ocean acidification**, **stratospheric ozone depletion**, **atmospheric aerosol loading**, and **novel entities** (e.g., plastics, persistent synthetic chemicals). Current assessments conclude that several of these boundaries — including climate change, biosphere integrity, land-system change, biogeochemical flows, and novel entities — have already been **transgressed**, meaning human activity has pushed the relevant process beyond its estimated safe limit, increasing the risk of destabilizing, possibly irreversible, changes to the Earth system as a whole.

> The planetary boundaries framework treats Earth itself as a single interconnected system (Section 1.2): transgressing one boundary (e.g., land-system change through deforestation) can interact with and worsen others (e.g., biosphere integrity, biogeochemical flows, climate change), illustrating how localized human decisions accumulate into global-scale systemic risk.

> GIẢI THÍCH TIẾNG VIỆT
>
> VN **Khung giới hạn hành tinh (planetary boundaries)** xác định chín quá trình quan trọng của hệ Trái Đất (biến đổi khí hậu, toàn vẹn sinh quyển, thay đổi sử dụng đất, sử dụng nước ngọt, dòng địa hoá sinh học nitơ–phốt-pho, acid hoá đại dương, suy giảm tầng ozone, sol khí khí quyển, và các thực thể mới như nhựa/hoá chất tổng hợp bền vững). Nhiều giới hạn trong số này (biến đổi khí hậu, toàn vẹn sinh quyển, thay đổi sử dụng đất, dòng địa hoá sinh học, thực thể mới) đã bị coi là **vượt ngưỡng (transgressed)**, làm tăng nguy cơ hệ Trái Đất chuyển sang trạng thái bất ổn định, có thể không thể đảo ngược.

Planetary boundary	What it measures	Commonly cited status
Climate change	Atmospheric CO_2 concentration / radiative forcing	Transgressed
Biosphere integrity	Species extinction rate / ecosystem function	Transgressed
Land-system change	Proportion of forested land converted to other uses	Transgressed
Biogeochemical flows	Human-induced nitrogen and phosphorus flows	Transgressed
Novel entities	Release of plastics and persistent synthetic chemicals	Transgressed (assessed more recently)
Freshwater use	Human consumption of accessible freshwater	Within or near the boundary
Ocean acidification	Ocean surface carbonate saturation state	Within the boundary, approaching it
Stratospheric ozone depletion	Stratospheric ozone concentration	Within the boundary (recovering, aided by the Montreal Protocol)
Atmospheric aerosol loading	Concentration of particulates in the atmosphere	Not yet fully/globally quantified

Simplified summary of the planetary boundaries framework; classifications are periodically revised as monitoring data improve.

1.4.3 Environmental impact assessment (EIA)

An **environmental impact assessment (EIA)** is a formal, structured study, typically required by law before a significant development project (e.g., a mine, dam, highway, or industrial plant) may proceed, that evaluates the project's likely environmental (and often social and economic) consequences before a final decision to approve or reject it is made. A typical EIA establishes **baseline conditions** (the state of the environment before the project), predicts likely impacts on air, water, soil, biodiversity, and local communities, considers alternatives (including the option of not proceeding at all), and proposes **mitigation measures** to reduce identified harms. EIAs are usually required for larger projects or those in sensitive locations (e.g., near protected areas, wetlands, or population centres) and typically must be reviewed by regulators, and often opened for public consultation, before a permit is granted.

> An EIA does not guarantee that a project will be environmentally sound — it is a decision-support and disclosure tool, not an enforcement mechanism in itself. Its usefulness depends on the rigour of the science behind it, the independence of the assessors, and whether regulators and the public actually act on its findings.

VN **GIẢI THÍCH TIẾNG VIỆT**

Đánh giá tác động môi trường (EIA) là một nghiên cứu chính thức, thường bắt buộc theo luật trước khi triển khai một dự án phát triển lớn (mỏ, đập thuỷ điện, đường cao tốc, nhà máy), nhằm dự đoán và đánh giá các tác động đến môi trường (và thường cả xã hội, kinh tế) trước khi ra quyết định phê duyệt. EIA thường bao gồm: xác lập điều kiện nền (baseline), dự đoán tác động, xem xét phương án thay thế (kể cả không triển khai dự án), và đề xuất biện pháp giảm thiểu (mitigation).

Typical stages of an EIA

1. **Screening** — deciding whether a proposed project is significant enough to legally require an EIA at all.
2. **Scoping** — identifying which potential impacts (e.g., air quality, water quality, noise, biodiversity, cultural heritage) are significant enough to warrant detailed investigation.
3. **Baseline study** — documenting existing environmental (and often social) conditions before the project begins, to allow later comparison.
4. **Impact prediction and evaluation** — estimating the likely scale, duration, and significance of each impact identified during scoping.
5. **Consideration of alternatives** — including alternative designs, locations, or the option of not proceeding with the project at all.
6. **Mitigation** — proposing measures to avoid, reduce, or compensate for the impacts predicted.
7. **Public consultation and regulatory review** — allowing affected communities, experts, and regulators to review and respond to the assessment before a final decision.
8. **Monitoring** — tracking actual impacts once the project is underway, to check real outcomes against the predictions made.

Ví dụ mẫu · Applying the EIA stages to a highway project

A proposed highway would cut through a wetland known to support a breeding population of an endangered amphibian. Outline, stage by stage, how an EIA would typically address this specific risk.

Screening: because the project is large-scale infrastructure crossing a sensitive habitat, it is screened as requiring a full EIA.
Scoping: the amphibian's breeding habitat is identified as a significant issue requiring detailed investigation, alongside other likely impacts (noise, runoff, habitat fragmentation).
Baseline study: surveys establish the current population size, breeding sites, and hydrology of

the wetland before construction begins.
Impact prediction: ecologists estimate how many breeding sites would be destroyed or degraded by construction and by altered water flow, and how this might affect the population's long-term viability.
Alternatives: the assessment considers rerouting the highway around the wetland, elevating the road on a bridge/causeway above it, or not proceeding with this specific route at all.
Mitigation: if the road proceeds through or near the wetland, measures might include amphibian tunnels beneath the road, seasonal construction restrictions during the breeding season, and restoration of an equivalent wetland area nearby.
Consultation and monitoring: regulators, ecologists, and the public review the assessment before approval; if the project proceeds, the amphibian population and wetland hydrology are monitored afterward to check whether predictions and mitigation measures are working as intended.

VN **GIẢI THÍCH TIẾNG VIỆT**

Các bước điển hình của một EIA: **sàng lọc (screening)** — xác định dự án có cần EIA hay không; **xác định phạm vi (scoping)** — chọn ra các tác động cần nghiên cứu sâu; **khảo sát nền (baseline study)** — ghi nhận điều kiện môi trường hiện có; **dự đoán và đánh giá tác động**; **xem xét phương án thay thế** (kể cả không thực hiện dự án); **đề xuất giảm thiểu (mitigation)**; **tham vấn cộng đồng và thẩm định**; và **giám sát (monitoring)** sau khi dự án triển khai để đối chiếu thực tế với dự đoán ban đầu.

In practice, an EIA's usefulness is also limited by factors beyond the technical process itself: assessments are sometimes commissioned or funded by the very developer proposing the project, raising concerns about independence; EIAs typically evaluate one project in isolation and may understate **cumulative impacts** when several separate projects affect the same region simultaneously; and baseline studies may not fully incorporate the observations and priorities of local or Indigenous communities with long-term, place-specific ecological knowledge. These limitations do not make EIAs useless, but they explain why an approved EIA is best treated as one input into a decision, rather than as proof that a project is environmentally safe.

1.4.4 The tragedy of the commons

Many environmental resources — the open ocean and its fish stocks, the atmosphere, groundwater beneath multiple landowners, communal grazing land — are **open-access resources**: no single owner can exclude other users, and no one user bears the full cost of their own overuse. The **tragedy of the commons** (a term popularized by ecologist Garrett Hardin in 1968) describes the resulting pattern: because each individual user gains the entire benefit of an additional unit of use (e.g., one more fish caught, one more animal grazed) while the associated cost (resource depletion) is shared among *all* users, every individual user has a rational, self-interested incentive to keep increasing their own use — even though, if every user reasons the same way, the shared resource is driven toward collapse, which is against the long-run interest of the whole group, including each individual within it.

Ví dụ mẫu · Tragedy of the commons on a shared fishery

An open-access coastal fishery can sustainably yield $2{,}000$ tonnes of fish per year without depleting the fish stock (its natural income). 40 independent fishing crews operate in the fishery, none owning any exclusive right to it. Each crew reasons: "If I catch more fish, I personally profit more, and the fish stock is so large that my own extra catch barely affects it." Explain why this individually rational reasoning, if adopted by all 40 crews, leads to the fishery's collapse, and describe two contrasting types of solution.

Why collapse results: each crew correctly perceives that its *own* additional catch has a negligible individual effect on the total stock, so each has an incentive to expand its catch, since it personally captures 100% of the benefit (revenue from extra fish) while bearing only a small fraction ($1/40$, if divided evenly) of the shared cost (a smaller, more depleted stock for everyone next year). But because all 40 crews reason identically and act on that same incentive simultaneously, the sum of many individually "negligible" increases in catch pushes total extraction well above the sustainable $2{,}000$-tonne natural income — the stock (natural capital) itself begins to be drawn down, ultimately collapsing the fishery to the detriment of every crew, including those who tried to restrain their own catch.

Solution type 1 — regulation of a shared commons: a government or collective body sets and enforces a total allowable catch (e.g., $2{,}000$ tonnes/year), divided into individual quotas, with monitoring and penalties for violation — access remains shared, but use is now regulated.
Solution type 2 — privatization / property rights: the fishery (or fishing rights within it) is divided into exclusive parcels or transferable individual quotas owned by specific crews or communities, so that whoever depletes "their" portion of the resource directly and fully bears the cost of doing so, aligning individual incentive with sustainable use.
Both approaches remove the defining feature of the tragedy of the commons — that an individual can capture the full benefit of overuse while paying only a fraction of the cost — either by imposing shared, enforced rules (regulated commons) or by making costs and benefits fall on the same party (privatization).

VN GIẢI THÍCH TIẾNG VIỆT

Bi kịch của tài sản chung (tragedy of the commons): khi một tài nguyên là tài sản chung, không ai sở hữu riêng và không ai bị loại trừ khỏi việc sử dụng, mỗi cá nhân có động cơ tăng khai thác vì họ hưởng toàn bộ lợi ích riêng nhưng chỉ gánh một phần nhỏ chi phí chung (tài nguyên suy giảm) — dẫn đến khai thác quá mức và sụp đổ tài nguyên nếu ai cũng hành động như vậy, dù điều này đi ngược lại lợi ích lâu dài của cả nhóm. Hai hướng giải quyết: (1) **quản lý/quy định** tài sản chung — đặt hạn ngạch, giám sát, chế tài (vẫn dùng chung nhưng có luật); (2) **tư nhân hoá/quyền sở hữu** — chia tài nguyên thành các phần sở hữu riêng để chi phí và lợi ích của việc khai thác quá mức gắn liền với đúng một chủ thể.

1.4.5 A third path: community-based common-pool resource management

Government regulation and privatization are not the only two solutions to the tragedy of the commons. Economist and Nobel laureate Elinor Ostrom documented numerous real-world cases in which communities successfully manage a shared resource sustainably over long periods, without either full government control or private ownership, by developing their own local institutions. Commonly observed features of successful **community-based common-pool resource management** include:

- **Clearly defined boundaries** — of both the resource itself and of who is entitled to use it.
- **Rules matched to local conditions** — harvesting or access rules devised by, and appropriate to, the specific community and resource, rather than imposed uniformly from outside.
- **Collective monitoring** — users themselves (or accountable local monitors) observe compliance, rather than relying solely on distant government inspectors.
- **Graduated sanctions** — penalties for breaking the rules start mild and escalate with repeated violation, rather than being uniformly severe from the first offense.
- **Accessible conflict-resolution mechanisms** — low-cost, local ways for users to resolve disputes over resource use.

This shows that the tragedy of the commons is not an inevitable outcome of all shared resource use — it is the likely outcome specifically when a resource is *open-access* (unregulated and unmanaged); many resources are instead managed as functioning "commons" with enforced local rules, achieving sustainable use without formal privatization.

VN GIẢI THÍCH TIẾNG VIỆT

Ngoài quy định của nhà nước và tư nhân hoá, nhà kinh tế học đoạt giải Nobel **Elinor Ostrom** đã chỉ ra rằng nhiều cộng đồng trên thế giới tự quản lý tài nguyên chung một cách bền vững nhờ các thể chế địa phương với đặc điểm chung: ranh giới rõ ràng, quy tắc phù hợp với điều kiện địa phương, giám sát bởi chính cộng đồng, chế tài tăng dần theo mức độ vi phạm, và cơ chế giải quyết tranh chấp dễ tiếp cận. Điều này cho thấy bi kịch của tài sản chung không phải là kết cục tất yếu của mọi tài nguyên dùng chung, mà chủ yếu xảy ra khi tài nguyên đó là **tài nguyên truy cập mở (open-access)** không có quản lý — nhiều tài nguyên khác vẫn được quản lý bền vững như "tài sản chung có tổ chức" mà không cần tư nhân hoá.

1.5 Humans and pollution

1.5.1 Defining pollution

Pollution is the addition, by human activity, of a substance or form of energy to the environment at a rate faster than the environment can render it harmless, causing damage to the environment, to living organisms, or to human health and well-being. The offending substance or agent itself is a **pollutant**. Pollutants may be chemical (e.g., CO_2, heavy metals, pesticides), biological (e.g., pathogens in sewage), or physical/energy-based (e.g., noise, heat, light, radiation).

Pollution is classified along two useful dimensions:

- **Acute vs. chronic pollution. Acute pollution** is a single, sudden, often intense release — e.g., an oil tanker spill — with impacts that are immediate and usually easy to detect and attribute to the event. **Chronic pollution** is a lower-level release occurring continuously or repeatedly over a long period — e.g., ongoing vehicle exhaust emissions in a city — whose cumulative impacts may be harder to detect immediately but can be just as, or more, damaging over time.
- **Point source vs. non-point (diffuse) source.** A **point source** is a single, identifiable, localized origin of pollution (e.g., a single factory discharge pipe), which is comparatively easy to monitor, regulate, and hold accountable. A **non-point (diffuse) source** arises from numerous, dispersed, and often hard-to-pinpoint origins (e.g., fertilizer runoff from many farms across a watershed), which is far harder to monitor and regulate because no single actor can be clearly identified as solely responsible. (Water pollution point/non-point sources are treated in depth in a later chapter; the general distinction is introduced here because it applies just as much to air and soil pollution.)

VN GIẢI THÍCH TIẾNG VIỆT

Ô nhiễm (pollution) là việc con người đưa vào môi trường một chất hoặc dạng năng lượng với tốc độ nhanh hơn khả năng môi trường tự làm sạch, gây hại cho sinh vật hoặc con người. **Ô nhiễm cấp tính (acute)**: xảy ra đột ngột, một lần, tác động tức thời (ví dụ tràn dầu). **Ô nhiễm mãn tính (chronic)**: xảy ra liên tục ở mức thấp trong thời gian dài, tác động tích luỹ khó nhận biết ngay (ví dụ khí thải xe cộ hằng ngày). **Nguồn điểm (point source)**: một nguồn ô nhiễm xác định rõ vị trí (một ống xả thải); **nguồn không xác định/phân tán (non-point source)**: nhiều nguồn rải rác khó xác định trách nhiệm cụ thể (nước chảy tràn mang phân bón từ nhiều cánh đồng).

Pollutants are also usefully grouped by the medium most immediately affected: **air pollution** (e.g., particulate matter, sulfur dioxide, ground-level ozone), **water pollution** (e.g., pathogens, excess nutrients, oil), and **soil pollution** (e.g., heavy metals, persistent pesticide residues). Not every pollutant is a form of matter, either: **noise pollution** from traffic or industry, **light pollution** that disrupts nocturnal wildlife and human sleep cycles, and **thermal pollution** from heated wastewater discharged into a river are all pollution of an *energy* form rather than a physical substance. The same pollutant can also move between media over time — for example, airborne particulates eventually settle onto soil and water — a reminder that the systems approach (Section 1.2), recognizing flows and transfers across an environment's linked storages, applies just as directly to pollution as it does to nutrient or energy cycling.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ô nhiễm còn được phân loại theo môi trường bị ảnh hưởng trực tiếp: **ô nhiễm không khí** (bụi mịn, sulfur dioxide, ozone tầng thấp), **ô nhiễm nước** (mầm bệnh, dư thừa dinh dưỡng, dầu tràn), **ô nhiễm đất** (kim loại nặng, dư lượng thuốc trừ sâu bền vững). Một số dạng ô nhiễm là năng lượng chứ không phải vật chất: **ô nhiễm tiếng ồn**, **ô nhiễm ánh sáng** (ảnh hưởng động vật hoạt động về đêm và giấc ngủ con người), **ô nhiễm nhiệt** (nước thải nóng đổ ra sông). Một chất ô nhiễm có thể di chuyển giữa các môi trường theo thời gian (ví dụ bụi trong không khí lắng xuống đất và nước) — minh hoạ cho việc cách tiếp cận hệ thống (dòng chảy, transfer) ở Mục 1.2 áp dụng trực tiếp cho cả vấn đề ô nhiễm.

1.5.2 Dose–response relationships

The severity of a pollutant's effect on an organism generally depends on the **dose** received — the amount of a substance absorbed or ingested, often expressed relative to body mass. A **dose–response** relationship describes how the biological effect changes as dose increases. Several standard measures quantify this relationship:

- **Threshold dose:** the dose below which no measurable harmful effect is observed; doses above the threshold produce increasing harm.
- **LD_{50}** (median lethal dose): the dose of a substance that is lethal to 50% of a test population within a specified period — a standard measure of acute toxicity used to compare the relative toxicity of different substances (a lower LD_{50} indicates a more toxic substance, since a smaller dose is enough to kill half the test population).
- **Acceptable daily intake (ADI):** an estimate of the amount of a substance (usually expressed per kilogram of body weight per day) that a person can consume daily over a lifetime without appreciable health risk, typically set well below the threshold dose to build in a margin of safety.

Ví dụ mẫu · Applying LD_{50} and ADI

A food-safety agency sets the acceptable daily intake (ADI) of a certain preservative at 0.5 mg per kg of body weight per day. An adult has a body mass of 70 kg and eats food containing a total of 28 mg of the preservative in one day. (a) Calculate this adult's actual daily intake per kg of body weight. (b) Determine whether this intake exceeds the ADI, and by what factor.

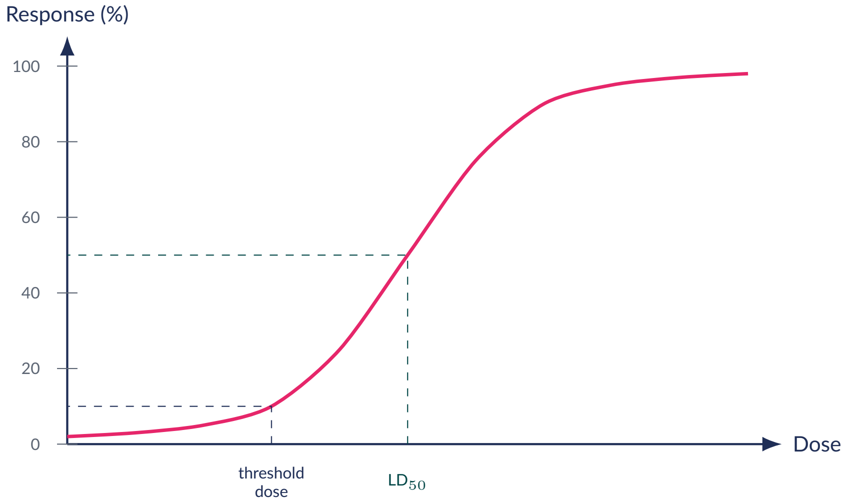
(a) Actual intake per kg body weight $= \dfrac{28\text{ mg}}{70\text{ kg}} = 0.4$ mg/kg/day.

(b) Compare to the ADI of 0.5 mg/kg/day: since $0.4 < 0.5$, this adult's intake is **below** the ADI — specifically, $\dfrac{0.4}{0.5} = 0.8$, i.e., 80% of the ADI, so no health risk is expected from this single day's exposure under the ADI standard.

Note the ADI is deliberately set with a safety margin well below any dose shown to cause measurable harm (i.e., well below the threshold dose determined from toxicological testing, and far below the substance's LD_{50}), precisely so that ordinary day-to-day variation in intake, as computed above, remains safe.

VN **GIẢI THÍCH TIẾNG VIỆT**

Liều ngưỡng (threshold dose): liều thấp nhất bắt đầu gây tác hại đo được. **LD$_{50}$**: liều gây chết cho 50% số cá thể thử nghiệm trong một khoảng thời gian xác định — dùng để so sánh độc tính giữa các chất (LD$_{50}$ càng thấp, chất càng độc). **Lượng ăn vào chấp nhận được hằng ngày (ADI)**: lượng một chất mà một người có thể tiêu thụ mỗi ngày suốt đời mà không có nguy cơ đáng kể cho sức khoẻ, thường được đặt thấp hơn nhiều so với liều ngưỡng để tạo biên độ an toàn.



A generic dose–response curve: response (the percentage of a test population affected) rises only slowly below the threshold dose, then rises steeply; the dose at which 50% of the population is affected is the LD$_{50}$. A more toxic substance has a curve shifted to the left (a lower LD$_{50}$).

For example, if Chemical A has an LD$_{50}$ of 50 mg/kg and Chemical B has an LD$_{50}$ of 5 mg/kg, Chemical B is the more acutely toxic substance, since a dose ten times smaller (5 mg/kg versus 50 mg/kg of body weight) is sufficient to be lethal to half of a test population.

1.5.3 The precautionary principle

Environmental decision-making frequently must be made under conditions of **scientific uncertainty** — the full consequences of a chemical, technology, or activity may not be conclusively established for years or decades, by which time serious or irreversible harm may already have occurred. The **precautionary principle** holds that when an activity raises threats of serious or irreversible harm to human health or the environment, precautionary measures should be taken *even if* some cause-and-effect relationships are not yet fully established scientifically — in other words, lack of full scientific certainty should not be used as a reason to postpone cost-effective measures to prevent harm.

Ví dụ mẫu · Applying the precautionary principle

A newly developed agricultural pesticide has been used commercially for three years. Early, limited studies suggest — but do not conclusively prove — a possible link between the pesticide and declining bee populations in treated areas; the mechanism is not yet fully understood, and industry-funded studies dispute the link. Explain how a regulator applying the precautionary principle would respond, and contrast this with a regulator demanding full scientific proof before acting.

Precautionary approach: because pollinator decline would be a serious and potentially irreversible harm (bees are essential to crop pollination and ecosystem function, and population collapse is difficult or impossible to reverse quickly), the regulator restricts or suspends the pesticide's use — e.g., through a moratorium — while further research is conducted, rather than waiting for conclusive proof of harm. The reasoning is that the cost of restricting a pesticide that later turns out to be harmless is comparatively small and reversible, whereas the cost of permitting continued use of a pesticide that later turns out to be genuinely harmful could be very large and irreversible (collapse of pollinator populations, cascading effects on food production and ecosystems).

Full-proof-first approach: a regulator waiting for conclusive scientific certainty before acting would allow continued unrestricted use throughout the entire research period; if the link is later confirmed, considerable and potentially irreversible harm may already have occurred by the time action is finally taken.

This tension — acting early under uncertainty, versus waiting for full proof — recurs throughout environmental policy (e.g., historical debates over CFCs and ozone depletion, or greenhouse gases and climate change).

VN GIẢI THÍCH TIẾNG VIỆT

Nguyên tắc phòng ngừa (precautionary principle): khi một hoạt động có nguy cơ gây hại nghiêm trọng hoặc không thể đảo ngược, cần hành động phòng ngừa *ngay cả khi* chưa có bằng chứng khoa học đầy đủ và chắc chắn — việc thiếu chắc chắn khoa học tuyệt đối không nên được dùng làm lý do để trì hoãn các biện pháp phòng ngừa có chi phí hợp lý. Nguyên tắc này thường được áp dụng khi chi phí của việc "chờ đến khi chắc chắn rồi mới hành động" (nếu tác hại thực sự xảy ra) lớn hơn nhiều so với chi phí của việc hành động phòng ngừa sớm (nếu sau này hoá ra không cần thiết).

1.5.4 Bioaccumulation and biomagnification

Some pollutants — especially persistent, fat-soluble synthetic chemicals such as the pesticide **DDT** and certain heavy metals — are not readily excreted or broken down by an organism's metabolism. Two related but distinct processes describe how such substances build up in living systems:

- **Bioaccumulation:** the build-up of a persistent substance *within a single organism* over its lifetime, occurring whenever the rate of intake (e.g., through food, water, or air) exceeds the rate of excretion or breakdown, so the concentration in that organism's tissues rises over time.
- **Biomagnification:** the *increase* in concentration of a persistent substance at each successive **trophic level** of a food chain, because a predator consumes many prey organisms (each already carrying an accumulated body burden of the substance) over its lifetime, and retains nearly all of the substance it ingests from them (since it is not readily excreted), while gaining comparatively little new body mass from all that consumed prey combined — so the substance becomes progressively more concentrated per unit body mass at higher trophic levels.

Persistent organic pollutants such as DDT are especially prone to bioaccumulation and biomagnification because they are **lipophilic** (fat-soluble) rather than water-soluble: once absorbed, they dissolve into and are stored within an organism's fatty tissue rather than being readily filtered out and excreted in urine or sweat (a process that generally requires water solubility). Because fat is passed on substantially intact up a food chain — a predator's own fat reserves are built largely from the fat it digests from its prey — a persistent, fat-soluble pollutant is carried forward efficiently at each trophic transfer, which is precisely why biomagnification is most pronounced for lipophilic pollutants such as DDT, PCBs, and certain mercury compounds.

Ví dụ mẫu · Biomagnification of DDT along a food chain

The persistent pesticide DDT is measured at each trophic level of an aquatic food chain, in parts per million (ppm):

Trophic level	DDT concentration (ppm)
Water (environment)	0.000003
Phytoplankton (producer)	0.0005
Zooplankton (primary consumer)	0.04
Small fish (secondary consumer)	0.5
Large fish (tertiary consumer)	2
Osprey / bird of prey (top predator)	25

(a) Calculate the magnification factor from water to phytoplankton, and from small fish to the osprey. (b) Calculate the overall magnification factor from water to the osprey. (c) Explain, in terms of trophic structure, why the increase from small fish to large fish is proportionally smaller than the increase from zooplankton to small fish.

(a) Magnification factor $= \dfrac{\text{higher-level concentration}}{\text{lower-level concentration}}$.

Water → phytoplankton: $\dfrac{0.0005}{0.000003} \approx 167$ (phytoplankton absorb DDT directly from surrounding water and concentrate it roughly 167-fold even at the very base of the food chain — technically bioaccumulation from the abiotic environment, since phytoplankton are not consuming prey).

Small fish → osprey: this step spans two trophic transfers (small fish → large fish → osprey), so first find large fish → osprey: $\dfrac{25}{2} = 12.5$; and small fish → large fish: $\dfrac{2}{0.5} = 4$. (If instead a single direct ratio small fish → osprey is wanted: $\dfrac{25}{0.5} = 50$.)

(b) Water → osprey overall: $\dfrac{25}{0.000003} \approx 8.33 \times 10^6$ — an increase of roughly 8.3 million times from the water concentration to the top predator.

(c) Each trophic level up a food chain loses roughly 90% of the energy (and biomass) available to it (Chapter 2), so a top predator must consume a very large number of prey organisms — each already carrying its own accumulated DDT burden — relative to its own body mass; the DDT is retained (not excreted) and effectively transferred almost completely into the predator's much smaller total biomass. The proportional jump at any single step depends on how many prey organisms (and how much accumulated DDT) are concentrated into the smaller biomass of the next level up; because large fish already start from a higher baseline concentration than zooplankton did, and the numeric *ratio* of biomass consumed can differ between these particular steps of this chain, the fold-increase is not identical at every step — but the overall trend across the whole chain is a steady, cumulative rise from a vanishingly small concentration in the water to a very high concentration in the top predator.

(!) Lỗi thường gặp: Do not confuse bioaccumulation with biomagnification. **Bioaccumulation** happens within *one* organism, over its own lifetime (intake exceeds excretion). **Biomagnification** happens *across* trophic levels, in a food chain, as concentration increases from one trophic level to the next. The two processes work together: biomagnification up a food chain is only possible because the substance also bioaccumulates within each individual organism along the way (if it were rapidly excreted by every organism, it could not build up in the first place, at any level).

VN GIẢI THÍCH TIẾNG VIỆT

Tích luỹ sinh học (bioaccumulation): sự tích tụ của một chất bền vững *bên trong một cá thể sinh vật* theo thời gian sống của nó, xảy ra khi tốc độ hấp thụ lớn hơn tốc độ đào thải/phân huỷ. **Khuếch đại sinh học (biomagnification):** nồng độ của chất đó *tăng dần qua mỗi bậc dinh dưỡng* trong chuỗi thức ăn, vì vật ăn thịt tiêu thụ rất nhiều con mồi (mỗi con đã mang sẵn một lượng chất tích luỹ) nhưng lại giữ lại gần như toàn bộ lượng chất đó trong khi khối lượng cơ thể tăng thêm không nhiều — dẫn đến nồng độ trên một đơn vị khối lượng cơ thể tăng vọt ở các bậc dinh dưỡng cao hơn (ví dụ điển hình: DDT tích luỹ trong chim săn mồi ở đỉnh chuỗi thức ăn, gây mỏng vỏ trứng và suy giảm quần thể). Nguyên nhân sâu xa: các chất này thường **tan trong mỡ (lipophilic)** chứ không tan trong nước nên khó bị đào thải qua nước tiểu/mồ hôi, lại được giữ lại gần như nguyên vẹn khi mô mỡ được chuyển qua từng bậc dinh dưỡng.

How the five subtopics connect: an environmental value system (Section 1.1) shapes how a person interprets a system's behaviour (Sections 1.2–1.3), including whether a given equilibrium shift is judged acceptable. Sustainability (Section 1.4) is fundamentally a question of keeping the flows taken from natural capital within its regenerative limits — monitored partly through tools such as EIA and threatened by tragedy-of-the-commons dynamics. Pollution (Section 1.5) can itself be understood as a flow of matter or energy that a system's storages, thresholds, and feedbacks cannot safely absorb — so the same systems concepts (storage, flow, threshold, feedback) developed early in this unit apply directly to understanding, and managing, both sustainability and pollution problems.

VN GIẢI THÍCH TIẾNG VIỆT

Năm phần của Unit 1 liên kết chặt chẽ với nhau: hệ giá trị môi trường (1.1) quyết định cách một người diễn giải sự vận hành của một hệ thống (1.2–1.3); phát triển bền vững (1.4) về bản chất là giữ dòng khai thác từ vốn tự nhiên trong giới hạn tái tạo của nó — được giám sát một phần qua EIA và bị đe doạ bởi động lực bi kịch tài sản chung; ô nhiễm (1.5) có thể hiểu là một dòng vật chất/năng lượng vượt quá khả năng hấp thụ an toàn của các kho chứa, ngưỡng và cơ chế phản hồi của hệ thống — cùng những khái niệm hệ thống được học từ đầu chương.

1.6 Problem Bank

Bài tập luyện tập

Earth receives a continuous input of solar energy and radiates heat back to space, but (aside from occasional meteorite infall) exchanges essentially no matter with its surroundings. Earth is best classified as which type of system?

(A) An isolated system
(B) A closed system
(C) An open system
(D) A steady-state system

Lời giải chi tiết

Energy (solar radiation in, heat out) crosses the boundary, but matter does not — this is precisely the definition of a closed system. **(B)**.

Bài tập luyện tập

Melting Arctic sea ice exposes darker ocean water, which absorbs more solar radiation than ice did, warming the water and causing further ice melt. This feedback loop is:

(A) Negative feedback, stabilizing the climate system

(B) Positive feedback, destabilizing the climate system

(C) A steady-state equilibrium

(D) An example of natural income

Lời giải chi tiết

The initial change (warming, ice melt) is amplified rather than counteracted — less ice leads to more warming leads to still less ice — so this is positive feedback, which destabilizes the system and pushes it further from its original state. **(B)**.

Bài tập luyện tập

An aquifer holds $M = 1.8 \times 10^9$ m^3 of groundwater. Wells extract water from it at a combined rate of $F = 3.0 \times 10^7$ m^3/yr. (a) Calculate the residence time of water in the aquifer. (b) Atmospheric water vapour has a residence time of roughly one week. Explain, in terms of the flows involved, why the aquifer's residence time is so much longer.

Lời giải chi tiết

(a) $\tau = \dfrac{M}{F} = \dfrac{1.8 \times 10^9 \text{ m}^3}{3.0 \times 10^7 \text{ m}^3/\text{yr}} = 60$ years.

(b) Atmospheric water vapour is exchanged extremely rapidly through the water cycle — evaporation and precipitation continuously and quickly move water into and out of the atmospheric storage, so any given water molecule spends only about a week there on average. Groundwater in an aquifer, by contrast, moves extremely slowly through dense rock and sediment, and is recharged and extracted at a comparatively very low rate relative to the huge volume stored, so it takes decades (60 years here) for the storage to turn over — this is why aquifers, once contaminated or overdrawn, take far longer to recover than a surface water body or the atmosphere.

Bài tập luyện tập

A policy-maker consistently favours government regulation, pollution taxes, technological fixes, and continued but better-managed economic growth, while accepting that some environmental trade-offs are necessary to maintain human quality of life. This position is best described as:

(A) Ecocentric, close to deep ecology

(B) Anthropocentric, in the role of environmental manager

(C) Technocentric, close to the cornucopian extreme

(D) An expression of intrinsic value only

Lời giải chi tiết

Favouring negotiated, regulated compromise between development and protection (rather than either minimal interference or unrestricted growth) is the hallmark of the anthropocentric "environmental manager" position, the central segment of the EVS spectrum. **(B)**.

Bài tập luyện tập

A government official states: "This wetland has no economic use to us, but I still believe it should be protected because every ecosystem has a right to exist regardless of its usefulness to humans." This statement expresses:

(A) Instrumental value of the wetland

(B) Intrinsic value of the wetland

(C) A cornucopian view of the wetland

(D) Natural income from the wetland

Lời giải chi tiết

Valuing the wetland simply because it has a right to exist, independent of any human use, is the definition of intrinsic value — a hallmark of ecocentric reasoning. **(B)**.

Bài tập luyện tập

Which of the following is an example of a transformation rather than a transfer?

(A) Water flowing from a reservoir into a river downstream

(B) Wind depositing sand from a dune onto a nearby beach

(C) Decomposers breaking down dead leaf litter into inorganic nutrients

(D) A bird physically carrying a seed from one location to another

Lời giải chi tiết

Options (A), (B), and (D) all involve matter moving location without changing its physical or chemical form (transfers). Option (C) involves a chemical/biological change of form — complex organic matter is converted into simple inorganic nutrients — which is the definition of a transformation. **(C)**.

Bài tập luyện tập

A regional climate model projects rainfall patterns over the next 50 years based on an assumed future greenhouse gas emission pathway and simplified representations of cloud formation and ocean heat uptake. Identify two limitations of this model, and explain how each could reduce confidence in its 50-year projection.

Lời giải chi tiết

Limitation 1 — dependence on assumptions: the projection is only as reliable as the assumed emissions pathway. If actual future emissions follow a different trajectory (e.g., faster decarbonization, or continued high emissions), the real rainfall outcome could diverge substantially from the model's projection even if the model's internal physics is otherwise sound.

Limitation 2 — structural simplification and uncertainty: cloud formation and ocean heat uptake are extremely complex physical processes that are not yet fully understood and must be simplified to be represented computationally. Because these simplifications carry genuine scientific uncertainty (and may involve feedbacks not fully captured), the model's simulated response to warming could be systematically too weak or too strong, widening the plausible range of outcomes — an error that compounds further the longer the projection horizon (here, 50 years).

Bài tập luyện tập

Which statement correctly applies the second law of thermodynamics to energy flow through a food chain?

(A) Energy transfers between trophic levels are 100% efficient, since energy cannot be created or destroyed

(B) At each trophic transfer, some usable energy is converted to heat and lost from the system, so less energy is available to higher trophic levels

(C) Matter and energy both cycle repeatedly between trophic levels without loss

(D) Producers violate the second law by creating usable energy directly from sunlight

Lời giải chi tiết

The first law (conservation of energy) means energy is never destroyed outright, so (A) misapplies it to imply perfect efficiency. The second law specifically states that every energy transformation/transfer degrades some usable energy into low-grade heat, which is why food chains lose usable energy at every trophic transfer. **(B)**.

Bài tập luyện tập

Using the first and second laws of thermodynamics, explain why energy must continually enter an ecosystem from an external source (the sun), whereas carbon can be recycled indefinitely within the ecosystem.

Lời giải chi tiết

By the first law, the solar energy entering an ecosystem is never destroyed — it is transformed (e.g., light energy into chemical energy via photosynthesis, chemical energy into heat via respiration and metabolism). By the second law, however, every one of these transformations degrades some of that energy into low-grade heat that radiates away and cannot be recaptured by the ecosystem to do further biological work. Because usable energy is therefore progressively and irreversibly lost at every transfer along a food chain, it must be constantly resupplied from an external source (the sun) to sustain the system — energy flows through the ecosystem in one direction only. Carbon atoms, by contrast, are not degraded by these same transformations: a carbon atom is chemically the same whether it is in atmospheric CO_2, plant glucose, or animal tissue, so it can be transferred and transformed repeatedly between organisms and the physical environment without a comparable loss — this conservation of matter is what allows carbon (and other elements) to cycle indefinitely, unlike energy.

Bài tập luyện tập

A grassland is grazed by cattle at a moderate stocking rate for decades; each year, grass cover recovers once seasonal grazing pressure eases. During one severe drought year, the stocking rate is much higher than usual; grass cover is reduced so severely that bare soil is exposed, triggering soil erosion and reduced water infiltration. Even after the drought ends and stocking returns to its original rate, the grassland does not recover its original vegetation cover, and instead persists as an eroded, largely bare landscape. (a) Identify which period exhibited resilience, and which event pushed the system past a threshold. (b) Identify the type of feedback loop that reinforces the new, degraded state, and justify your answer.

Lời giải chi tiết

(a) During the decades of moderate grazing, the grassland exhibited **resilience**: each year's grazing disturbance was absorbed and the system returned to its original vegetated state. The drought-year combination of severe grazing pressure and low rainfall pushed the system past a **threshold** — after this event, the grassland did not return to its original state even once the disturbance (heavy grazing) was removed, indicating it had shifted to a new stable state.

(b) Positive feedback. Reduced vegetation cover exposes bare soil, which reduces water infiltration/retention and increases erosion; this leaves even less water and topsoil available to support plant regrowth, further reducing vegetation cover. Each step amplifies (rather than counteracts) the original loss of vegetation, which is why the degraded, eroded state is self-reinforcing and persists long after grazing pressure returns to normal — consistent with desertification driven by a positive feedback loop.

Bài tập luyện tập

A forest can sustainably yield $8{,}000$ m^3 of timber per year (its natural income) without reducing its overall growing stock. A logging company instead harvests $11{,}000$ m^3 per year for 5 consecutive years. Calculate the total volume of timber drawn down from the forest's natural capital (its underlying stock) over this period, beyond what sustainable harvesting would have allowed.

Lời giải chi tiết

Total sustainable extraction over 5 years (at the natural-income rate): $8{,}000$ m^3/yr $\times$ 5 yr $=$ $40{,}000$ m^3.
Total actual extraction over 5 years: $11{,}000$ m^3/yr $\times$ 5 yr $=$ $55{,}000$ m^3.
Excess drawn from natural capital: $55{,}000 - 40{,}000 =$ **15,000 m^3**. This volume was not replaced by the forest's own regrowth, so it represents a genuine reduction in the forest's underlying stock (natural capital) rather than a sustainable harvest of its natural income — if harvesting continues at $11{,}000$ m^3/yr, the stock will keep shrinking, and the forest's future sustainable yield (natural income) will itself eventually decline.

Bài tập luyện tập

The 1987 report that defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" is known as:

(A) The Kyoto Protocol

(B) The Paris Agreement

(C) The Brundtland Report (*Our Common Future*)

(D) The Rio Earth Summit Declaration

Lời giải chi tiết

This is the standard definition of sustainable development from the Brundtland Report, *Our Common Future*, published by the World Commission on Environment and Development in 1987. **(C)**.

Bài tập luyện tập

Name three of the nine planetary boundaries that current scientific assessments consider to have already been transgressed, and explain one way in which transgressing the land-system change boundary could worsen the biosphere integrity boundary.

Lời giải chi tiết

Any three of: climate change, biosphere integrity (biodiversity loss), land-system change, biogeochemical flows (nitrogen and phosphorus cycles), and novel entities are currently considered transgressed.

Interaction: large-scale land-system change (e.g., converting forest to agricultural land) destroys and fragments natural habitat, directly reducing the area and connectivity available to wild species; this lowers population sizes and increases extinction risk, worsening the biosphere integrity boundary. Because Earth's systems are interconnected (Section 1.2), transgressing one boundary frequently compounds stress on another rather than remaining a contained, isolated impact.

Bài tập luyện tập

Which of the following is *not* a typical component of an environmental impact assessment (EIA)?

(A) Establishing baseline environmental conditions before the project begins

(B) Predicting likely impacts on air, water, soil, and biodiversity

(C) Guaranteeing that the proposed project will cause no environmental harm

(D) Proposing mitigation measures to reduce identified impacts

Lời giải chi tiết

An EIA is a decision-support and disclosure tool — it predicts and evaluates likely impacts and proposes mitigation, but it cannot guarantee an outcome; whether harm actually occurs still depends on how the project is built, operated, and regulated afterward. **(C)**.

Bài tập luyện tập

Beneath a farming region, a groundwater aquifer is accessed freely by any farmer able to drill a well, with no permits or extraction limits in place. Each farmer decides individually how much to pump, reasoning that the aquifer is enormous and that their own pumping has a negligible effect on the water table. Using the concept of the tragedy of the commons, explain what is likely to happen to the aquifer over time if this reasoning is widespread among farmers, and propose two contrasting policy solutions.

Lời giải chi tiết

Each farmer captures the full private benefit of extra water pumped (higher crop yields, more income) while personally bearing only a small fraction of the shared cost (a lower water table affecting every well in the region). Because many farmers reason identically and act on this same incentive, the sum of many individually "negligible" withdrawals can exceed the aquifer's natural recharge rate (its natural income), progressively drawing down the stored groundwater (its natural capital) — potentially lowering the water table past a threshold where wells run dry, pumping costs become prohibitive, or (in coastal or unstable ground) land subsidence or saltwater intrusion occurs.

Solution 1 — regulation: a water authority issues extraction permits capping total regional withdrawal at or below the estimated sustainable recharge rate, and monitors and enforces compliance with penalties for violation.
Solution 2 — privatization / tradable water rights: legally enforceable, tradable groundwater extraction rights are allocated to individual farmers; a farmer who wishes to pump more must acquire additional rights (at a cost), aligning the private cost of extraction with the shared cost of depletion.

Bài tập luyện tập

The dose of a substance that is lethal to 50% of a test population within a specified period is known as:

(A) The threshold dose
(B) The acceptable daily intake (ADI)
(C) The LD_{50}
(D) The bioaccumulation factor

Lời giải chi tiết

This is the definition of the median lethal dose, LD_{50}, a standard measure used to compare the acute toxicity of different substances (a lower LD_{50} indicates a more toxic substance). **(C)**.

Bài tập luyện tập

A food-safety agency sets the acceptable daily intake (ADI) of a food additive at 0.2 mg per kg of body weight per day. A child with a body mass of 20 kg consumes food containing a total of 5 mg of the additive in one day. Calculate the child's actual intake per kg of body weight, and determine by what factor (or percentage) this exceeds the ADI.

Lời giải chi tiết

Actual intake per kg body weight: $\dfrac{5\text{ mg}}{20\text{ kg}} = 0.25$ mg/kg/day.

Compare to the ADI of 0.2 mg/kg/day: $\dfrac{0.25}{0.2} = 1.25$, i.e., the child's intake is $1.25\times$ the ADI, or 25% **above** the acceptable daily intake. Because the ADI is deliberately set with a built-in safety margin below the dose shown to cause measurable harm, a single day at 25% above the ADI is not necessarily acutely dangerous, but sustained daily intake at this level would be a public-health concern warranting further monitoring or reformulation of the child's diet.

Bài tập luyện tập

A new nanomaterial is used as a protective coating in consumer textiles. Preliminary, inconclusive studies suggest it may harm aquatic invertebrates when washed into waterways during laundering, but the mechanism is unconfirmed and industry-funded studies dispute the finding. Describe how a regulator applying the precautionary principle would respond, and explain the underlying reasoning, contrasting it with a regulator who insists on waiting for full scientific certainty.

Lời giải chi tiết

A regulator applying the precautionary principle would restrict or limit the nanomaterial's use (e.g., requiring further safety testing before wide-scale approval, or capping permitted concentrations) even though harm is not yet conclusively proven, because the potential harm — disruption of aquatic ecosystems — could be serious and difficult to reverse once the nanomaterial has dispersed into waterways and accumulated in sediment or organisms. The underlying reasoning is that the cost of premature restriction (economic cost to industry if the material later proves harmless) is smaller and more easily reversed than the cost of unrestricted use if the material later proves genuinely harmful (aquatic ecosystem damage that may be very difficult or impossible to reverse). A regulator instead waiting for full scientific certainty would permit continued, unrestricted use throughout the entire research period, during which substantial and possibly irreversible harm could already occur before conclusive evidence is finally obtained.

Bài tập luyện tập

An earthworm living in pesticide-contaminated soil gradually builds up the pesticide in its own body tissue over its lifetime, because it cannot efficiently excrete or break down the compound. This is a direct example of:

(A) Biomagnification

(B) Bioaccumulation

(C) The precautionary principle

(D) A dose-response threshold

Lời giải chi tiết

Build-up of a persistent substance within a single organism over its own lifetime (intake exceeding excretion/breakdown) is the definition of bioaccumulation. Biomagnification would instead describe the substance's concentration increasing across successive trophic levels of a food chain. **(B)**.

Bài tập luyện tập

Mercury concentrations are measured through an aquatic food chain, in ppm: water 0.0002, algae 0.01, small fish 0.4, tuna 6. Calculate the magnification factor (a) from water to algae, (b) from algae to small fish, (c) from small fish to tuna, and (d) overall from water to tuna. Confirm that the three step-wise factors multiply to give the overall factor.

Lời giải chi tiết

Magnification factor $= \dfrac{\text{higher-level concentration}}{\text{lower-level concentration}}$.

(a) Water $\to$ algae: $\dfrac{0.01}{0.0002} = 50.$

(b) Algae $\to$ small fish: $\dfrac{0.4}{0.01} = 40.$

(c) Small fish $\to$ tuna: $\dfrac{6}{0.4} = 15.$

(d) Water $\to$ tuna overall: $\dfrac{6}{0.0002} = 30{,}000.$

Check: $50 \times 40 \times 15 = 2{,}000 \times 15 = 30{,}000$, matching the overall factor calculated directly in (d) — confirming that step-wise magnification factors along a food chain multiply together to give the total magnification from the base of the chain to the top predator.

Bài tập luyện tập

A government requires every fishing vessel operating in a national fishery to hold an individual transferable quota (ITQ) capping its annual catch, with financial penalties for exceeding it. This policy is best described as an attempt to prevent the tragedy of the commons through:

(A) An expression of deep ecology

(B) Regulation of an open-access resource

(C) An environmental impact assessment

(D) The precautionary principle

Lời giải chi tiết

Capping and enforcing individual catch limits on a shared, open-access resource is a regulatory solution to the tragedy of the commons — access remains shared, but use is now controlled and monitored. **(B)**.

Bài tập luyện tập

A mining company proposes an open-pit mine in a forest considered sacred by a local indigenous community. The company's environmental consultant, holding a technocentric worldview, concludes from the EIA that impacts are "manageable," since reclamation technology can restore vegetation after mining ends and a biodiversity offset elsewhere will compensate for habitat loss. The indigenous community, holding an ecocentric worldview, rejects this conclusion and opposes the mine regardless of any proposed mitigation. Explain why these two groups reach different conclusions from the same EIA findings, referring explicitly to instrumental and intrinsic value.

Lời giải chi tiết

The technocentric consultant evaluates the forest largely in terms of its **instrumental value**: because its ecological functions are treated as measurable and, in principle, substitutable, an equivalent area protected elsewhere (an offset) or vegetation restored later by technology is considered an acceptable trade for the loss of this specific site, so the EIA's finding of "manageable" impact is treated as decisive.

The indigenous community instead assigns **intrinsic value** (here, reinforced by cultural and spiritual significance) to this particular forest — a value that does not derive solely from an ecological function an offset could replace, and is not restored simply because vegetation cover is technically reestablished elsewhere or on the same site later. From this standpoint, no amount of technical mitigation addresses the core objection, because the objection is not primarily about the *quantity* of ecological function lost but about the forest's worth existing independently of any service it provides to people.

The EIA's technical findings (which impacts occur, their scale, what mitigation is feasible) are not actually in dispute between the two groups — what differs is the EVS-based judgment about which type of value (instrumental vs. intrinsic) should be decisive, which is why identical data produce opposite conclusions.

Bài tập luyện tập

Match each concept to its correct example.
I. Negative feedback II. Positive feedback III. Threshold/tipping point
1. A thermostat switching off a heater once room temperature reaches its set point.
2. Loss of Arctic sea ice reducing surface albedo and accelerating further warming.
3. A coral reef shifting permanently to an algae-dominated state after a severe, prolonged heatwave.

(A) I–1, II–2, III–3
(B) I–2, II–1, III–3
(C) I–3, II–1, III–2
(D) I–1, II–3, III–2

Lời giải chi tiết

A thermostat counteracts a temperature change (negative feedback, I–1); sea-ice loss amplifies warming (positive feedback, II–2); an irreversible shift to a new stable state after a severe disturbance is a threshold/tipping point (III–3). **(A)**.

Bài tập luyện tập

A river's phosphorus storage is measured at 500 tonnes, with an outflow (removal via sedimentation and downstream transport) of 25 tonnes per year. (a) Calculate the residence time of phosphorus in this storage. (b) Non-point source fertilizer runoff begins adding phosphorus to the river faster than the existing outflow can remove it, so storage M increases year on year. Explain, using the concepts of steady-state equilibrium and threshold, what is likely to happen to the river system if this trend continues.

Lời giải chi tiết

(a) $\tau = \dfrac{M}{F} = \dfrac{500 \text{ tonnes}}{25 \text{ tonnes/yr}} = 20$ years.

(b) The river was previously in steady-state equilibrium, with phosphorus inflow approximately balancing the 25 tonnes/yr outflow, keeping storage roughly stable. Once non-point source runoff pushes inflow above outflow, storage M increases continuously rather than staying in balance — the system is no longer at steady state. If phosphorus concentration keeps rising, the river risks crossing a **threshold** into eutrophication: excess nutrients trigger algal blooms; when the algae die and decompose, oxygen-consuming decomposition can deplete dissolved oxygen, harming aerobic organisms (including some that might otherwise help process nutrients), which can further reinforce degraded water quality. Once such a threshold is crossed, the river may settle into a new, degraded stable state that does not reverse quickly even if fertilizer runoff is later reduced, since resilience has been exceeded.

Bài tập luyện tập

Which of the following best distinguishes a point source of pollution from a non-point (diffuse) source?

(A) Point sources are always more harmful than non-point sources

(B) A point source is a single, identifiable, localized origin of pollution; a non-point source arises from numerous, dispersed origins that are hard to attribute to one actor

(C) Non-point sources only occur in urban areas, while point sources only occur in rural areas

(D) Point sources release pollutants continuously, while non-point sources only release pollutants in a single acute event

Lời giải chi tiết

The defining distinction is not severity or location type but identifiability: a point source (e.g., a single factory discharge pipe) can be pinpointed and regulated directly, while a non-point source (e.g., fertilizer runoff from many farms) arises from many dispersed origins across a landscape, making it far harder to monitor, attribute, and regulate. **(B)**.

Bài tập luyện tập

A fishery's natural income (the sustainable annual catch that does not deplete the underlying fish stock) is estimated at $5{,}000$ tonnes per year. A cornucopian technocentrist and a deep ecologist are each asked to recommend an annual catch limit. Explain, with reference to their positions on the EVS spectrum, what each is likely to recommend and why, and state where an anthropocentric environmental manager's recommendation would likely fall relative to the two.

Lời giải chi tiết

A **cornucopian technocentrist**, trusting that technology and market substitution can resolve any future resource shortfall, is likely to recommend a catch limit at or even above the estimated $5{,}000$-tonne natural income — prioritizing near-term economic yield on the reasoning that any resulting depletion of the fish stock could later be offset by aquaculture, more efficient fishing technology, or substitute resources, and placing little weight on the risk that the population could collapse past a recoverable threshold.

A **deep ecologist**, holding that the fish population has intrinsic value regardless of its economic usefulness, is likely to recommend a catch limit well below $5{,}000$ tonnes per year, or a full harvesting moratorium — prioritizing a wide margin of safety for the population and the wider ecosystem it supports, and rejecting the premise that ongoing extraction, even at a scientifically estimated "sustainable" rate, is acceptable if the resource is treated purely as a stock for human use.

An **anthropocentric environmental manager**, occupying the middle of the EVS spectrum, would likely recommend a catch limit close to the estimated natural income itself (at or modestly below $5{,}000$ tonnes/year) — seeking to balance continued economic use of the fishery against maintaining the underlying stock (natural capital) for future generations, placing their recommendation between the higher figure favoured by the cornucopian and the much lower (or zero) figure favoured by the deep ecologist.

Ecology and Ecosystems

> **Mục tiêu Unit:** Phân biệt loài (species), quần thể (population), quần xã (community) và hệ sinh thái (ecosystem); phân biệt nơi ở (habitat) với ổ sinh thái (niche), ổ sinh thái cơ bản (fundamental) và thực tế (realized), nguyên lý loại trừ cạnh tranh (competitive exclusion); yếu tố vô sinh (abiotic) và hữu sinh (biotic), yếu tố giới hạn (limiting factor), sức chứa (carrying capacity) và giới hạn chịu đựng (tolerance limits); các kiểu tương tác (ăn thịt, ăn cỏ, ký sinh, hỗ sinh, hội sinh, cạnh tranh nội/ngoại loài); dòng năng lượng, hai định luật nhiệt động lực học trong hệ sinh thái, bậc dinh dưỡng, chuỗi và lưới thức ăn; năng suất sơ cấp GPP–NPP ($NPP = GPP - R$) và năng suất thứ cấp GSP–NSP ($NSP = GSP - R$) cùng đơn vị kJ m^{-2} yr^{-1}; hiệu suất sinh thái (quy tắc ∼10%) và lý do truyền năng lượng kém hiệu quả; tháp số lượng, sinh khối và năng lượng, vì sao tháp năng lượng luôn thẳng đứng; các quần xã sinh vật lớn (biome) và khí hậu chi phối, biểu đồ khí hậu (climograph); phân vùng (zonation) so với diễn thế (succession), diễn thế nguyên sinh/thứ sinh, quần xã tiên phong $\rightarrow$ đỉnh cực, và loài chọn lọc kiểu r so với kiểu K.

2.1 The organisation of living systems

2.1.1 From individuals to the ecosphere

Ecology studies life organised into a nested hierarchy of increasing scale. A **species** is a group of organisms that share common characteristics and can interbreed to produce fertile offspring. A **population** is a group of organisms of the *same* species living in the same area at the same time, and capable of interbreeding. A **community** is a group of populations of *different* species living and interacting in the same area at the same time. An **ecosystem** is a community of interacting organisms (the biotic component) together with the non-living, physical environment (the abiotic component) with which they interact, considered as a functional unit through which energy flows and matter cycles. The largest scale, the **ecosphere** (or biosphere), is the part of the Earth and its atmosphere that is inhabited by living things.

> The distinguishing test between the levels is what varies. A *population* contains one species; a *community* contains many species but no non-living component; an *ecosystem* adds the abiotic environment (soil, water, air, light, temperature) and treats energy flow and nutrient cycling as part of the system.

> VN GIẢI THÍCH TIẾNG VIỆT
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> Sự sống được tổ chức theo thứ bậc tăng dần: **loài** (nhóm có thể giao phối sinh con hữu thụ) $\rightarrow$ **quần thể** (các cá thể cùng loài, cùng nơi, cùng thời điểm) $\rightarrow$ **quần xã** (nhiều quần thể khác loài tương tác với nhau) $\rightarrow$ **hệ sinh thái** (quần xã cộng với môi trường vô sinh, xem như một đơn vị chức năng có dòng năng lượng và chu trình vật chất). Điểm phân biệt cốt lõi: quần thể có một loài; quần xã có nhiều loài nhưng chưa gồm phần vô sinh; hệ sinh thái bổ sung yếu tố vô sinh (đất, nước, ánh sáng, nhiệt độ).

2.1.2 Habitat versus niche

A **habitat** is the physical place, with its characteristic set of conditions, where an organism or population normally lives — an *address*. A **niche** describes the particular role or "profession" of a species within its ecosystem: where it lives, what it feeds on, what feeds on it, how it reproduces, its tolerance ranges, and every interaction it has with the biotic and abiotic environment. The niche is therefore a description of *how* an organism makes its living, not merely *where* it lives.

Ecologists distinguish two versions of the niche. The **fundamental niche** is the full range of conditions and resources in which a species *could* survive and reproduce in the absence of competition or other limiting interactions — its potential, theoretical niche. The **realized niche** is the actual range of conditions and resources a species *does* occupy in the presence of competitors, predators and other constraints. The realized niche is always equal to or smaller than the fundamental niche, because interactions such as competition restrict a species to part of what it could otherwise exploit.

Fundamental vs realized niche

$$\text{realized niche} \subseteq \text{fundamental niche}$$

The classic evidence is Connell's study of two barnacle species on a Scottish shore. *Chthamalus* could physiologically survive across the whole intertidal range (its fundamental niche spans high and low shore), but where it overlaps with the faster-growing *Balanus*, it is crowded off the lower rocks and confined to the high shore — its realized niche. Remove *Balanus* and *Chthamalus* expands back toward its fundamental niche.

VN GIẢI THÍCH TIẾNG VIỆT

Nơi ở (habitat) là "địa chỉ" — nơi sinh vật sống; **ổ sinh thái (niche)** là "nghề nghiệp" — vai trò của loài: ăn gì, bị ăn bởi ai, sinh sản ra sao, giới hạn chịu đựng thế nào. **Ổ sinh thái cơ bản** là toàn bộ điều kiện loài *có thể* sống khi không bị cạnh tranh; **ổ sinh thái thực tế** là phần loài *thực sự* chiếm giữ khi có cạnh tranh và các loài khác. Vì cạnh tranh luôn thu hẹp phạm vi, ổ thực tế luôn nhỏ hơn hoặc bằng ổ cơ bản.

2.1.3 The competitive exclusion principle

Gause's **competitive exclusion principle** states that two species competing for exactly the same limiting resource cannot coexist indefinitely: the more efficient competitor will eventually exclude the other from that niche. Coexistence becomes possible only when the species differ sufficiently in their realized niches — a process called **resource partitioning** (for example, warblers feeding at different heights in the same tree, or the two barnacles occupying different shore zones). Complete niche overlap leads to competitive exclusion; partial overlap allows partitioning and coexistence.

Ví dụ mẫu · Reading a competitive-exclusion growth experiment

Two protist species, X and Y, are grown on the same bacterial food supply. Grown separately, each reaches a stable population of about 60 individuals per mL. Grown together in one flask, species X climbs to 58 per mL by day 16 while species Y falls steadily from 12 to 0 by day 18. Interpret the result.

Step 1 — identify the shared limiting resource. Both species depend on the same bacterial food; nothing partitions it (one flask, one food type), so their niches overlap completely.

Step 2 — apply the principle. Because the resource is limiting and the niches coincide, the two cannot coexist indefinitely. The more efficient competitor (X, which still reaches $58 \approx 60$) monopolises the food; the weaker competitor (Y) is driven to local extinction.

Step 3 — state the conclusion. This is competitive exclusion: $Y \to 0$. To coexist, X and Y would need to differ in realized niche (e.g., feed on different bacteria or at different times), i.e. partition the resource.

2.2 Abiotic and biotic factors, limits and carrying capacity

2.2.1 The two kinds of environmental factor

The factors that determine where and how well an organism lives fall into two classes. **Abiotic factors** are the non-living, physical and chemical features of an environment: temperature, light intensity, pH, salinity, dissolved oxygen, soil moisture, wind, water flow, and mineral (nutrient) availability. **Biotic factors** are the living components and their effects: predators, prey, competitors, parasites, pathogens, mutualists, and the availability of food organisms. Both act together — a plant may be limited by low temperature (abiotic) in winter but by grazing pressure (biotic) in summer.

2.2.2 Limiting factors and Liebig's law

A **limiting factor** is the single factor, in shortest supply relative to need, that restricts the growth, abundance or distribution of a population at a given time. **Liebig's law of the minimum** states that growth is controlled not by the total resources available but by the scarcest one: if nitrogen is the resource in shortest supply, adding more light or water will not increase yield until the nitrogen shortage is relieved. As one factor is corrected, a different factor may become limiting in turn.

2.2.3 Tolerance limits and the tolerance range

Every species can survive only within a certain range of each abiotic factor, called its **range of tolerance**. Within this range lies an **optimum** zone where the species thrives; toward each end are **zones of physiological stress** where survival is possible but performance drops; beyond the **limits of tolerance** at each extreme lie **zones of intolerance** where the organism cannot survive. Species with wide tolerance ranges tend to be widely distributed; those with narrow ranges make useful **indicator species**, because their presence or absence signals particular conditions (for example, certain mayfly larvae indicate clean, well-oxygenated water).

> A tolerance graph of performance (e.g., growth rate) against an abiotic factor is bell-shaped: a central *optimum* flanked by two *stress zones*, bounded by two *limits of tolerance*, outside which are the *zones of intolerance*. The width of the curve measures how much environmental variation the species can withstand.

> VN **GIẢI THÍCH TIẾNG VIỆT**
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> **Yếu tố vô sinh** (nhiệt độ, ánh sáng, pH, độ mặn, oxy hoà tan, dinh dưỡng...) và **yếu tố hữu sinh** (vật ăn thịt, con mồi, đối thủ cạnh tranh, ký sinh, cộng sinh) cùng quyết định phân bố loài. **Yếu tố giới hạn** là yếu tố khan hiếm nhất so với nhu cầu, kìm hãm quần thể (định luật cực tiểu Liebig: tăng trưởng do yếu tố thiếu nhất quyết định). **Giới hạn chịu đựng** là khoảng của mỗi yếu tố mà loài còn sống được, gồm vùng tối ưu ở giữa, hai vùng stress, và ngoài giới hạn là vùng không chịu được. Loài có khoảng chịu đựng hẹp thường là **loài chỉ thị**.

2.2.4 Carrying capacity and population growth

The **carrying capacity** (K) is the maximum population size of a species that an environment can support sustainably over the long term, given the available resources (food, water, space, nutrients). When a population colonises a new area with abundant resources, it may at first grow **exponentially** (a J-shaped curve). As density rises, limiting factors intensify — food runs short, waste accumulates, disease spreads, predators concentrate — so **environmental resistance** (the sum of all limiting factors) increases and slows growth. The result is typically **logistic** (S-shaped, sigmoid) growth that levels off at or oscillates around K. If a population overshoots K, resource depletion causes a **dieback** (population crash) back to or below carrying capacity.

Phases of an S-shaped population curve

- **Lag phase** — few individuals, slow absolute increase while the population establishes.
- **Exponential (log) phase** — resources are effectively unlimited, birth rate greatly exceeds death rate, numbers rise steeply.
- **Transitional phase** — environmental resistance mounts; growth rate begins to fall.
- **Plateau (stationary) phase** — birth rate $\approx$ death rate; population fluctuates around carrying capacity K.

Ví dụ mẫu · Identifying the limiting factor at carrying capacity

A reindeer herd is introduced to an island with no predators. Numbers rise from 25 to about $2{,}000$ in twenty years, briefly overshoot to $2{,}300$, then crash to 150. Lichen (their winter food) cover falls from 95% to under 5% over the same period. Identify the phase reached, the limiting factor, and explain the crash.

Step 1 — growth pattern. With no predators and abundant lichen, early growth is exponential (J-shaped): $25 \to 2{,}000$.

Step 2 — limiting factor. Because predation is absent, the population is limited from below by *food*: lichen is the resource in shortest supply. Lichen grows very slowly, so it cannot regenerate as fast as it is eaten.

Step 3 — overshoot and dieback. The herd overshoots carrying capacity ($2{,}300 > K$). With lichen cover collapsing below 5%, winter starvation causes a mass die-off (crash) to 150 — well below the original, now-degraded K. The environment's carrying capacity has itself been lowered because the food base was overexploited.

Conclusion. Food (lichen) is the limiting factor; the crash illustrates overshoot followed by dieback when a population exceeds a carrying capacity it is simultaneously eroding.

2.3 Interactions between species

2.3.1 The main interaction types

Species interact in characteristic ways, conventionally summarised by the sign of the effect on each partner ($+$ benefit, $-$ harm, 0 no significant effect):

Interaction	Species 1	Species 2	Description
Predation	$+$	$-$	one animal (predator) kills and eats another (prey)
Herbivory	$+$	$-$	an animal eats part of a plant (may not kill it)
Parasitism	$+$	$-$	parasite lives on/in a host, harming it over time
Mutualism	$+$	$+$	both partners benefit
Commensalism	$+$	0	one benefits, the other is unaffected
Competition	$-$	$-$	both are harmed by shared demand for a resource

Sign summary of the six interactions on the IB syllabus.

Predation is one animal (the predator) hunting, killing and consuming another (the prey); it is a powerful density-dependent control on prey numbers and often produces coupled predator–prey population cycles. **Herbivory** is an animal consuming a plant or alga; unlike predation it frequently damages rather than kills the food organism. **Parasitism** is a relationship in which a parasite lives on or inside a host, gaining nutrition at the host's expense and typically harming but not immediately killing it (e.g., tapeworms, ticks, mistletoe). **Mutualism** benefits both partners (e.g., mycorrhizal fungi and plant roots; pollinators and flowering plants; nitrogen-fixing *Rhizobium* bacteria in legume root nodules). **Commensalism** benefits one partner while the other is essentially unaffected (e.g., epiphytic orchids using a tree merely for support). **Competition** harms both participants because they demand the same limited resource.

2.3.2 Intraspecific versus interspecific competition

Intraspecific competition occurs *between members of the same species*. Because individuals of one species have nearly identical niches, this is the most intense form of competition and is the key density-dependent force pushing a population toward its carrying capacity. **Interspecific competition** occurs *between different species* whose niches overlap; its outcomes are competitive exclusion (Section 2.1) or, where niches differ enough, resource partitioning and coexistence.

VN GIẢI THÍCH TIẾNG VIỆT

Sáu kiểu tương tác theo dấu tác động: **ăn thịt** $(+/-)$, **ăn cỏ** $(+/-$, thường không giết cây), **ký sinh** $(+/-$, sống nhờ vật chủ), **hỗ sinh/cộng sinh** $(+/+$, ví dụ nấm rễ, vi khuẩn cố định đạm, thụ phấn), **hội sinh** $(+/0$, ví dụ lan biểu sinh bám cây), và **cạnh tranh** $(-/-)$. **Cạnh tranh nội loài** (cùng loài) mạnh nhất vì ổ sinh thái gần như trùng khớp và là lực chính đẩy quần thể về sức chứa K; **cạnh tranh ngoại loài** (khác loài) dẫn tới loại trừ cạnh tranh hoặc phân chia tài nguyên để cùng tồn tại.

Ví dụ mẫu · Classifying interactions from field notes

Classify each relationship and give its sign pair: (a) oxpecker birds ride buffalo, eating ticks off their skin; (b) a cuckoo lays eggs in a warbler's nest and the warbler raises the chick, losing its own; (c) barnacles attach to a whale's skin and filter-feed from passing water; (d) two oak seedlings under the same tree both grow poorly for lack of light.

(a) The bird gets food; the buffalo loses parasites — both benefit: *mutualism* $(+/+)$.

(b) The cuckoo gains; the warbler is harmed (raises a foreign chick, loses its own brood). It is a parasite of parental care — *parasitism* (brood parasitism), $+/-$.

(c) The barnacle gains transport and feeding opportunity; the whale is essentially unaffected — *commensalism* $(+/0)$.

(d) Same species, same limiting resource (light), both harmed — *intraspecific competition* $(-/-)$.

2.4 Energy flow through ecosystems

2.4.1 The Sun as the ultimate source

Almost all ecosystems are powered by the **Sun**. **Producers** (autotrophs — green plants, algae, cyanobacteria) capture a small fraction of incoming solar radiation by **photosynthesis**, converting light energy into the chemical energy of organic molecules. This is the single entry point of energy into most food chains; all **consumers** (heterotrophs) obtain their energy, directly or indirectly, by eating producers or one another, and **decomposers** (detritivores and saprotrophs) release energy from dead organic matter.

2.4.2 The laws of thermodynamics in ecosystems

Two physical laws govern energy in every ecosystem. The **first law of thermodynamics** (conservation of energy) states that energy can be transformed from one form to another but cannot be created or destroyed; in an ecosystem, light energy is transformed into chemical energy, then into heat, but the total is conserved. The **second law of thermodynamics** states that in any energy transformation some energy is degraded into a lower-quality, dispersed form — **heat** — so the entropy (disorder) of the system and its surroundings increases. Living systems maintain their high internal order only by continuously taking in energy and exporting heat; they are open systems, not violations of the second law.

> Because of the second law, *energy flow through an ecosystem is one-way (non-cyclic)*: it enters as sunlight, passes along the food chain, and is ultimately lost as heat at every step. This is why an ecosystem needs a constant external energy supply, whereas matter (carbon, nitrogen) can be recycled indefinitely.

2.4.3 Trophic levels, food chains and food webs

A **trophic level** is the position an organism occupies in a food chain — its feeding level. Producers form the first trophic level; **primary consumers** (herbivores) the second; **secondary consumers** (carnivores eating herbivores) the third; **tertiary consumers** the fourth, and so on. A **food chain** shows a single linear sequence of who eats whom, with arrows pointing in the direction of *energy flow* (from the eaten to the eater):

$$\text{grass} \rightarrow \text{grasshopper} \rightarrow \text{frog} \rightarrow \text{snake} \rightarrow \text{hawk}$$

A **food web** is a more realistic model: many interconnected food chains showing that most consumers eat several kinds of food and are eaten by several kinds of predator. Food webs illustrate why removing one species can have knock-on effects throughout a community.

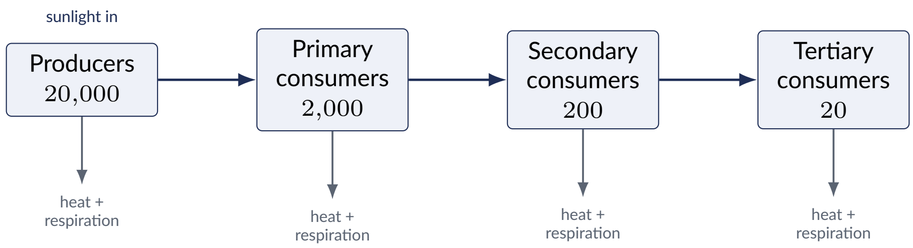

Figure 2.1 — One-way energy flow (kJ m^{-2} yr^{-1}) through four trophic levels; roughly 90% is lost as heat and respiration at each transfer, so only $\sim 10\%$ passes on.

GIẢI THÍCH TIẾNG VIỆT

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Mặt Trời là nguồn năng lượng gốc: **sinh vật sản xuất** bắt một phần nhỏ ánh sáng qua quang hợp, biến thành năng lượng hoá học. **Định luật I** (bảo toàn): năng lượng chỉ chuyển dạng, không tự sinh/mất. **Định luật II**: mỗi lần chuyển hoá, một phần năng lượng bị thoái hoá thành nhiệt, entropy tăng — nên **dòng năng lượng đi một chiều**, phải được bổ sung liên tục, trong khi vật chất có thể tuần hoàn. **Bậc dinh dưỡng** là vị trí ăn uống trong chuỗi thức ăn; mũi tên trong chuỗi/lưới thức ăn chỉ chiều truyền năng lượng (từ con bị ăn sang con ăn).

Ví dụ mẫu · Reading arrows in a food web

In a grassland web: grass is eaten by rabbits and grasshoppers; grasshoppers are eaten by shrews and lizards; rabbits are eaten by foxes; shrews are eaten by owls. (a) Which organisms are producers? (b) State the trophic level occupied by the shrew. (c) A disease wipes out the rabbits; predict two effects.

(a) Only *grass* is a producer (autotroph); everything else is a consumer.

(b) The shrew eats grasshoppers (primary consumers), so it is a secondary consumer — the *third* trophic level.

(c) With rabbits gone: (i) foxes lose a food source and must switch prey or decline; (ii) the grass previously eaten by rabbits is released, so grass and the grasshopper population competing for it may increase — illustrating knock-on effects of removing one node from a web.

2.5 Productivity

2.5.1 Primary productivity: GPP and NPP

Productivity is the rate at which biomass (energy stored in organic matter) is generated per unit area per unit time; typical units are kJ m^{-2} yr^{-1} or g m^{-2} yr^{-1}. For producers:

- **Gross primary productivity (GPP)** is the total rate at which producers convert light energy into chemical energy (the total amount of glucose synthesised) per unit area per unit time.
- **Respiratory loss (**R**)** is the energy producers use for their own respiration (metabolism, growth, transport).
- **Net primary productivity (NPP)** is the energy stored as new biomass and therefore available to the next trophic level:

Net primary productivity

$$\boxed{NPP = GPP - R} \qquad \text{units: kJ m}^{-2}\,\text{yr}^{-1}$$

NPP is the rate of biomass accumulation available to consumers (herbivores) — it is what an ecosystem "offers" to the next level after producers have paid their own respiratory costs.

2.5.2 Secondary productivity: GSP and NSP

Consumers build biomass too. Not all food eaten is absorbed: some passes out as faeces. Of the energy assimilated, some is respired.

- **Gross secondary productivity (GSP)** is the total energy or biomass assimilated by consumers — the energy content of food eaten minus faecal losses ($GSP =$ food eaten $-$ faecal loss).
- **Net secondary productivity (NSP)** is the energy stored as new consumer biomass, i.e. GSP minus respiratory loss:

Net secondary productivity

$$\boxed{NSP = GSP - R} \qquad \text{units: kJ m}^{-2}\,\text{yr}^{-1}$$

where $GSP =$ (energy in food consumed)$-$(energy lost in faeces). NSP is the new consumer biomass available to the *next* trophic level.

2.5.3 Ecological (trophic) efficiency and the 10% rule

Ecological efficiency (also trophic-level transfer efficiency) is the percentage of energy at one trophic level that is passed on to and fixed as biomass in the next:

Ecological efficiency

$$\text{efficiency}(\%) = \frac{\text{productivity of level } (n+1)}{\text{productivity of level } n} \times 100$$

In most ecosystems this is only about 5%–20%, averaged as the "**10% rule**": roughly 90% of the energy at one level is *not* passed on.

Energy transfer between trophic levels is inefficient for several reasons: (i) not all of a lower level is eaten (roots, bones, and some individuals are missed); (ii) not all that is eaten is digested and assimilated — much leaves as **faeces**; (iii) a large share of assimilated energy is spent on **respiration** (movement, maintaining body temperature in endotherms, and other metabolism) and is lost as heat under the second law; (iv) some is lost in excretion (e.g., urea). Only what remains as new biomass (NPP or NSP) is available to the next level. Because heat cannot be reused by organisms, these losses are irreversible and compound at every step, which is why food chains rarely exceed four or five links.

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Năng suất sơ cấp: GPP là tổng năng lượng producers cố định được; R là hô hấp; $NPP = GPP - R$ là biomass mới dành cho bậc sau (đơn vị kJ m^{-2} yr^{-1}). **Năng suất thứ cấp:** GSP là năng lượng đồng hoá = thức ăn ăn vào − phân thải; $NSP = GSP - R$. **Hiệu suất sinh thái** = (năng suất bậc n+1)/(năng suất bậc n)×100, thường ∼10%. Truyền năng lượng kém hiệu quả vì: không phải mọi thứ bị ăn, không phải mọi thứ ăn vào được tiêu hoá (mất qua phân), phần lớn năng lượng đồng hoá dùng cho hô hấp và mất dưới dạng nhiệt (định luật II). Vì thế chuỗi thức ăn hiếm khi dài quá 4–5 mắt xích.

Ví dụ mẫu · Calculating NPP from GPP and respiration

A field of grass fixes energy at a gross rate of $GPP = 20{,}800$ kJ m^{-2} yr^{-1}. The grass loses $R = 8{,}200$ kJ m^{-2} yr^{-1} to its own respiration. (a) Find NPP. (b) What percentage of GPP is stored as new biomass?

(a) $NPP = GPP - R = 20{,}800 - 8{,}200 = 12{,}600$ kJ m^{-2} yr^{-1}.

(b) Fraction stored $= \dfrac{NPP}{GPP} \times 100 = \dfrac{12{,}600}{20{,}800} \times 100 = 60.6\%$. So about 60.6% of the gross fixed energy becomes new biomass; the remaining 39.4% is respired away as heat.

Ví dụ mẫu · Secondary productivity NSP = GSP - R

Caterpillars on the grass above eat plant material containing $2{,}100$ kJ m^{-2} yr^{-1}. Of this, $1{,}300$ kJ m^{-2} yr^{-1} leaves in faeces. The caterpillars respire 620 kJ m^{-2} yr^{-1}. (a) Find GSP. (b) Find NSP. (c) What fraction of ingested energy becomes new caterpillar biomass?

(a) GSP = eaten − faeces $= 2{,}100 - 1{,}300 = 800$ kJ m^{-2} yr^{-1} (assimilated energy).

(b) $NSP = GSP - R = 800 - 620 = 180$ kJ m^{-2} yr^{-1}.

(c) $\dfrac{NSP}{\text{eaten}} \times 100 = \dfrac{180}{2{,}100} \times 100 = 8.6\%$. Only about 8.6% of ingested energy ends up as new biomass — close to the ∼10% rule, with most lost to faeces and respiration.

Ví dụ mẫu · Trophic efficiency between two levels

Producers in a lake have $NPP = 9{,}000$ kJ m^{-2} yr^{-1}. The zooplankton (primary consumers) that feed on them have $NSP = 810$ kJ m^{-2} yr^{-1}. Calculate the ecological efficiency of this transfer and comment.

$$\text{efficiency} = \frac{\text{productivity of level } 2}{\text{productivity of level } 1} \times 100 = \frac{810}{9{,}000} \times 100 = 9.0\%.$$

The transfer is 9.0% — consistent with the ∼10% rule. About 91% of producer energy never reaches the zooplankton, lost as uneaten producers, faeces, and respiration.

Ví dụ mẫu · Energy remaining after several trophic levels

Producers store $NPP = 40{,}000$ kJ m^{-2} yr^{-1}. Assuming a constant 10% transfer efficiency at each step, how much energy is available to (a) primary consumers, (b) secondary consumers, (c) tertiary consumers? (d) What fraction of the original producer energy reaches the tertiary consumers?

Each step multiplies by 0.10.

(a) Primary consumers: $40{,}000 \times 0.10 = 4{,}000$ kJ m^{-2} yr^{-1}.
(b) Secondary consumers: $4{,}000 \times 0.10 = 400$ kJ m^{-2} yr^{-1}.
(c) Tertiary consumers: $400 \times 0.10 = 40$ kJ m^{-2} yr^{-1}.
(d) Fraction $= \dfrac{40}{40{,}000} = 0.001 = 0.1\%$, i.e. $(0.10)^3$. Only one part in a thousand of producer energy reaches the fourth trophic level — why top predators are rare and food chains are short.

Ví dụ mẫu · Working backwards to a required prey base

A population of hawks (tertiary consumers) requires 25 kJ m^{-2} yr^{-1} of net productivity to be sustained. Assuming 10% efficiency at each transfer and a food chain producer → herbivore → small bird → hawk, what minimum NPP must the producers supply?

Working back up the chain, each lower level must be $10\times$ larger:
Small birds needed: $25 \div 0.10 = 250$ kJ m^{-2} yr^{-1}.
Herbivores needed: $250 \div 0.10 = 2{,}500$ kJ m^{-2} yr^{-1}.
Producers (NPP) needed: $2{,}500 \div 0.10 = 25{,}000$ kJ m^{-2} yr^{-1}.
So the producers must fix at least $25{,}000$ kJ m^{-2} yr^{-1} of net biomass — $1{,}000\times$ the hawks' requirement, since $25 = 25{,}000 \times (0.10)^3$.

2.6 Ecological pyramids

2.6.1 Three kinds of pyramid

An **ecological pyramid** is a graphical model in which horizontal bars, stacked from producers at the base upward, represent some quantity at each trophic level; bar width is drawn proportional to the quantity.

- A **pyramid of numbers** shows the number of *organisms* at each level. It is quick to measure but can be misleading: a single large tree (one producer) supporting thousands of insects gives an *inverted* pyramid, and parasites make the top levels wide.
- A **pyramid of biomass** shows the standing stock (dry mass, usually g m^{-2}) at each level at one moment. It is usually upright, but can be inverted in aquatic systems where tiny, fast-reproducing phytoplankton have a small *standing* biomass at any instant yet support a larger mass of zooplankton — a snapshot problem.
- A **pyramid of productivity (energy)** shows the *rate* of energy flow or biomass production (kJ m^{-2} yr^{-1}) at each level over time.

2.6.2 Why energy (productivity) pyramids are always upright

Because a productivity pyramid measures the *rate of energy flow* through each level over a period (not a single snapshot), and because the second law of thermodynamics guarantees that energy is lost as heat at every transfer, each level must receive less energy than the one below it. There is no way for a higher trophic level to process more energy per year than reaches it. Therefore a pyramid of productivity can *never* be inverted — it is always upright, unlike numbers or standing-biomass pyramids, which are snapshots and can be inverted.

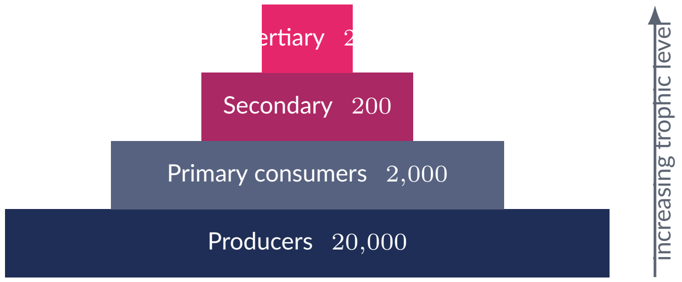

Figure 2.2 — An upright pyramid of productivity (kJ m^{-2} yr^{-1}). Each level carries $\sim 10\%$ of the level below, so the pyramid narrows upward and can never be inverted.

Ví dụ mẫu · Building and interpreting a pyramid

A meadow provides these annual productivities (kJ m^{-2} yr^{-1}): producers $18{,}000$; primary consumers $1{,}600$; secondary consumers 190. (a) Name the pyramid type that is always upright. (b) Compute the two transfer efficiencies. (c) A student measures 12 oak trees, $10{,}000$ aphids and 300 ladybirds and draws a pyramid of numbers — why does it look inverted at the base?

(a) A *pyramid of productivity*: base bar $18{,}000$, then $1{,}600$, then 190 — each drawn narrower, giving an upright shape.

(b) Producer → primary: $\dfrac{1{,}600}{18{,}000} \times 100 = 8.9\%$. Primary → secondary: $\dfrac{190}{1{,}600} \times 100 = 11.9\%$. Both near the ~10% rule.

(c) A pyramid of *numbers* counts individuals, not energy. A few large oak trees (12) support thousands of tiny aphids (10,000), so the producer bar is *narrower* than the primary-consumer bar — an inverted base. Numbers ignore body size, which is exactly why productivity pyramids are preferred.

2.7 Biomes and their distribution

2.7.1 What is a biome?

A **biome** is a large geographical region characterised by a distinctive climate and a matching community of plants and animals adapted to it. Biomes with similar climate look structurally similar even on different continents, because **temperature and precipitation** are the two dominant abiotic drivers that determine which life forms can survive. Their global distribution is governed largely by latitude (controlling temperature and the pattern of atmospheric circulation) and by proximity to oceans and mountains (controlling precipitation).

Biome	Temperature	Precipitation	Typical vegetation
Tropical rainforest	hot, ~ 25–$30\,^\circ$C all year	very high, > 2000 mm yr^{-1}	tall broadleaf evergreen, layered canopy
Desert	extreme range, hot days	very low, < 250 mm yr^{-1}	sparse succulents, drought-adapted shrubs
Tundra	very cold, $< 0\,^\circ$C mean	low, < 250 mm yr^{-1}	mosses, lichens, dwarf shrubs; permafrost
Temperate forest	seasonal, mild summers	moderate, 500–1500 mm	deciduous broadleaf trees, marked seasons
Grassland	seasonal, warm summers	intermediate, 250–750 mm	grasses, few trees; regular drought/fire

Figure 2.3 — Five major terrestrial biomes and their climate drivers (temperature and precipitation).

2.7.2 Climographs

A **climograph** (climate graph) is a single chart summarising a location's average climate through the year: **monthly mean temperature** is plotted as a line (read on one axis) and **monthly precipitation** as bars (read on a second axis). The shape of a climograph is a fingerprint of the biome: a rainforest shows high, flat temperature and high rainfall every month; a tundra shows temperatures mostly below freezing with low precipitation; a grassland shows a warm growing season with a pronounced dry period. Comparing climographs lets you classify a site's biome from its temperature and precipitation pattern alone.

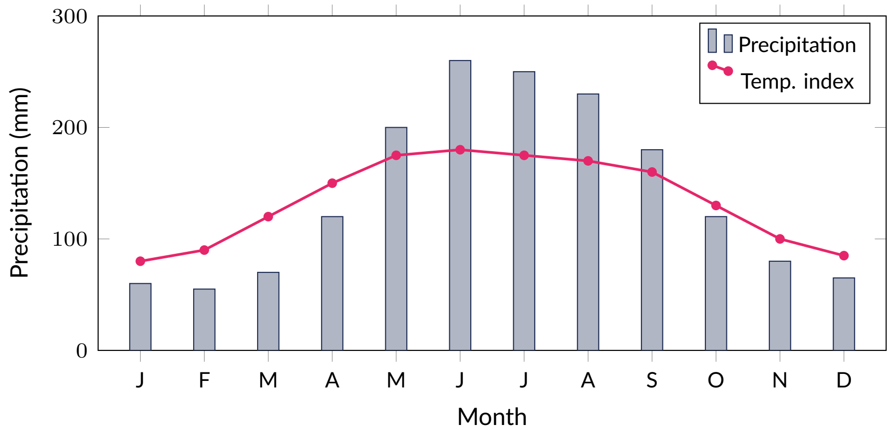

Figure 2.4 — Schematic climograph of a tropical wet region: precipitation bars (wet season May–September) and a temperature-index line held high and steady all year. Temperature index shown on the same scale for illustration.

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Biome là vùng địa lý rộng có khí hậu đặc trưng và quần xã sinh vật thích nghi tương ứng; hai yếu tố chi phối chính là **nhiệt độ** và **lượng mưa**, thay đổi theo vĩ độ và vị trí so với đại dương/núi. Rừng mưa nhiệt đới: nóng, mưa nhiều quanh năm; hoang mạc: mưa rất ít; đài nguyên (tundra): rất lạnh, có tầng đất đóng băng vĩnh cửu; rừng ôn đới: theo mùa rõ; đồng cỏ: mưa trung bình, có mùa khô/cháy. **Biểu đồ khí hậu (climograph)** vẽ nhiệt độ trung bình tháng (đường) và lượng mưa tháng (cột) trên cùng một biểu đồ — hình dạng của nó cho biết biome.

Ví dụ mẫu · Classifying a biome from climate data

Site Z records a mean annual temperature of $-8\,^\circ$C (every month below $10\,^\circ$C, most below $0\,^\circ$C) and total annual precipitation of 180 mm, with a permanently frozen subsoil. Vegetation is limited to mosses, lichens and dwarf shrubs. Which biome is this, and justify using the two climate drivers.

Temperature: extremely cold, mean below freezing, no month above $10\,^\circ$C — rules out forests and grasslands, which need a warm growing season.

Precipitation: only 180 mm yr^{-1} — as dry as a desert, but combined with the cold and permafrost.

Vegetation and permafrost: low mosses/lichens and a permanently frozen subsoil are diagnostic.

Conclusion: this is *tundra*. Cold plus low precipitation plus permafrost prevents tree growth and gives low productivity; the short cool "summer" allows only low-growing plants.

2.8 Zonation and succession

2.8.1 Zonation — change across space

Zonation is the arrangement or layering of plant and animal communities into distinct bands (zones) in response to a gradient of one or more abiotic factors *across space*, at a single moment in time. Classic examples are the bands of seaweed and animals down a rocky seashore (a gradient of tidal exposure and desiccation) and the change of vegetation with altitude up a mountain (a gradient of temperature and oxygen). Zonation is a spatial pattern; it is *not* a change over time.

2.8.2 Succession — change over time

Succession is the orderly, directional change in the species composition of a community over *time*, as organisms modify their own environment and are replaced by others, proceeding toward a stable **climax community**. **Primary succession** begins on newly exposed, lifeless substrate that has never supported a community — bare rock from a lava flow, a new sand dune, land exposed by a retreating glacier — and must start by building soil. **Secondary succession** begins where an existing community has been disturbed or destroyed (fire, flood, abandoned farmland) but *soil and some seeds/roots remain*; it is therefore much faster than primary succession because the soil stage is skipped.

> Remember the distinction: *zonation* is change in space (a gradient at one time); *succession* is change in time (at one place). Primary succession starts with no soil; secondary succession starts with soil already present, so it reaches climax far more quickly.

2.8.3 The course of a primary succession

Succession runs from **pioneer species** to a **climax community**:

1. **Pioneer stage** — hardy pioneers (lichens, mosses, some algae) colonise bare rock. They tolerate extreme conditions, need few nutrients, and begin to weather the rock and add organic matter when they die.
2. **Soil building** — dead pioneers plus weathered rock form a thin soil that can hold water and nutrients, allowing small herbs and grasses to establish.
3. **Intermediate stages** — deeper soil supports shrubs and then fast-growing (often r-selected) trees; each community changes light, moisture and nutrient conditions, making the site suitable for the next.
4. **Climax community** — a relatively stable, self-perpetuating community (e.g., mature forest) dominated by long-lived, K-selected species, in dynamic equilibrium with the climate and soil.

2.8.4 How ecosystem properties change during succession

As succession proceeds from pioneer to climax, characteristic trends appear:

- **Species diversity** generally *rises* through the mid-successional stages (more niches, more habitat structure) and may dip slightly at the climax as a few dominant competitors take over.
- **Biomass** and the complexity of food webs *increase*, reaching a maximum in the climax community.
- **Soil** deepens; its organic (humus) content, water-holding capacity and nutrient store all *increase*.
- **Gross productivity (GPP)** rises as the plant cover and leaf area increase.
- The **GPP : R ratio** *falls toward* 1: in early succession GPP greatly exceeds respiration R, so there is large net production and rapid biomass build-up (NPP high). In the climax community, the large standing biomass respires so much that $R \approx GPP$, so **NPP falls toward zero** even though GPP is high — the ecosystem stores little *additional* biomass and is near steady state.

Productivity ratio through succession

$$\frac{GPP}{R} \gg 1 \text{ (early: high NPP, fast growth)} \quad \longrightarrow \quad \frac{GPP}{R} \approx 1 \text{ (climax: NPP} \to 0\text{, steady state)}$$

Recall $NPP = GPP - R$: when R climbs to nearly equal GPP, net production and further biomass accumulation approach zero even though gross productivity is at its highest.

2.8.5 r-selected and K-selected species

The species that dominate early versus late succession differ in life strategy.

Feature	r-selected (pioneers)	K-selected (climax)
Body size	small	large
Maturity	rapid	slow
Reproduction	early, many offspring	late, few offspring
Parental care	little/none	extensive
Offspring survival	low	high
Lifespan	short	long
Population near K?	fluctuates, often $> K$ then crash	stable, near K
Best suited to	new, disturbed habitats	mature, stable habitats

Figure 2.5 — r-selected pioneers versus K-selected climax species. Early succession favours fast, opportunistic r-strategists; late succession favours competitive K-strategists.

r**-selected species** ("r" from the maximal growth-rate term) reproduce rapidly, produce many small offspring with little parental care, and thrive in the empty, unstable conditions of early succession or after disturbance; their populations boom and bust. K**-selected species** ("K" from carrying capacity) invest in few, well-cared-for offspring, mature slowly, live long, and are strong competitors that dominate stable climax communities near carrying capacity.

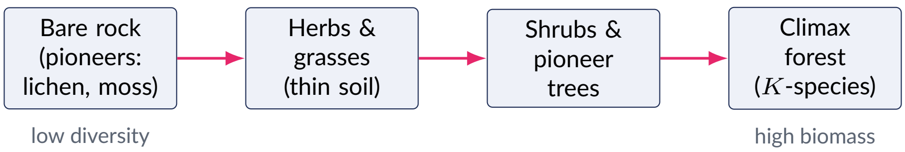

Figure 2.6 — Primary succession: pioneers → climax community. Diversity, biomass and soil depth increase; the GPP : R ratio falls toward 1.

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Phân vùng (zonation) là sự thay đổi quần xã theo *không gian* (theo gradient của yếu tố vô sinh, tại một thời điểm — ví dụ các đới trên bờ đá, theo độ cao núi). **Diễn thế (succession)** là sự thay đổi theo *thời gian*, đi từ loài tiên phong đến quần xã đỉnh cực. **Diễn thế nguyên sinh** bắt đầu trên nền trơ chưa có sự sống (phải tạo đất, rất chậm); **diễn thế thứ sinh** bắt đầu nơi đã có đất và hạt/rễ còn sót (nhanh hơn). Trong diễn thế: đa dạng, sinh khối, độ sâu đất và GPP tăng; **tỉ số GPP/R giảm về** ≈ 1 nên NPP giảm dần về gần 0 ở đỉnh cực. Loài **kiểu** r (tiên phong): nhỏ, sinh sản nhanh, nhiều con, sống ngắn; loài **kiểu** K (đỉnh cực): lớn, ít con, chăm con, sống lâu, cạnh tranh mạnh, gần sức chứa K.

Ví dụ mẫu · Productivity ratios in early vs late succession

An early-successional grassland has $GPP = 15{,}000$ kJ m^{-2} yr^{-1} and $R = 4{,}000$ kJ m^{-2} yr^{-1}. A neighbouring climax forest has $GPP = 40{,}000$ kJ m^{-2} yr^{-1} and $R = 39{,}000$ kJ m^{-2} yr^{-1}. (a) Compute NPP and the GPP : R ratio for each. (b) Which is accumulating biomass faster, and why does the forest have far higher GPP yet store almost no new biomass?

Grassland: $NPP = 15{,}000 - 4{,}000 = 11{,}000$ kJ m^{-2} yr^{-1}; $GPP : R = 15{,}000/4{,}000 = 3.75$.

Forest: $NPP = 40{,}000 - 39{,}000 = 1{,}000$ kJ m^{-2} yr^{-1}; $GPP : R = 40{,}000/39{,}000 = 1.03$.

(b) The *grassland* accumulates biomass far faster ($NPP = 11{,}000$ vs $1{,}000$). The forest fixes much more energy (high GPP) but its enormous standing biomass respires almost as much as it fixes, so $R \approx GPP$, the ratio approaches 1, and net production is nearly zero — the signature of a climax community at steady state.

2.9 Biogeochemical cycles: carbon, nitrogen and phosphorus

2.9.1 Gaseous versus sedimentary cycles

Chapter 1 established that, unlike energy, matter is conserved and therefore cycles indefinitely between living organisms and the physical environment. These pathways are called **biogeochemical cycles** — "bio" because organisms drive many of the transformations, "geo" because rock, soil, water and atmosphere act as the major storages. ESS distinguishes two broad categories.

> A **gaseous cycle** has a large, fast-exchanging atmospheric storage, so the element can be redistributed globally within days to years (carbon and nitrogen are the standard examples: both spend significant time as atmospheric gases, CO2 and N2 respectively). A **sedimentary cycle** has no significant gaseous phase; the element is instead stored mainly in rock, sediment and soil and is redistributed far more slowly, chiefly through weathering, runoff and geological uplift (phosphorus is the standard example). Sedimentary-cycle elements therefore recover far more slowly than gaseous-cycle elements once a storage is depleted or a flow is disrupted, echoing the residence-time reasoning of Chapter 1.

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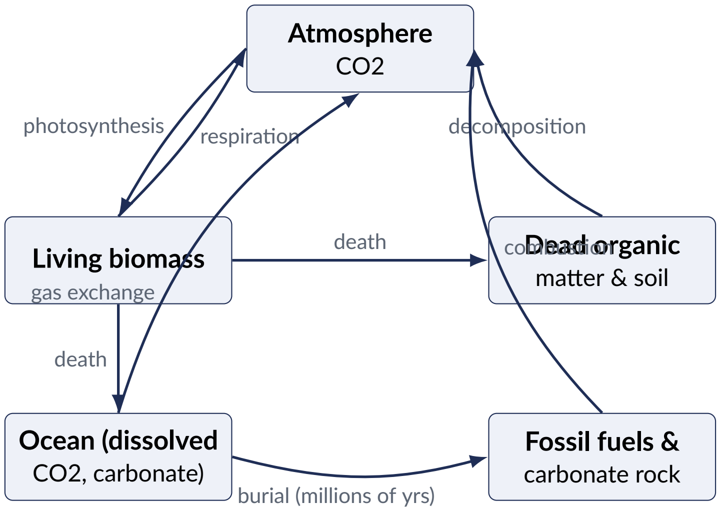
> **Chu trình khí (gaseous cycle)** có một kho chứa khí quyển lớn, trao đổi nhanh (ngày đến năm) — ví dụ carbon (CO2) và nitơ (N2). **Chu trình trầm tích (sedimentary cycle)** hầu như không có pha khí đáng kể, nguyên tố chủ yếu nằm trong đá, trầm tích và đất, luân chuyển rất chậm qua phong hoá, dòng chảy mặt và nâng địa chất — ví dụ điển hình là phốt-pho. Vì luân chuyển chậm hơn nhiều, các nguyên tố theo chu trình trầm tích phục hồi chậm hơn nhiều so với chu trình khí một khi kho chứa bị cạn kiệt hoặc dòng chảy bị gián đoạn — nhất quán với khái niệm thời gian lưu trú (residence time) ở Chương 1.

2.9.2 The carbon cycle

Carbon moves between the atmosphere (as CO2), the oceans (dissolved CO2, bicarbonate and carbonate ions, and marine organisms), living biomass, soil and dead organic matter, and long-term geological storages (fossil fuels, carbonate rock).

> Key carbon flows: **photosynthesis** removes atmospheric CO2 and fixes it into organic (biomass) carbon; **respiration** (by producers, consumers and decomposers) returns carbon to the atmosphere as CO2; **decomposition** breaks down dead organic matter, releasing CO2 (aerobic) or methane, CH4 (anaerobic, e.g. in waterlogged soils and wetlands); **combustion** of biomass or fossil fuels rapidly returns carbon accumulated over a long period (in the case of fossil fuels, over millions of years) to the atmosphere as CO2; and **ocean–atmosphere gas exchange** continuously moves CO2 between the atmosphere and dissolved inorganic carbon in surface seawater. Over geological time, some marine organisms build carbonate shells and skeletons that, after death, can be buried and eventually lithified into carbonate rock (e.g. limestone) — an extremely slow, long-term carbon storage.



The carbon cycle: photosynthesis and respiration exchange carbon rapidly between the atmosphere and living biomass; decomposition, ocean gas exchange, burial and combustion link slower and faster storages.

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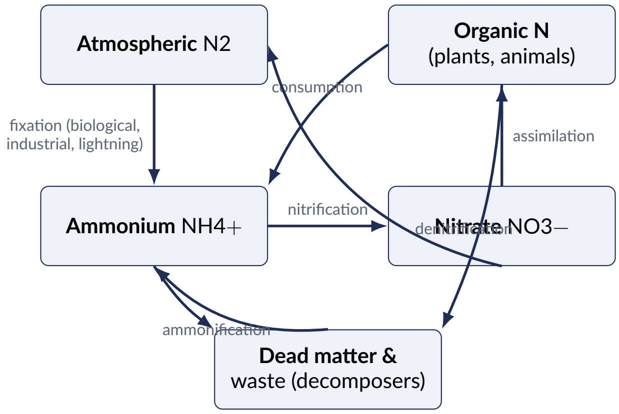
Chu trình carbon: **quang hợp** lấy CO_2 khí quyển và cố định thành carbon hữu cơ (sinh khối); **hô hấp** (của sinh vật sản xuất, tiêu thụ, phân giải) trả carbon về khí quyển dưới dạng CO_2; **phân giải** chất hữu cơ chết giải phóng CO_2 (hiếu khí) hoặc mêtan CH_4 (kỵ khí, ví dụ đất ngập nước); **đốt cháy** sinh khối/nhiên liệu hoá thạch trả lại rất nhanh lượng carbon đã tích luỹ trong thời gian rất dài (hàng triệu năm với nhiên liệu hoá thạch); **trao đổi khí đại dương–khí quyển** liên tục chuyển CO_2 giữa khí quyển và carbon vô cơ hoà tan trong nước biển bề mặt. Xác sinh vật biển có vỏ/khung carbonate có thể bị chôn vùi và hoá đá thành đá vôi qua thời gian địa chất — kho chứa carbon cực kỳ lâu dài.

2.9.3 The nitrogen cycle

Although the atmosphere is nearly 78% nitrogen gas (N_2), this form is unusable by almost all organisms because the strong triple bond between the two nitrogen atoms makes N_2 chemically inert. Nitrogen must first be **fixed** — converted into a chemically reactive form — before it can enter living systems.

Nitrogen fixation converts inert N_2 into ammonia/ammonium (NH_3/NH_4^+), through three main pathways: **biological fixation** by free-living soil bacteria and by symbiotic bacteria (e.g. *Rhizobium*) living in the root nodules of legume plants; **industrial fixation** via the Haber–Bosch process, which manufactures synthetic ammonia for fertiliser; and **atmospheric (lightning) fixation**, in which the energy of a lightning strike breaks the N_2 triple bond, allowing nitrogen to combine with oxygen and eventually dissolve into soil as nitrate in rainfall. Once fixed, **nitrification** (performed by soil bacteria) oxidises ammonium first to nitrite (NO_2^-) and then to nitrate (NO_3^-), the form most readily absorbed by plant roots. **Assimilation** is the uptake of ammonium or nitrate by plants to build proteins and nucleic acids, after which the nitrogen can pass along a food chain. **Ammonification** (decomposition of nitrogen-containing waste and dead organic matter by decomposers) returns nitrogen to the soil as ammonium. Finally, **denitrification** (performed by anaerobic bacteria, typically in waterlogged or oxygen-poor soils) converts nitrate back into N_2 gas, returning it to the atmosphere and completing the cycle.



The nitrogen cycle: fixation converts inert N2 into usable ammonium; nitrification, assimilation and ammonification cycle nitrogen through soil and organisms; denitrification returns it to the atmosphere.

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Cố định đạm (nitrogen fixation) chuyển N2 trơ thành amoni/amoniac qua ba con đường: **sinh học** (vi khuẩn cố định đạm tự do và vi khuẩn cộng sinh *Rhizobium* ở nốt sần rễ cây họ đậu), **công nghiệp** (quy trình Haber–Bosch sản xuất phân đạm), và **khí quyển** (sét phá vỡ liên kết ba của N2). **Nitrat hoá (nitrification)**: vi khuẩn oxy hoá amoni thành nitrit rồi nitrat — dạng cây hấp thụ dễ nhất. **Đồng hoá (assimilation)**: cây hấp thụ amoni/nitrat để tạo protein. **Amoni hoá (ammonification)**: vi sinh vật phân giải chất hữu cơ chết/chất thải trả đạm về đất dưới dạng amoni. **Khử nitrat (denitrification)**: vi khuẩn kỵ khí (đất ngập nước) chuyển nitrat trở lại thành khí N2, khép kín chu trình.

(!) Lỗi thường gặp: Do not confuse **nitrification** (ammonium → nitrite → nitrate; requires oxygen) with **denitrification** (nitrate → atmospheric N2; requires anaerobic conditions) — they are near-opposite processes performed by different bacteria under opposite oxygen conditions, and mixing them up is one of the most common IB exam errors on this topic.

2.9.4 The phosphorus cycle: a sedimentary cycle

Phosphorus illustrates a sedimentary cycle in its purest form: it has **no significant atmospheric gas phase**, so the cycle depends entirely on the slow physical weathering of phosphate-containing rock.

Weathering of phosphate rock slowly releases phosphate ions ($PO4^{3}-$) into soil and water. Plants take up dissolved phosphate directly from soil water (**assimilation**); it then passes along food chains, and decomposition of dead matter and waste returns it to the soil (analogous to ammonification in the nitrogen cycle, but there is no gaseous step). Because there is no atmospheric pathway to spread phosphorus globally on a short timescale, phosphate that is washed by runoff into rivers, lakes and eventually the ocean can settle as sediment and, over geological time, be uplifted back into exposed rock — a cycle that operates on a timescale of thousands to millions of years, far slower than the carbon or nitrogen cycles. This slowness is precisely why phosphorus is so often the **limiting nutrient** for plant growth in natural ecosystems, and why phosphate runoff from fertilisers is such a powerful trigger of freshwater eutrophication (Chapter 4): a nutrient that is naturally scarce and slow-cycling produces an outsized ecological response when suddenly supplied in a fast, concentrated pulse.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phốt-pho là ví dụ điển hình của **chu trình trầm tích**: hầu như không có pha khí, phụ thuộc hoàn toàn vào **phong hoá** đá chứa phốt-phát để giải phóng ion phốt-phát vào đất/nước. Cây hấp thụ trực tiếp từ đất (đồng hoá), truyền qua chuỗi thức ăn, và phân giải trả lại đất (giống amoni hoá nhưng không có bước khí). Vì không có con đường khí quyển để phát tán nhanh trên toàn cầu, phốt-phát trôi ra sông hồ và đại dương có thể lắng đọng thành trầm tích rồi hàng triệu năm sau mới được nâng trở lại thành đá lộ thiên — vô cùng chậm so với chu trình carbon hay nitơ. Đây là lý do phốt-pho thường là **chất dinh dưỡng giới hạn (limiting nutrient)** trong tự nhiên, và vì sao phân bón chứa phốt-phát chảy tràn lại gây ra hiện tượng phú dưỡng hoá (eutrophication) mạnh đến vậy ở nước ngọt.

Ví dụ mẫu · Comparing recovery times after disruption

A river is contaminated by two separate spills: one releases excess dissolved nitrate (part of the nitrogen cycle), the other releases excess phosphate (part of the phosphorus cycle) from a mining operation upstream. Both spills are stopped immediately and are of comparable size. Explain which contamination would be expected to persist longer in the wider environment, and why, referring to the gaseous/sedimentary distinction.

The **phosphate** contamination would be expected to persist far longer. Excess nitrate can eventually be removed from the water–soil system via denitrification (anaerobic bacteria converting it back to atmospheric N2), a genuine exit pathway that a purely sedimentary cycle lacks. Phosphate has no equivalent gaseous exit: once released, it can only be removed from the local system by very slow processes — uptake and long-term burial in sediment, or physical transport — with no atmospheric pathway to disperse or convert it away. This is a direct, practical consequence of nitrogen being a gaseous cycle and phosphorus being a sedimentary cycle.

VN GIẢI THÍCH TIẾNG VIỆT

Vì nitơ có "lối thoát" qua khí quyển (khử nitrat → N2) còn phốt-pho thì không, ô nhiễm phốt-phát thường tồn tại lâu hơn nhiều trong môi trường so với ô nhiễm nitrat có cùng quy mô — đây là hệ quả trực tiếp của việc nitơ theo chu trình khí còn phốt-pho theo chu trình trầm tích.

2.10 Practice problems

Bài tập luyện tập

Which statement correctly distinguishes a community from an ecosystem?

(A) A community includes the abiotic environment; an ecosystem does not

(B) An ecosystem includes the abiotic environment; a community is only the interacting living populations

(C) A community contains one species; an ecosystem contains many

(D) They are synonyms at different scales

Lời giải chi tiết

A *community* is all the interacting populations of different species in an area — living components only. An *ecosystem* adds the non-living (abiotic) environment and treats energy flow and nutrient cycling as part of the functional unit. A population (not a community) contains one species, so (C) is wrong; (A) reverses the definitions. **(B)**

Bài tập luyện tập

Explain the difference between a species' fundamental niche and its realized niche, and state which is larger and why.

Lời giải chi tiết

The **fundamental niche** is the full range of conditions and resources in which a species could survive and reproduce in the *absence* of competition or other limiting interactions — its theoretical potential. The **realized niche** is the actual, usually smaller, range it occupies in the *presence* of competitors, predators and other constraints. The fundamental niche is larger (or equal), because interactions such as interspecific competition can only restrict a species to *part* of what it could otherwise exploit; they cannot let it live outside its physiological limits. Hence realized niche $\subseteq$ fundamental niche (e.g., *Chthamalus* barnacles pushed to the high shore by *Balanus*).

Bài tập luyện tập

Two species of paramecium are grown together on one food source and one declines to extinction while the other persists. This best illustrates:

(A) mutualism
(B) commensalism
(C) the competitive exclusion principle
(D) secondary succession

Lời giải chi tiết

Two species using the same limiting resource with fully overlapping niches cannot coexist indefinitely; the more efficient competitor excludes the other — Gause's competitive exclusion principle. Coexistence would require resource partitioning (different realized niches). **(C)**

Bài tập luyện tập

A grass sward has a gross primary productivity of $24{,}000$ kJ m^{-2} yr^{-1} and respires $9{,}600$ kJ m^{-2} yr^{-1}. (a) Calculate NPP. (b) Calculate the percentage of GPP stored as new biomass. (c) State what happens to the energy represented by R.

Lời giải chi tiết

(a) $NPP = GPP - R = 24{,}000 - 9{,}600 = 14{,}400$ kJ m^{-2} yr^{-1}.

(b) $\dfrac{NPP}{GPP} \times 100 = \dfrac{14{,}400}{24{,}000} \times 100 = 60\%$.

(c) The R energy ($9{,}600$ kJ m^{-2} yr^{-1}) is used in the producers' own respiration for metabolism, and is ultimately lost from the ecosystem as *heat* (second law of thermodynamics); it is not available to consumers.

Bài tập luyện tập

Caterpillars eat leaf material with an energy content of $3{,}000$ kJ m^{-2} yr^{-1}. They egest $1{,}950$ kJ m^{-2} yr^{-1} in faeces and respire 780 kJ m^{-2} yr^{-1}. (a) Find GSP. (b) Find NSP. (c) What percentage of ingested energy becomes new caterpillar biomass?

Lời giải chi tiết

(a) GSP = eaten − faeces = $3{,}000 - 1{,}950 = 1{,}050$ kJ m^{-2} yr^{-1} (assimilated).
(b) $NSP = GSP - R = 1{,}050 - 780 = 270$ kJ m^{-2} yr^{-1}.
(c) $\frac{NSP}{\text{eaten}} \times 100 = \frac{270}{3{,}000} \times 100 = 9.0\%$ — close to the ∼10% rule, most energy lost to faeces and respiration.

Bài tập luyện tập

Producers fix $NPP = 30{,}000$ kJ m^{-2} yr^{-1}. Assuming 10% transfer at each step, the energy available to secondary consumers is:

(A) $3{,}000$ kJ m^{-2} yr^{-1}
(B) 300 kJ m^{-2} yr^{-1}
(C) 30 kJ m^{-2} yr^{-1}
(D) $3{,}000{,}000$ kJ m^{-2} yr^{-1}

Lời giải chi tiết

Primary consumers: $30{,}000 \times 0.10 = 3{,}000$. Secondary consumers: $3{,}000 \times 0.10 = 300$ kJ m^{-2} yr^{-1} (i.e. $30{,}000 \times (0.10)^2$). **(B)**

Bài tập luyện tập

Explain, with reference to the second law of thermodynamics, why a pyramid of productivity can never be inverted, whereas a pyramid of biomass sometimes can.

Lời giải chi tiết

A pyramid of **productivity** measures the *rate of energy flow* through each trophic level over a period of time. The second law guarantees that at every transfer some energy is degraded to heat, so each level necessarily processes less energy per year than the level below it; a higher level can never receive — let alone pass on — more energy than it is given, so the pyramid must narrow upward and cannot invert. A pyramid of **biomass**, by contrast, is a *snapshot* of standing mass at one instant. In aquatic systems tiny phytoplankton reproduce and are eaten so fast that their standing biomass at any moment can be smaller than the mass of zooplankton they support, giving a (temporarily) inverted biomass pyramid — an artefact of the snapshot, not a violation of energy conservation.

Bài tập luyện tập

A herd introduced to a predator-free island grows exponentially, overshoots, then crashes as its food plants are stripped. Which sequence of terms best describes this?

(A) lag → plateau → climax
(B) exponential growth → overshoot → dieback
(C) primary succession → pioneer → climax
(D) commensalism → mutualism → competition

Lời giải chi tiết

With no predators and abundant food, growth is exponential (J-shaped); the population exceeds carrying capacity (overshoot); food collapse then causes a population crash (dieback) back to or below K. **(B)**

Bài tập luyện tập

Define *limiting factor* and use Liebig's law of the minimum to explain why adding fertiliser rich in phosphorus might fail to increase crop yield.

Lời giải chi tiết

A **limiting factor** is the single resource, in shortest supply relative to demand, that restricts the growth or abundance of a population at a given time. **Liebig's law of the minimum** states that growth is controlled by the scarcest resource, not the total available. If the crop is actually short of *nitrogen* (or water, or light), then adding *phosphorus* — which was not the factor in shortest supply — will not raise yield, because the nitrogen shortage still caps growth. Only relieving the true limiting factor increases yield; a different factor may then become limiting in turn.

Bài tập luyện tập

A hawk population needs 18 kJ m^{-2} yr^{-1} of net productivity. The chain is producer → mouse → snake → hawk, with 10% efficiency per step. What minimum NPP must producers supply?

Lời giải chi tiết

Work backwards, dividing by 0.10 at each step:
Snakes: $18 \div 0.10 = 180$ kJ m^{-2} yr^{-1}.
Mice: $180 \div 0.10 = 1{,}800$ kJ m^{-2} yr^{-1}.
Producers: $1{,}800 \div 0.10 = 18{,}000$ kJ m^{-2} yr^{-1}.
The producers must supply at least $18{,}000$ kJ m^{-2} yr^{-1}, which is $18 \times (1/0.10)^3 = 18 \times 1000$, i.e. $1{,}000$ times the hawks' requirement.

Bài tập luyện tập

An oxpecker bird removes and eats ticks from the skin of a buffalo. The relationship is best classified as:

(A) parasitism $(+/-)$
(B) commensalism $(+/0)$
(C) mutualism $(+/+)$
(D) predation $(+/-)$

Lời giải chi tiết

The bird gains food (the ticks); the buffalo benefits by having parasites removed. Both partners benefit, so it is mutualism $(+/+)$. Predation and parasitism harm one partner; commensalism leaves one unaffected — here the buffalo is helped, not merely unaffected. **(C)**

Bài tập luyện tập

Distinguish between intraspecific and interspecific competition, and explain why intraspecific competition is the more intense of the two and how it relates to carrying capacity.

Lời giải chi tiết

Intraspecific competition is between members of the *same* species; **interspecific** competition is between members of *different* species. Intraspecific competition is more intense because individuals of one species have essentially identical niches — they need exactly the same food, space, mates and other resources — so overlap is complete and rivalry maximal. As a population grows, intraspecific competition intensifies (a density-dependent effect), raising death rates and lowering birth rates until births balance deaths; this is the principal force stabilising the population at its **carrying capacity** K. Interspecific competition, by contrast, acts only where niches overlap and can be relaxed by resource partitioning.

Bài tập luyện tập

Producer NPP is $50{,}000$ kJ m^{-2} yr^{-1}; primary-consumer NSP is $4{,}500$ kJ m^{-2} yr^{-1}. (a) Calculate the ecological efficiency of this transfer. (b) List three reasons why over 90% of producer energy fails to reach the primary consumers.

Lời giải chi tiết

(a) efficiency $= \dfrac{4{,}500}{50{,}000} \times 100 = 9.0\%$.
(b) Any three: (i) not all producer biomass is eaten (roots, dead matter, some plants missed); (ii) not all eaten material is digested/assimilated — much is egested as faeces; (iii) a large fraction of assimilated energy is used in respiration and lost as heat (second law); (iv) some energy is lost in excretion (e.g., urea). Only the residual new biomass (NSP) reaches the next level.

Bài tập luyện tập

A student measures one large oak tree supporting $8{,}000$ aphids, which support 200 ladybirds, and draws a pyramid of numbers. (a) Sketch its shape. (b) Explain why it is inverted at the base. (c) Which type of pyramid would be upright here, and why?

Lời giải chi tiết

(a) The base bar (1 oak) is *narrower* than the primary-consumer bar (8,000 aphids); above that the bar narrows again (200 ladybirds) — so the pyramid bulges at the second level and is inverted at the base.
(b) A pyramid of numbers counts *individuals* regardless of size. A single very large producer (the oak) can feed thousands of tiny herbivores, so counting heads makes the producer level look small.
(c) A pyramid of **productivity (energy)** would be upright, because it measures the rate of energy flow, and the second law forces each higher level to carry less energy than the one below; body-size distortion is removed.

Bài tập luyện tập

Which two abiotic factors are the primary determinants of a terrestrial biome's identity and global distribution?

(A) soil pH and altitude
(B) temperature and precipitation
(C) salinity and dissolved oxygen
(D) day length and wind speed

Lời giải chi tiết

Biomes are defined and distributed chiefly by **temperature** and **precipitation**, which together determine which plant life-forms can survive; these vary with latitude and proximity to oceans and mountains. The other factors matter locally but do not define biomes globally. **(B)**

Bài tập luyện tập

Site data: mean monthly temperatures all between 25 and $28\,^{\circ}$C year-round; total precipitation $2{,}400$ mm yr^{-1} spread through every month; tall, layered evergreen broadleaf forest. Identify the biome and justify with both climate drivers.

Lời giải chi tiết

Temperature: consistently hot (25–$28\,^{\circ}$C) with almost no seasonal variation — typical of equatorial latitudes.
Precipitation: very high ($> 2{,}000$ mm yr^{-1}) and distributed all year, with no marked dry season.
Vegetation: tall, layered evergreen broadleaf canopy is diagnostic.
Together these indicate a **tropical rainforest** — warm, wet, aseasonal conditions supporting high biomass and the highest biodiversity of any terrestrial biome.

Bài tập luyện tập

Distinguish zonation from succession. Give one example of each.

Lời giải chi tiết

Zonation is the arrangement of communities into distinct bands along an abiotic *gradient across space*, at one point in time — e.g., bands of seaweeds and animals down a rocky shore (tidal-exposure gradient), or vegetation belts up a mountainside (temperature/altitude gradient).
Succession is the directional change in community composition *over time* at one place, from pioneers toward a climax community — e.g., lichens → mosses → grasses → shrubs → forest on newly exposed rock. Key contrast: zonation is spatial (many communities, one time); succession is temporal (one place, changing through time).

Bài tập luyện tập

Which best distinguishes primary from secondary succession?

(A) Primary succession is faster because soil is already present

(B) Secondary succession starts on bare rock with no soil

(C) Primary succession starts on lifeless substrate with no soil; secondary succession starts where soil (and often seeds/roots) already remain

(D) They differ only in the climate zone where they occur

Lời giải chi tiết

Primary succession begins on newly exposed, lifeless substrate that has never held a community (e.g., lava rock, new dunes) and must build soil from scratch, so it is slow. **Secondary** succession begins after a disturbance where soil, seeds and roots survive (e.g., after fire or on abandoned farmland), so it skips the soil-building stage and is much faster. **(C)**

Bài tập luyện tập

Describe how (a) species diversity, (b) total biomass, (c) soil depth/organic content, and (d) the GPP : R ratio change as an ecosystem proceeds from early succession to a climax community.

Lời giải chi tiết

(a) **Diversity** generally increases through mid-succession as more niches and habitat structure develop, sometimes dipping slightly at the climax as dominant competitors take over.
(b) **Biomass** increases steadily, reaching a maximum in the climax community with its large, long-lived organisms and complex food webs.
(c) **Soil** deepens and its humus (organic) content, water-holding capacity and nutrient store all increase.
(d) The **GPP : R ratio** falls from well above 1 (early: GPP $\gg R$, high NPP, rapid biomass gain) toward ≈ 1 at the climax (large biomass respires almost as much as it fixes, so $NPP \to 0$ and the system nears steady state).

Bài tập luyện tập

An early-successional community has $GPP = 18{,}000$ and $R = 5{,}000$ kJ m^{-2} yr^{-1}; a climax community has $GPP = 45{,}000$ and $R = 44{,}000$ kJ m^{-2} yr^{-1}. (a) Find NPP and GPP : R for each. (b) Explain which is closer to steady state.

Lời giải chi tiết

(a) Early: $NPP = 18{,}000 - 5{,}000 = 13{,}000$ kJ m^{-2} yr^{-1}; $GPP : R = 18{,}000/5{,}000 = 3.6$.
Climax: $NPP = 45{,}000 - 44{,}000 = 1{,}000$ kJ m^{-2} yr^{-1}; $GPP : R = 45{,}000/44{,}000 = 1.02$.
(b) The **climax** community is closer to steady state: its GPP : R ratio is almost exactly 1, so respiration nearly balances gross production and net biomass accumulation (NPP) is small. The early community, with ratio 3.6 and large NPP, is still rapidly building biomass and is far from equilibrium.

Bài tập luyện tập

Which set of traits characterises an r-selected pioneer species rather than a K-selected climax species?

(A) Large body, long life, few well-cared-for offspring, stable population near K

(B) Small body, rapid maturity, many offspring, little parental care, boom-and-bust population

(C) Slow reproduction, strong competitor, high offspring survival

(D) Late maturity, extensive parental care, populations at carrying capacity

Lời giải chi tiết

r-selected pioneers are small, mature and reproduce rapidly, produce many offspring with little parental care and low offspring survival, are short-lived and have boom-and-bust populations suited to new, disturbed habitats. Options (A), (C) and (D) all describe K-selected climax species. **(B)**

Bài tập luyện tập

A tolerance graph plots an insect's growth rate against water temperature. Explain what the terms *optimum*, *zone of physiological stress*, *limit of tolerance* and *zone of intolerance* mean on this graph, and why a narrow-tolerance species can act as an indicator species.

Lời giải chi tiết

The curve is bell-shaped. The **optimum** is the central temperature range where growth rate is highest and the insect thrives. On either side of the optimum lie **zones of physiological stress**, where the insect survives but grows poorly because conditions are becoming difficult. The edges of survival are the **limits of tolerance** (the maximum and minimum temperatures the insect can withstand). Beyond those limits lie the **zones of intolerance**, where the insect cannot survive. A species with a *narrow* tolerance range is present only within a small band of conditions, so its presence or absence reliably signals those specific conditions — making it a useful **indicator species** (e.g., of clean, cool, well-oxygenated water).

Bài tập luyện tập

A food chain is producer → zooplankton → small fish → large fish. Producer NPP is $60{,}000$ kJ m^{-2} yr^{-1}. Transfer efficiencies are 12%, 10% and 8% respectively. Calculate the productivity available to the large fish, and the overall efficiency from producers to large fish.

Lời giải chi tiết

Zooplankton: $60{,}000 \times 0.12 = 7{,}200$ kJ m^{-2} yr^{-1}.
Small fish: $7{,}200 \times 0.10 = 720$ kJ m^{-2} yr^{-1}.
Large fish: $720 \times 0.08 = 57.6$ kJ m^{-2} yr^{-1}.
Overall efficiency $= \dfrac{57.6}{60{,}000} \times 100 = 0.096\%$ (equivalently $0.12 \times 0.10 \times 0.08 = 0.00096$). Barely one part in a thousand of producer energy reaches the top predator, illustrating why long chains cannot support large top-predator populations.

Bài tập luyện tập

Explain why energy must be constantly resupplied to an ecosystem whereas nutrients such as carbon and nitrogen can be recycled, linking your answer to the laws of thermodynamics.

Lời giải chi tiết

By the **first law**, energy is conserved — it changes form but is not destroyed. By the **second law**, every transformation degrades some energy into low-quality **heat**, which organisms cannot recapture to do biological work. As energy passes along a food chain, more and more of it becomes dispersed heat lost from the ecosystem, so the *useful* energy content falls at every step; energy flow is therefore **one-way** and must be continually replenished from an external source (the Sun). **Matter**, by contrast, is not degraded in the same way: the same carbon and nitrogen atoms are repeatedly built into and released from organic molecules by producers, consumers and decomposers, so nutrients **cycle** indefinitely within the ecosystem while energy flows through it and out.

Bài tập luyện tập

Two warbler species live in the same conifer trees but one feeds mainly in the upper canopy and the other in the lower branches. (a) Name this phenomenon. (b) Explain how it allows the two species to coexist despite similar diets, referring to the competitive exclusion principle and realized niches.

Lời giải chi tiết

(a) This is **resource partitioning** (niche differentiation).
(b) The competitive exclusion principle states that two species cannot coexist indefinitely if their niches overlap completely while competing for the same limiting resource. By feeding at different heights, the two warblers use *different* parts of the resource, so their **realized niches** no longer fully overlap. Competition is reduced enough that neither excludes the other, allowing stable coexistence. Partitioning the resource (here, foraging zone) is the general mechanism by which similar species avoid competitive exclusion.

Biodiversity and Conservation

Mục tiêu Unit: Ba cấp độ đa dạng sinh học (gene, loài, sinh cảnh); cách đo đa dạng loài qua độ phong phú (richness) và độ đồng đều (evenness); chỉ số đa dạng Simpson; phân bố đa dạng sinh học toàn cầu và khái niệm điểm nóng đa dạng sinh học (biodiversity hotspot); nguồn gốc đa dạng sinh học qua chọn lọc tự nhiên và các cơ chế hình thành loài (dị vực – allopatric, đồng vực – sympatric); tốc độ tuyệt chủng nền (background) so với tuyệt chủng hàng loạt (mass extinction); năm mối đe dọa chính đối với đa dạng sinh học và Danh lục Đỏ IUCN; bảo tồn tại chỗ (in-situ) và chuyển chỗ (ex-situ); nguyên tắc thiết kế khu bảo tồn (SLOSS, hành lang sinh thái), phục hồi hoang dã (rewilding); CITES, Công ước Đa dạng Sinh học (CBD) và hai lập luận giá trị kinh tế/nội tại trong bảo tồn.

3.1 An introduction to biodiversity

3.1.1 Three levels of biodiversity

Biodiversity (biological diversity) is the variety of life, considered at three interconnected levels. **Genetic diversity** is the range of genes/alleles present within a species or a single population of that species; it is the raw material for adaptation, since a genetically diverse population is more likely to contain individuals able to survive a new disease, pest, or changing climate. **Species diversity** is the variety of species within a community or region, and itself has two components: **species richness** (the number of different species present) and **species evenness** (how equally the individuals are distributed among those species). **Habitat diversity** (sometimes called ecosystem diversity) is the range of different habitats, communities or ecosystems found within a given area, landscape, or across the whole biosphere.

The three levels of biodiversity operate at different scales but are linked: a landscape with high **habitat diversity** (forest, wetland, grassland, river) tends to support higher **species diversity**, because different habitats provide different niches; and a species surviving across many separate populations, or possessing large population sizes, tends to retain higher **genetic diversity** than one reduced to a single small, isolated population.

GIẢI THÍCH TIẾNG VIỆT

VN Đa dạng sinh học được xét ở ba cấp độ: **đa dạng di truyền** (gene) — sự đa dạng của các alen/-gene trong một loài hoặc một quần thể, là "nguyên liệu thô" cho khả năng thích nghi; **đa dạng loài** — gồm **độ phong phú** (richness, tức số lượng loài) và **độ đồng đều** (evenness, tức mức độ phân bố số lượng cá thể giữa các loài có cân bằng hay không); và **đa dạng sinh cảnh/hệ sinh thái** — sự đa dạng của các môi trường sống (rừng, đầm lầy, đồng cỏ...) trong một khu vực. Ba cấp độ này liên kết chặt chẽ: nhiều sinh cảnh khác nhau thường kéo theo nhiều loài khác nhau, và loài tồn tại ở nhiều quần thể lớn thường giữ được đa dạng di truyền cao hơn loài chỉ còn một quần thể nhỏ, cô lập.

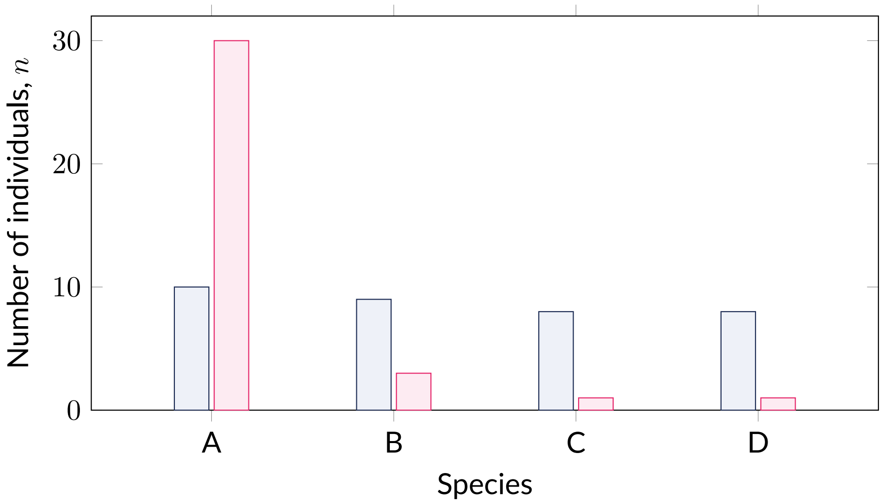
3.1.2 Quantitative skill: Simpson's Diversity Index

Species richness alone is a poor measure of diversity, because it ignores how abundance is distributed among species. Two communities can contain exactly the same number of species yet feel very different in practice if one is dominated by a single overwhelmingly common species while the other has individuals spread roughly evenly across all its species. **Simpson's Diversity Index** solves this by combining richness and evenness into a single number.

Simpson's Diversity Index

$$D = 1 - \sum\left(\frac{n}{N}\right)^2$$

where n is the number of individuals of a particular species and N is the total number of individuals of all species in the sample. D ranges from 0 (theoretically, a single species entirely dominates — minimum diversity) toward a maximum approaching 1 (many species, each present in similar numbers — maximum diversity). The calculation proceeds species-by-species: for each species, compute n/N, square it, sum these squared proportions across all species (this sum is sometimes written λ, the probability that two individuals picked at random from the sample belong to the same species), and subtract the total from 1.



Species abundance in two hypothetical communities, each with $N = 35$ individuals across four species (A–D). Community 1 (blue) is relatively even; Community 2 (pink) is dominated almost entirely by species A.

Simpson's Index — Community 1, the even community

Community 1 contains four species with $n = 10,\ 9,\ 8,\ 8$ individuals ($N = 35$). Calculate D.

$$\sum\left(\frac{n}{N}\right)^2 = \left(\frac{10}{35}\right)^2 + \left(\frac{9}{35}\right)^2 + \left(\frac{8}{35}\right)^2 + \left(\frac{8}{35}\right)^2$$
$$= 0.08163 + 0.06612 + 0.05224 + 0.05224 = 0.2522$$
$$D = 1 - 0.2522 = 0.75 \text{ (to 2 s.f.)}$$

A value this close to the maximum indicates a fairly diverse community: four species are present (moderate richness) and individuals are distributed fairly evenly among them (high evenness).

Simpson's Index — Community 2, the dominated community

Community 2 contains the *same* four species and the *same* total $N = 35$, but with $n = 30, 3, 1, 1$. Calculate D and compare with Community 1.

$$\sum\left(\frac{n}{N}\right)^2 = \left(\frac{30}{35}\right)^2 + \left(\frac{3}{35}\right)^2 + \left(\frac{1}{35}\right)^2 + \left(\frac{1}{35}\right)^2$$
$$= 0.7347 + 0.00735 + 0.00082 + 0.00082 = 0.7437$$
$$D = 1 - 0.7437 = 0.26 \text{ (to 2 s.f.)}$$

Even though Community 2 has exactly the same species richness as Community 1 (four species, $N = 35$), its Simpson's Index is far lower (0.26 vs. 0.75) because one species (30 of the 35 individuals) dominates almost completely — evenness, not richness, is what collapsed here.

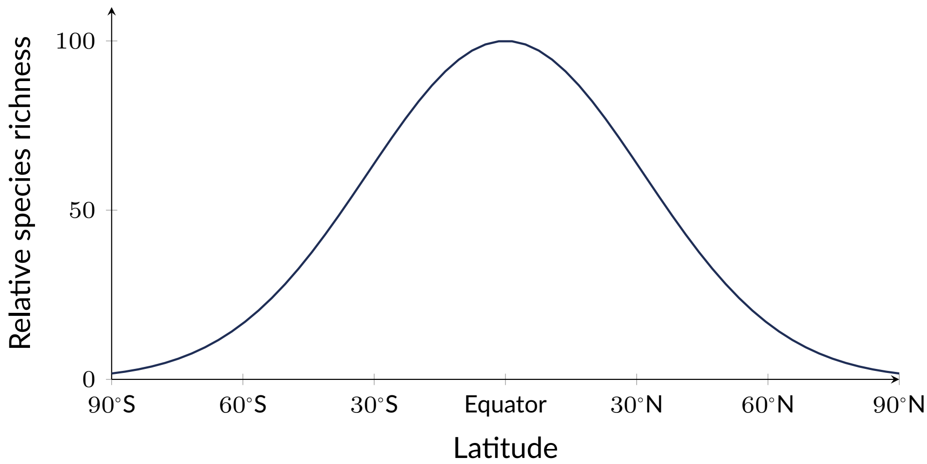
VN **GIẢI THÍCH TIẾNG VIỆT**

Cần phân biệt rõ **độ phong phú** (richness — chỉ đơn giản đếm số loài) và **độ đa dạng** (diversity — kết hợp cả richness lẫn evenness). Hai cộng đồng ở trên có *cùng* số loài (4 loài) và cùng tổng số cá thể ($N = 35$), nhưng Cộng đồng 1 có $D \approx 0{,}75$ (khá đa dạng, cá thể phân bố khá đều giữa 4 loài) trong khi Cộng đồng 2 chỉ có $D \approx 0{,}26$ (kém đa dạng, vì một loài chiếm tới 30/35 cá thể). Đây chính là lý do chỉ số Simpson được ưa dùng hơn chỉ đếm số loài đơn thuần: nó phản ánh đúng "cảm giác" đa dạng thực tế khi ta bắt gặp các sinh vật một cách ngẫu nhiên trong tự nhiên.

(!) Lỗi thường gặp: A community can have very high species richness (many different species present) yet still show low overall diversity if that richness is not matched by evenness — for example, a habitat with 20 species where one species makes up 95% of all individuals is not very diverse in practice, because a random encounter with an organism there will almost always be the same dominant species. Do not treat "species richness" and "Simpson's Diversity Index" as interchangeable terms: richness simply counts species present; Simpson's Index (or any diversity index) combines richness with evenness.

3.1.3 Global patterns of biodiversity

Biodiversity is not spread evenly across the planet. As a broad global pattern, species richness tends to be highest near the equator and to decline, on average, toward the poles — the **latitudinal diversity gradient**. This pattern holds across an enormous range of unrelated groups (flowering plants, ants, birds, marine fish, corals), which suggests a shared set of underlying causes rather than a coincidence affecting only one type of organism.



Schematic representation (not empirical data) of the general latitudinal gradient in species richness: richness tends to peak near the equator and decline toward the poles, across most groups of organisms.

Several factors together help explain the latitudinal gradient. (1) **Solar energy and growing season**: equatorial regions receive intense, year-round solar radiation and have no cold season, supporting high, continuous net primary productivity that can sustain more consumers and more specialized niches. (2) **Habitat complexity**: tropical ecosystems such as rainforests have complex vertical structure (canopy, sub-canopy, understorey) and coral reefs have complex three-dimensional structure, creating many more distinct physical niches than structurally simpler tundra or open ocean. (3) **Climate stability and evolutionary time**: tropical climates have been comparatively stable over geological time (largely undisturbed by repeated glaciations that repeatedly wiped out temperate/polar populations), giving lineages a longer, less interrupted period in which to accumulate genetic divergence and speciate.

VN GIẢI THÍCH TIẾNG VIỆT

Đa dạng sinh học không phân bố đều trên Trái Đất: nhìn chung, độ phong phú loài cao nhất gần xích đạo và giảm dần về hai cực — gọi là **gradient đa dạng theo vĩ độ**. Ba nguyên nhân chính: (1) vùng xích đạo nhận năng lượng mặt trời dồi dào quanh năm, mùa sinh trưởng dài, năng suất sinh học cao; (2) sinh cảnh nhiệt đới (rừng mưa, rạn san hô) có cấu trúc phức tạp hơn, tạo nhiều ổ sinh thái (niche) hơn; (3) khí hậu nhiệt đới ổn định hơn qua các thời kỳ địa chất (ít bị gián đoạn bởi các đợt băng hà), cho các dòng loài nhiều thời gian hơn để tích lũy khác biệt di truyền và hình thành loài mới.

3.1.4 Biodiversity hotspots

Because conservation resources are limited, ecologists prioritize regions where protection will do the most good. A **biodiversity hotspot** is a region that is exceptionally rich in species found nowhere else (endemic species) *and* that has already lost a large proportion of its original habitat — making it both irreplaceable and urgently threatened.

The commonly used criteria for a region to qualify as a biodiversity hotspot are: (1) it must contain **at least 1,500 endemic vascular plant species** (species found nowhere else on Earth), *and* (2) it must have already **lost at least 70% of its original native habitat**. Both conditions must be met: a region can be extremely species-rich yet not qualify as a hotspot if its habitat remains largely intact, because hotspot status specifically flags places where conservation action is both valuable (high endemism) and urgent (habitat already mostly gone).

Hotspot	Region	Notable feature
Cape Floristic Region	South Africa	A small area of fynbos shrubland holding an extraordinary concentration of endemic plant species relative to its size
Madagascar and the Indian Ocean Islands	East Africa (island)	Long geographic isolation has produced exceptionally high endemism (most lemur species occur nowhere else); extensive deforestation for agriculture
Tropical Andes	South America	The single richest recognized hotspot in total species; steep elevational gradients create many distinct climate zones over short distances, driving speciation

Three named biodiversity hotspots.

Applying the hotspot criteria

A region contains an estimated $2{,}200$ endemic vascular plant species and has lost approximately 75% of its original native vegetation to agriculture and urban development over the last two centuries. Determine whether this region satisfies the standard criteria for classification as a biodiversity hotspot.

Criterion 1 (endemism): the standard threshold is at least $1{,}500$ endemic vascular plant species; this region has $2{,}200$, so the criterion is met.
Criterion 2 (habitat loss): the standard threshold is at least 70% habitat loss; this region has lost approximately 75%, so the criterion is met.
Because *both* conditions are satisfied, this region would qualify as a biodiversity hotspot: an exceptionally irreplaceable pool of endemic plant diversity combined with habitat already reduced to a small, threatened remnant.

3.2 Origins of biodiversity

3.2.1 Evolution by natural selection

Biodiversity is not a fixed inheritance; it is continually generated (and lost) over time through evolutionary processes. **Evolution by natural selection** is the process by which heritable characteristics that improve an organism's chances of survival and reproduction become more common in a population over successive generations, producing gradual "descent with modification".

The mechanism of natural selection

Four ingredients are required. (1) **Variation**: individuals within a population differ in their heritable traits, ultimately because of random **mutation** (changes to DNA sequence) and **recombination** (new allele combinations produced during sexual reproduction) — this variation exists *before*, and independently of, any particular environmental pressure. (2) **Heritability**: at least some of this variation can be passed from parent to offspring. (3) **Differential survival and reproduction**: in a given environment, individuals whose traits happen to be advantageous survive and/or reproduce more successfully than others ("the environment selects"). (4) **Change in allele frequency**: because the advantageous alleles are passed on more often, their frequency in the population rises generation after generation, gradually shifting the population's characteristics — this cumulative change is evolution.

GIẢI THÍCH TIẾNG VIỆT

VN Chọn lọc tự nhiên cần 4 yếu tố: (1) **biến dị** — các cá thể trong quần thể vốn đã khác nhau về mặt di truyền do đột biến và tái tổ hợp ngẫu nhiên (biến dị có sẵn *trước khi* áp lực môi trường xuất hiện, không phải "sinh ra theo nhu cầu"); (2) **tính di truyền** — biến dị đó có thể truyền từ bố mẹ sang con; (3) **sự sống sót/sinh sản khác biệt** — cá thể mang đặc điểm có lợi trong môi trường cụ thể sẽ sống sót và sinh sản tốt hơn; (4) **thay đổi tần số alen** — qua nhiều thế hệ, alen có lợi trở nên phổ biến hơn, làm quần thể dần thay đổi đặc điểm — đó chính là quá trình tiến hóa.

(!) Lỗi thường gặp: Never describe natural selection as organisms "trying" to adapt, "needing" a trait, or evolving "for the good of the species". Natural selection has no foresight, intention or goal: heritable variation already exists in a population (from random mutation and recombination) before any environmental change occurs; selection simply acts on that pre-existing variation, so that individuals whose traits happen to confer a survival or reproductive advantage leave more descendants. Traits do not appear because they are needed — they are selected *if* they already happen to exist.

3.2.2 Speciation: allopatric and sympatric

Over many generations, natural selection acting on genetically diverging populations can produce entirely new species. **Speciation** is the formation of one or more new species from an existing species, such that the resulting populations become **reproductively isolated** — no longer able to interbreed and produce fertile offspring, even if brought back into contact.

Two modes of speciation

Allopatric speciation occurs when a physical/geographic barrier (a mountain range, a river, an ocean separating an island from the mainland) splits a population into two or more groups and prevents gene flow between them. Isolated from one another, the groups accumulate independent genetic changes (through mutation, drift and natural selection responding to potentially different local conditions) until they can no longer interbreed, even if the barrier later disappears. **Sympatric speciation** produces a new, reproductively isolated species *without* any geographic separation — the diverging populations continue to share the same location. This can occur through **polyploidy** (a sudden doubling, or other multiplication, of chromosome number, common in plants, which instantly makes the polyploid individual unable to produce fertile offspring with the original diploid population) or through strong **disruptive selection**/niche differentiation (e.g. a population splitting into two forms that specialize on different food resources or habitats within the same area, with assortative mating gradually producing reproductive isolation).

Allopatric vs sympatric speciation

Case 1: a population of finches on a mainland has a small group colonize a distant, isolated island where climate and food resources differ substantially from the mainland. With no gene flow between the island and mainland groups for many generations, the two diverge in beak shape and eventually cannot interbreed even if reunited. Case 2: within a single lake, a population of fish diverges into two forms — one specializing on shallow-water insects, the other on deep-water zooplankton — and individuals increasingly mate only within their own foraging group, eventually becoming reproductively isolated despite sharing the same lake throughout. Identify the mode of speciation in each case and justify your answer.

Case 1 (island finches): **allopatric speciation** — the ocean is a geographic barrier that physically

prevents gene flow between the mainland and island populations, allowing them to diverge independently.
Case 2 (lake fish): **sympatric speciation** — there is no geographic barrier at all; the two forms diverge *within the same lake* through disruptive selection on resource use and increasingly assortative mating, eventually becoming reproductively isolated despite continuous physical proximity.

GIẢI THÍCH TIẾNG VIỆT

VN

Hình thành loài dị vực (allopatric speciation) xảy ra khi một rào cản địa lý (dãy núi, sông, đại dương) chia quần thể thành các nhóm tách biệt, ngăn dòng gene — các nhóm sau đó tiến hóa độc lập cho đến khi không còn giao phối được với nhau. **Hình thành loài đồng vực** (sympatric speciation) xảy ra *không cần* tách biệt địa lý — ví dụ qua đa bội hóa (polyploidy, phổ biến ở thực vật) hoặc chọn lọc phân hóa mạnh khiến các nhóm trong cùng khu vực dần trở nên cách ly sinh sản. Đề thi IB thường cho một tình huống cụ thể và yêu cầu xác định đúng cơ chế nào (có rào cản địa lý hay không) rồi giải thích.

3.2.3 Background extinction and mass extinction

Extinction — the permanent disappearance of a species — is a normal part of the history of life, but its *rate* has not been constant.

The **background extinction rate** is the relatively slow, roughly constant rate of species loss observed over most of geological time, driven by ordinary environmental change (local habitat shifts, competition, disease) acting gradually on individual species. A **mass extinction** is a sudden (in geological terms), globally synchronized loss of a very large proportion of all species within a comparatively short interval — typically thousands to a few million years, essentially an instant compared with Earth's 4.6-billion-year history. Five major mass extinctions are recognized in the fossil record; the best known is the **End-Cretaceous extinction** (approximately 66 million years ago), which eliminated the non-avian dinosaurs along with a large fraction of all species then living, and is widely attributed to a massive asteroid impact (supported by evidence such as an iridium-enriched sediment layer, a rare element more common in asteroids than in Earth's crust, found worldwide at the boundary rock layer).

Comparing background and elevated extinction rates

Suppose palaeontological studies estimate a typical background extinction rate, for a particular group of organisms, of 0.1 extinctions per million species per year. Separately, researchers estimate the *current* extinction rate for the same group at 100 extinctions per million species per year. Calculate how many times higher the current estimate is than the background rate, and comment on how such comparisons should be interpreted.

$$\frac{\text{current rate}}{\text{background rate}} = \frac{100}{0.1} = 1{,}000\times$$

This suggests current extinction rates, for this group, might be roughly three orders of magnitude above the long-term background rate. Some scientists use this kind of comparison to argue that a human-driven "sixth mass extinction" may already be underway; however, estimating both the background rate (from an incomplete fossil record) and the current rate (from incomplete species inventories and monitoring) involves substantial uncertainty, so such figures should be treated as an active area of scientific research and debate rather than a precisely settled number.

VN GIẢI THÍCH TIẾNG VIỆT

Tốc độ tuyệt chủng nền (background extinction rate) là tốc độ tuyệt chủng chậm, tương đối ổn định trong phần lớn lịch sử địa chất, do các biến đổi môi trường thông thường gây ra. **Tuyệt chủng hàng loạt** (mass extinction) là sự mất mát đột ngột (theo thang thời gian địa chất) của một tỷ lệ rất lớn loài trong khoảng thời gian ngắn — ví dụ sự kiện tuyệt chủng cuối kỷ Creta (66 triệu năm trước) xóa sổ khủng long (trừ nhóm chim) do va chạm thiên thạch. Một số nhà khoa học lập luận rằng tốc độ tuyệt chủng hiện nay do con người gây ra có thể cao hơn tốc độ nền hàng trăm đến hàng nghìn lần, đôi khi gọi là "cuộc đại tuyệt chủng thứ sáu" — nhưng đây vẫn là một giả thuyết khoa học đang được tranh luận và nghiên cứu, chứ không phải một kết luận đã chốt tuyệt đối.

(!) Lỗi thường gặp: Do not assume mass extinctions are always caused by a single dramatic external event like an asteroid impact. While the End-Cretaceous extinction is the most famous example of an impact-driven event, the five recognized mass extinctions in Earth's history have been linked to a range of causes debated and researched by scientists, including massive volcanic activity, rapid climate change, and ocean chemistry changes acting over time — not only sudden extraterrestrial impacts.

3.3 Threats to biodiversity

Five major categories of human activity are responsible for most current biodiversity loss: habitat loss and fragmentation, invasive species, pollution, overexploitation, and climate change.

3.3.1 Habitat loss and fragmentation

Habitat loss is the direct destruction or conversion of natural habitat (forest clearance for agriculture, wetland drainage, urban expansion), removing the physical space and resources species depend on. **Habitat fragmentation** occurs when a large, continuous habitat is broken into smaller, isolated patches — for example by roads, farmland, or urban development cutting through a forest.

Fragmentation harms biodiversity beyond the raw area lost, through two additional mechanisms. (1) **Edge effects**: the boundary of a fragment has a different microclimate (more light, wind, and temperature fluctuation, and drier conditions) than the interior, and is more exposed to predators, invasive species, and human disturbance; species that require deep, stable "core" habitat conditions lose disproportionately more usable habitat than the total area lost would suggest, because smaller fragments have relatively more edge and less interior. (2) **Population isolation**: fragments separated from one another block movement, migration, and gene flow between populations, increasing the risk of **inbreeding depression** (reduced fitness from mating among genetically similar individuals) and making each isolated population more vulnerable to local extinction from random events (disease outbreaks, poor breeding seasons) since it can no longer be "rescued" by immigration from a neighboring population.

Fragmentation and edge-to-area ratio

A continuous forest patch is a square measuring 4 km $\times$ 4 km (area $=$ 16 km^2, perimeter $=$ 16 km). Roads and clearings later fragment it into four smaller, separated square patches of equal size, together covering the same total area of 16 km^2. Calculate the side length and perimeter of each new patch, the combined perimeter of all four patches, and compare the edge-to-area ratio before and after fragmentation.

Area per small patch $= 16 \div 4 = 4$ km^2, so side length $= \sqrt{4} = 2$ km. Perimeter per small patch $= 4 \times 2 = 8$ km. Combined perimeter of all four patches $= 4 \times 8 = 32$ km.

Edge-to-area ratio *before* fragmentation: 16 km $\div$ 16 km^2 $= 1.0$ km per km^2.
Edge-to-area ratio *after* fragmentation: 32 km $\div$ 16 km^2 $= 2.0$ km per km^2.
Fragmentation doubled the total edge relative to the same total area, even though no additional habitat was destroyed — meaning interior-dependent species now experience substantially less usable core habitat than the raw area figures alone suggest.

3.3.2 Invasive (alien) species

An **invasive (alien) species** is one introduced, deliberately or accidentally, outside its natural range, that establishes and spreads in a way that causes ecological or economic harm. Invasive species often succeed because the new environment lacks the natural predators, competitors, parasites, or diseases that kept their population in check in their native range, allowing rapid, largely unchecked population growth.

The **Nile perch**, deliberately introduced to Lake Victoria (East Africa) in the 1950s to boost commercial fishing, is a widely documented example: as a large predatory fish with no evolutionary history in the lake, it faced little to check its population growth, and its predation on the lake's native cichlid fish contributed to the decline or extinction of a large number of endemic cichlid species — one of the most significant modern losses of vertebrate species diversity attributed to a single introduced predator.

VN **GIẢI THÍCH TIẾNG VIỆT**

Loài xâm lấn (invasive species) thường thành công vì môi trường mới thiếu vắng thiên địch, đối thủ cạnh tranh, hoặc mầm bệnh vốn kiểm soát số lượng của chúng ở nơi bản địa. Ví dụ kinh điển: cá vược sông Nile (Nile perch) được đưa vào hồ Victoria (Đông Phi) những năm 1950 để phát triển nghề cá thương mại — do không có thiên địch tự nhiên, quần thể cá này bùng nổ và săn bắt mạnh các loài cá cichlid bản địa, góp phần khiến rất nhiều loài cichlid đặc hữu suy giảm hoặc tuyệt chủng.

3.3.3 Pollution

Pollution threatens biodiversity through several distinct pathways: persistent chemical pollutants (pesticides, industrial compounds), nutrient pollution causing eutrophication (Unit 4), plastic debris, and oil spills. A particularly important mechanism is **biomagnification**: certain pollutants (typically fat-soluble and slow to break down) become progressively more concentrated at each successive trophic level, because predators consume many contaminated prey and accumulate the pollutant faster than they excrete it (**bioaccumulation** within an individual organism, compounding across trophic levels as **biomagnification**).

Biomagnification — illustrative concentrations

The persistent pesticide DDT, historically implicated in eggshell thinning in birds of prey, illustrates biomagnification. Suppose (illustrative figures) phytoplankton contain 0.002 ppm of a persistent pollutant, zooplankton feeding on the phytoplankton contain 0.05 ppm, small fish feeding on the zooplankton contain 1.25 ppm, and a top predator (e.g. an osprey) feeding on the small fish contains 31.25 ppm. Calculate the multiplication factor at each trophic transfer and the overall biomagnification factor from phytoplankton to top predator.
Phytoplankton → zooplankton: $0.05 \div 0.002 = 25\times$. Zooplankton → small fish: $1.25 \div 0.05 = 25\times$. Small fish → top predator: $31.25 \div 1.25 = 25\times$.
Overall factor $= 31.25 \div 0.002 = 15{,}625\times$ (equivalently 25^3, since the concentration multiplies

by 25 across each of the three trophic transfers).
Even though the pollutant's concentration in the water/producers is extremely low, a predator at the top of the food chain can accumulate a dose thousands of times higher — explaining why apex predators (birds of prey, in the historical DDT case) suffered disproportionate harm (thin, easily broken eggshells and reduced reproductive success) even where environmental concentrations seemed negligible.

3.3.4 Overexploitation

Overexploitation is the harvesting of a wild population (through hunting, fishing, logging, or collection) at a rate faster than it can naturally replace itself, driving the population toward collapse. This includes commercial overfishing, historical commercial whaling that drove several great whale species to very low population levels, and illegal wildlife trade/poaching (e.g. for ivory, rhino horn, and other high-value wildlife products).

> The collapse of the **Northern Cod** fishery off the Grand Banks of Newfoundland is a widely cited case study: decades of intense industrial fishing removed cod faster than the population could reproduce, eventually collapsing the stock to a small fraction of its historical size and forcing the Canadian government to impose a fishing moratorium in 1992. Despite decades of protection since, the stock has still not fully recovered to its former abundance — illustrating that overexploitation can push even a historically enormous population past a point where recovery becomes slow and uncertain, and that fisheries management is far more effective when it prevents collapse than when it attempts to reverse one.

Quantifying overexploitation

A fish stock is estimated at $800{,}000$ tonnes of biomass in 1970. By 1995, after several decades of intensive fishing, the estimated biomass has fallen to $40{,}000$ tonnes. Calculate the percentage decline in biomass over this period.

$$\text{Percentage decline} = \frac{800{,}000 - 40{,}000}{800{,}000} \times 100\% = \frac{760{,}000}{800{,}000} \times 100\% = 95\%$$

A decline of this magnitude — losing 95% of the stock's biomass — illustrates why overexploited fisheries frequently require multi-decade recovery periods (if they recover at all), since a severely depleted breeding population produces far fewer offspring even once harvesting stops.

3.3.5 Climate change

Climate change (Unit 6) threatens biodiversity through several distinct mechanisms operating on different timescales.

(1) **Range shifts**: species track their preferred climate conditions by shifting their geographic range poleward or upslope; species already confined to mountaintops or polar regions may have nowhere further to shift, risking local or total extinction. (2) **Phenological mismatch**: the timing of life-cycle events (breeding, migration, flowering, emergence) can become decoupled from the timing of a food source or pollinator that responds differently to warming — for example, if a bird species times its breeding to coincide with peak caterpillar abundance, but rising spring temperatures shift the caterpillar peak earlier while the birds' migration timing (cued by day length rather than temperature) shifts less, chicks may hatch after the food peak has already passed. (3) **Coral bleaching**: corals rely on symbiotic algae (zooxanthellae) living in their tissue for most of their energy; sustained elevated sea temperatures cause corals to expel these algae, losing both their main energy source and their color (bleaching), and if warming persists the coral often dies — collapsing the structurally complex habitat that supports much of a reef's biodiversity.

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Biến đổi khí hậu đe dọa đa dạng sinh học qua ba cơ chế chính: (1) **dịch chuyển vùng phân bố** — loài di chuyển về phía cực hoặc lên cao hơn để theo kịp điều kiện khí hậu ưa thích, nhưng loài đã ở đỉnh núi hay vùng cực có thể không còn nơi nào để đi tiếp; (2) **lệch pha vật hậu học** (phenological mismatch) — thời điểm các sự kiện vòng đời (sinh sản, di cư, ra hoa) không còn khớp với thời điểm nguồn thức ăn hoặc thụ phấn sẵn có; (3) **tẩy trắng san hô** — nhiệt độ nước biển tăng cao khiến san hô trục xuất tảo cộng sinh (zooxanthellae), mất nguồn năng lượng chính và có thể chết nếu nhiệt độ cao kéo dài, kéo theo sụp đổ toàn bộ hệ sinh thái rạn san hô.

3.3.6 The IUCN Red List

The **International Union for Conservation of Nature (IUCN) Red List** is the most widely used global system for classifying a species' extinction risk, assessed against detailed criteria (population size and trend, geographic range and fragmentation, quantitative extinction-risk analysis) rather than any single factor alone.

Category	Code	Meaning	Example
Least Concern	LC	Widespread and abundant; not currently at significant risk	Mallard duck
Near Threatened	NT	Close to qualifying for a threatened category in the near future	Emperor penguin
Vulnerable	VU	Facing a high risk of extinction in the wild in the medium-term future	Giant panda
Endangered	EN	Facing a very high risk of extinction in the wild in the near future	Tiger
Critically Endangered	CR	Facing an extremely high risk of extinction in the wild, immediately	Javan rhinoceros
Extinct in the Wild	EW	Survives only in captivity/cultivation; no individuals remain in the original wild habitat	Père David's deer
Extinct	EX	No reasonable doubt that the last individual has died	Dodo

IUCN Red List categories, arranged in strict order of increasing extinction risk (LC $<$ NT $<$ VU $<$ EN $<$ CR $<$ EW $<$ EX).

For teaching purposes, this chapter uses simplified population-decline guidelines broadly consistent with the IUCN's population-reduction criterion: a decline of roughly $30–50\%$ points toward **Vulnerable**, roughly $50–80\%$ toward **Endangered**, and more than 80% toward **Critically Endangered**, measured over ten years or three generations (whichever is longer). Real IUCN assessments combine this population-decline criterion with several others (small and declining range, small and fragmented population size, quantitative extinction-risk modelling), and a species can qualify as threatened by meeting *any one* of several possible criteria — not population decline alone.

Classifying extinction risk from a decline scenario

A large mammal population has declined by an estimated 55% over the last three generations, mainly because of habitat loss whose underlying causes (continued agricultural expansion) have not been reversed; the remaining individuals are fragmented across several separate reserves. Using the simplified guidelines above, classify this population's most likely IUCN category and justify your answer.

A decline of 55% falls within the "roughly $50–80\%$" band, pointing to **Endangered (EN)** rather than Critically Endangered (which would require a decline beyond roughly 80%) or Vulnerable (which describes a smaller decline, roughly $30–50\%$). The facts that the decline's cause has not been reversed and that the population is now fragmented across separate reserves both reinforce the classification, since they indicate continuing risk and reduced capacity for the population to recover on its own.

(!) Lỗi thường gặp: The IUCN Red List categories are not ranked alphabetically, nor by how well-known a species is — they form a strict ordered scale of increasing extinction risk (LC $<$ NT $<$ VU $<$ EN $<$ CR $<$ EW $<$ EX). A common error is assuming "Vulnerable" is more severe than "Endangered", or forgetting that "Extinct in the Wild" (individuals survive only in captivity, none remain in the original wild habitat) is a distinct category, more severe than "Critically Endangered" (individuals still survive in the wild, however precariously).

3.4 Conservation of biodiversity

3.4.1 In-situ conservation

In-situ conservation protects species within their natural habitat and range — national parks, marine protected areas (MPAs), nature reserves, and community-managed conservancies, often linked by wildlife corridors.

In-situ conservation is generally the preferred approach where it remains feasible, because it protects the *whole community*, not just a single target species: natural behaviours (foraging, migration, courtship), species interactions (predation, competition, pollination, seed dispersal, mutualism), and ongoing natural selection/evolutionary processes are all preserved in a way that is impossible to fully replicate outside the wild.

3.4.2 Ex-situ conservation

Ex-situ conservation protects species (or their genetic material) outside their natural habitat — zoos, aquaria, botanic gardens, seed banks, and captive breeding/gene-banking programmes.

Ex-situ conservation functions as an "insurance policy", most valuable once a species' wild population or habitat has been reduced so severely that in-situ protection alone can no longer prevent extinction (for example, a species reduced to only a handful of individuals by poaching, disease, or total habitat loss). However, ex-situ conservation does *not*, by itself, address the original cause of decline in the wild; captive populations can also lose genetic diversity over generations and often struggle with the difficulty and cost of eventual reintroduction to the wild.

	In-situ conservation	**Ex-situ conservation**
Definition	Conserving species within their natural habitat/range	Conserving species (or genetic material) outside their natural habitat
Examples	National parks, marine protected areas, wildlife corridors, community conservancies	Zoos, aquaria, botanic gardens, seed banks, captive breeding/gene banks
Key advantage	Preserves natural behaviour, species interactions and ongoing natural selection; protects whole communities	Can rescue a species from imminent extinction once the wild population/habitat is critically reduced
Key limitation	Requires large protected areas and sustained long-term funding/political commitment	Does not address the original cause of decline; captive populations may lose genetic diversity, and reintroduction is often difficult

Comparing in-situ and ex-situ conservation.

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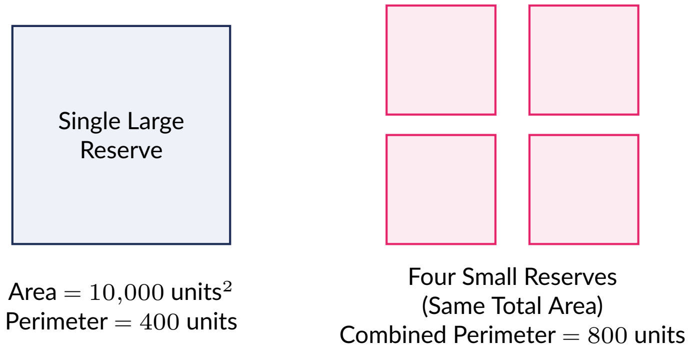
Bảo tồn tại chỗ (in-situ) — bảo vệ loài ngay trong môi trường sống tự nhiên (vườn quốc gia, khu bảo tồn biển, hành lang sinh thái) — thường được ưu tiên vì giữ được toàn bộ hành vi tự nhiên, mối quan hệ giữa các loài, và quá trình tiến hóa đang diễn ra. **Bảo tồn chuyển chỗ** (ex-situ) — bảo vệ loài (hoặc vật liệu di truyền) bên ngoài môi trường sống tự nhiên (sở thú, ngân hàng hạt giống, chương trình nhân giống nuôi nhốt) — đóng vai trò như một "chính sách bảo hiểm", đặc biệt cần thiết khi quần thể hoang dã đã suy giảm quá nghiêm trọng. Tuy nhiên, ex-situ *không* tự nó giải quyết nguyên nhân gốc rễ khiến loài suy giảm ngoài tự nhiên.

(!) Lỗi thường gặp: Ex-situ conservation (a captive breeding programme, a seed bank) is not, by itself, equivalent to "saving" a species. It typically preserves individuals or genetic material without addressing the original cause of decline in the wild (habitat loss, poaching, pollution); unless that underlying cause is also tackled and suitable habitat exists for eventual reintroduction, a captive population can persist indefinitely without ever restoring a viable wild population.

3.4.3 Protected area design: the SLOSS debate and corridors

A long-standing question in conservation planning is how best to arrange a fixed total area of protected land: the **SLOSS debate** (Single Large Or Several Small reserves).

> A **single large reserve** generally supports larger, more genetically and demographically viable populations (particularly important for wide-ranging or low-density species), and has proportionally more interior "core" habitat relative to edge (lower edge-to-area ratio), reducing exposure to edge effects. **Several small reserves**, on the other hand, can collectively protect a greater variety of habitat types across a wider geographic spread (spreading the risk that any single localized disturbance — fire, disease, a single storm — destroys the entire protected population), and may be all that is practically available where large intact tracts no longer exist. Where several small reserves are used, **wildlife corridors** — strips of habitat connecting fragmented patches — can partially offset the disadvantages of fragmentation by allowing gene flow, seasonal migration, and recolonization between patches.



The SLOSS comparison (schematic, not to scale): for the same total protected area, several small reserves have roughly double the combined edge (perimeter) of a single large reserve, and correspondingly less interior/core habitat relative to edge.

SLOSS — area and perimeter reasoning

A single large square reserve measures 100×100 units (area $= 10{,}000$ units^2; perimeter $= 4 \times 100 = 400$ units). An alternative design instead uses four separate small square reserves, each covering one quarter of the total area, so their combined area is also $10{,}000$ units^2. Calculate the side length and perimeter of each small reserve, the combined perimeter of all four, and state one ecological implication of the difference.

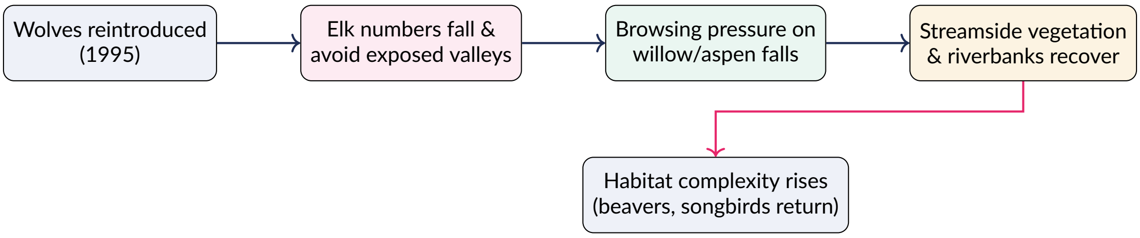
Area per small reserve $= 10{,}000 \div 4 = 2{,}500$ units^2, so side length $= \sqrt{2{,}500} = 50$ units. Perimeter per small reserve $= 4 \times 50 = 200$ units. Combined perimeter of all four $= 4 \times 200 = 800$ units.

For identical total protected area, the four small reserves have **double** the combined edge of the single large reserve (800 vs. 400 units). This means the several-small-reserves design has proportionally much less interior/core habitat relative to its edge, exposing a greater fraction of the protected area to edge effects (microclimate disturbance, predation, invasive species) and offering less refuge for species that require deep, undisturbed interior habitat.

3.4.4 Rewilding

Rewilding is the reintroduction of a species (often a keystone species or apex predator) or the restoration of natural ecological processes to a degraded ecosystem, with the aim of allowing the ecosystem to regulate itself with less ongoing human management.

A **keystone species** is one whose effect on the structure of its community or ecosystem is disproportionately large relative to its own abundance — its removal (or reintroduction) can trigger a cascade of changes throughout the food web, known as a **trophic cascade**. The reintroduction of **wolves to Yellowstone National Park** (1995), after their extirpation in the 1920s, is one of the most widely cited rewilding case studies: reduced elk numbers and changed elk grazing behaviour are linked, in this narrative, to the recovery of streamside willow and aspen vegetation, improved riverbank stability, and increased habitat complexity supporting beavers and songbirds — though ecologists continue to debate the relative strength of each link in this chain of effects.



A simplified trophic cascade: reintroducing an apex predator altered elk grazing pressure, which in turn changed vegetation and physical habitat structure. Ecologists continue to debate the relative strength of each link in this widely cited case study.

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Rewilding là việc tái du nhập một loài (thường là loài chủ chốt — keystone species — hoặc động vật ăn thịt đỉnh) hoặc phục hồi các quá trình sinh thái tự nhiên cho một hệ sinh thái đã suy thoái. **Loài chủ chốt** có ảnh hưởng đến cấu trúc quần xã lớn hơn nhiều so với độ phong phú (số lượng cá thể) của nó — việc mất đi hoặc tái du nhập loài này có thể tạo ra **hiệu ứng tầng dinh dưỡng** (trophic cascade) lan khắp lưới thức ăn. Ví dụ kinh điển: tái du nhập sói vào Vườn quốc gia Yellowstone (1995) được cho là đã làm giảm số lượng/ thay đổi hành vi của nai sừng tấm (elk), giúp thảm thực vật ven suối phục hồi, và gián tiếp làm tăng độ phức tạp sinh cảnh (hải ly, chim hót quay trở lại) — dù các nhà sinh thái học vẫn tranh luận về mức độ đóng góp chính xác của từng mắt xích trong chuỗi này.

3.4.5 CITES and international frameworks

Because many species are threatened by activities that cross national borders, several international agreements coordinate conservation action.

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) regulates and restricts international (cross-border) trade in endangered species and their derivative products (e.g. ivory, rhino horn, exotic timber), requiring permits for regulated trade and banning commercial trade in the most threatened listed species. The **Convention on Biological Diversity (CBD)**, adopted at the 1992 Rio Earth Summit, is the main international framework for biodiversity conservation, sustainable use, and fair sharing of genetic resource benefits, and periodically sets internationally agreed targets — most recently the Kunming-Montreal Global Biodiversity Framework (adopted 2022), which includes a widely publicized target to protect at least 30% of the world's land and sea areas by 2030 (often called "30 by 30").

What CITES can and cannot achieve

Explain what CITES can achieve on its own, and why effective protection of a CITES-listed species usually also requires additional in-situ measures.

CITES restricts or bans legal cross-border trade in listed species and their products, reducing the economic incentive for international commercial exploitation and giving customs and enforcement agencies a legal basis to seize illegal shipments. However, CITES cannot by itself stop poaching, domestic (within-country) trade, habitat loss, or black-market trafficking that evades border controls, and its effectiveness depends on individual signatory countries' willingness and capacity to enforce it. Effective protection of a CITES-listed species (e.g. elephants, rhinoceroses) therefore usually also requires in-situ measures — anti-poaching patrols, protected habitat, and community engagement — alongside the international trade restriction.

3.4.6 Valuing biodiversity: economic and intrinsic arguments

Conservation decisions are often justified using one of two broad kinds of argument, which map onto the EVS spectrum introduced in Unit 1.

The **economic (instrumental) argument** values biodiversity for the goods and services it provides to humans — ecosystem services (flood control, water filtration, pollination, climate regulation), ecotourism revenue, and potential future resources (medicines, genetic material) — and is most consistent with an **anthropocentric** or **technocentric** EVS, since it justifies protection in terms of human benefit and often relies on economic/technical valuation. The **intrinsic-value argument** holds that species and ecosystems have worth simply by existing, independent of any usefulness to humans, and is most consistent with an **ecocentric** (particularly deep-ecology) EVS. A key practical difference: an economic justification for protection is conditional on a cost-benefit comparison and could in principle be outweighed if an alternative use is calculated to be more profitable, whereas an intrinsic-value justification does not depend on any such calculation.

Economic vs intrinsic conservation arguments

A coastal government is deciding whether to protect a coral reef. An economic report estimates the reef provides $15 million per year in tourism revenue and storm-surge protection for coastal property, and recommends protection on cost-benefit grounds. A marine biologist objects that this framing is risky, since it implies the reef would deserve no protection if a developer offered to generate more than $15 million per year from a resort built in its place instead, and argues the reef should be protected because its species have a right to exist independent of any economic calculation. Identify the EVS position associated with each argument, and state one practical strength and one practical weakness of the economic argument as a conservation strategy.

The government report's argument is **anthropocentric/technocentric** (instrumental, economic valuation); the marine biologist's argument is **ecocentric** (intrinsic value). *Strength* of the economic argument: it translates ecological value into a language (money) that resonates with policymakers and investors, often successfully mobilizing funding and political will for protection in tourism-dependent economies. *Weakness*: it makes protection conditional and reversible — since the justification rests entirely on a cost-benefit comparison, protection could be abandoned if a competing use is calculated to be more profitable, rather than being treated as an unconditional commitment.

3.5 Practice problems

Questions on 3.1 — An introduction to biodiversity

Bài tập luyện tập

A second habitat is surveyed and found to contain exactly four species, P, Q, R and S, each represented by 15 individuals ($N = 60$). Calculate this habitat's Simpson's Diversity Index, and compare the result with Community 2 from the worked examples ($D \approx 0.26$).

Lời giải chi tiết

$$\sum \left(\frac{n}{N}\right)^2 = 4 \times \left(\frac{15}{60}\right)^2 = 4 \times (0.25)^2 = 4 \times 0.0625 = 0.25$$

$$D = 1 - 0.25 = 0.75$$

This habitat's Simpson's Index ($D = 0.75$) is far higher than Community 2's ($D \approx 0.26$), even though both examples involve four species. The difference is entirely due to **evenness**: this habitat's individuals are spread perfectly evenly across all four species, whereas Community 2 was dominated almost completely by a single species.

Bài tập luyện tập

Which of the following correctly matches a level of biodiversity with a valid example of it?

(A) Genetic diversity — the number of distinct ecosystems found in a national park

(B) Species diversity — the number of distinct alleles for a coat-colour gene in a single wolf population

(C) Habitat diversity — the variety of ecosystems (forest, wetland, grassland) found within a region

(D) Genetic diversity — the total number of species recorded along a rainforest transect

Lời giải chi tiết

(C). Habitat diversity is, by definition, the range of different habitats/ecosystems present within a region, so pairing it with "forest, wetland, grassland within a region" is correct. (A) and (D) both mislabel a habitat-level or species-level count as "genetic diversity"; genetic diversity specifically concerns variation in genes/alleles *within* a species or population, not counts of ecosystems or species. (B) mislabels an example of genetic diversity (alleles within one population) as "species diversity".

Bài tập luyện tập

A third habitat is surveyed and found to contain three species with $n = 20, 12, 3$ individuals ($N = 35$). Calculate this habitat's Simpson's Diversity Index and state, in one sentence, what the result suggests about the community's evenness.

Lời giải chi tiết

$$\sum \left(\frac{n}{N}\right)^2 = \left(\frac{20}{35}\right)^2 + \left(\frac{12}{35}\right)^2 + \left(\frac{3}{35}\right)^2 = 0.3265 + 0.1176 + 0.0073 = 0.4514$$

$$D = 1 - 0.4514 = 0.55 \text{ (to 2 s.f.)}$$

A value roughly midway between the two earlier examples (0.75 and 0.26) indicates moderate evenness: one species ($n = 20$) is somewhat dominant, but not as overwhelmingly as species

A was in Community 2, so the community retains a meaningfully higher diversity than a heavily dominated one.

Bài tập luyện tập

A newly surveyed region contains an estimated $1{,}200$ endemic vascular plant species and has lost approximately 80% of its original native vegetation. Determine whether this region qualifies as a biodiversity hotspot under the standard two-part criteria, and justify your answer.

Lời giải chi tiết

Criterion 1 (endemism): the threshold is at least $1{,}500$ endemic vascular plant species; this region has only $1{,}200$, so this criterion is **not** met.
Criterion 2 (habitat loss): the threshold is at least 70% habitat loss; this region's 80% loss **does** meet this criterion.
Because *both* conditions must be satisfied simultaneously and the endemism criterion fails, this region does **not** qualify as a biodiversity hotspot, despite its severe habitat loss — a reminder that hotspot status requires irreplaceable endemic richness *and* urgency, not urgency (habitat loss) alone.

Questions on 3.2 — Origins of biodiversity

Bài tập luyện tập

A population of bacteria is exposed to an antibiotic. Most bacteria die, but a small number, which happened to carry a pre-existing mutation conferring resistance, survive and reproduce, so that within a few generations most of the population is resistant. Identify the four ingredients of natural selection illustrated by this scenario.

Lời giải chi tiết

Variation: the resistance-conferring mutation already existed in some bacteria *before* the antibiotic was applied, arising from random mutation. **Heritability:** resistant bacteria pass the resistance-conferring gene to their offspring during reproduction. **Differential survival/reproduction:** in the presence of the antibiotic, resistant bacteria survive and reproduce while non-resistant bacteria mostly die. **Change in allele frequency:** because resistant bacteria reproduce disproportionately, the resistance allele becomes far more common in the population over successive generations — the population has evolved. Crucially, the mutation did not appear *because* the antibiotic was applied; it was already present, and the antibiotic merely selected for it.

Bài tập luyện tập

Two populations of a fruit fly species live on the same continuous mountainside but at different elevations. Over time they begin breeding at slightly different times of year (correlated with elevation-specific temperature cues) and increasingly fail to interbreed, even though no physical barrier separates them. Identify the mode of speciation illustrated and explain why.

Lời giải chi tiết

This is **sympatric speciation**: there is no geographic barrier at all separating the two populations (they occupy the same continuous mountainside), yet reproductive isolation is developing through a difference in breeding timing — a form of disruptive selection/niche differentiation acting on individuals that continue to share the same general location. This contrasts with allopatric speciation, which specifically requires a physical barrier preventing gene flow.

Bài tập luyện tập

Palaeontologists estimate a background extinction rate of 0.5 extinctions per million species per year for a group of marine invertebrates. Current monitoring estimates the group's present extinction rate at 250 extinctions per million species per year. Calculate how many times higher the current rate is than the background rate.

Lời giải chi tiết

$$\frac{\text{current rate}}{\text{background rate}} = \frac{250}{0.5} = 500\times$$

The current estimated rate is roughly 500 times the background rate for this group — a very large multiple, though (as with all such estimates) it carries real uncertainty from incomplete fossil and monitoring records.

Bài tập luyện tập

Which piece of evidence most directly supports the hypothesis that an asteroid impact caused the End-Cretaceous mass extinction?

(A) A gradual, multi-million-year decline in dinosaur diversity recorded in fossil layers

(B) A worldwide sediment layer enriched in iridium, an element rare in Earth's crust but common in asteroids, dated to the extinction boundary

(C) A sharp increase in fossilized pollen from flowering plants immediately after the boundary

(D) A decline in ocean salinity recorded in marine sediment cores from the same period

Lời giải chi tiết

(B). A globally distributed, extinction-boundary iridium layer is difficult to explain by ordinary terrestrial processes (iridium is rare in Earth's crust) but is consistent with debris from an asteroid impact settling worldwide — this is the classic physical evidence cited for the impact hypothesis. (A) would actually argue against a sudden impact-driven event. (C) and (D) are not the standard cited evidence for the impact hypothesis.

Questions on 3.3 — Threats to biodiversity

Bài tập luyện tập

A continuous square forest measures 6 km $\times$ 6 km (area $= 36$ km^2, perimeter $= 24$ km). It is fragmented by roads into nine equal, separated square patches covering the same total area of 36 km^2. Calculate the perimeter of each new patch, the combined perimeter of all nine, and the factor by which the total edge has increased.

Lời giải chi tiết

Area per small patch $= 36 \div 9 = 4$ km^2, so side length $= \sqrt{4} = 2$ km and perimeter per patch $= 4 \times 2 = 8$ km. Combined perimeter of all nine patches $= 9 \times 8 = 72$ km.
Edge increased from 24 km to 72 km, a factor of $72 \div 24 = 3\times$ (in general, splitting a square into n equal-area sub-squares multiplies total perimeter by $\sqrt{n} = \sqrt{9} = 3$). No habitat area was lost, yet the total edge — and hence the exposure of the remaining habitat to edge effects — tripled.

Bài tập luyện tập

A persistent pollutant is measured at 0.001 ppm in phytoplankton, 0.03 ppm in zooplankton, 0.9 ppm in small fish, and 27 ppm in a top predator feeding on the small fish. Calculate the multiplication factor at each trophic transfer and the overall biomagnification factor from phytoplankton to top predator.

Lời giải chi tiết

Phytoplankton → zooplankton: $0.03 \div 0.001 = 30\times$. Zooplankton → small fish: $0.9 \div 0.03 = 30\times$. Small fish → predator: $27 \div 0.9 = 30\times$.
Overall factor $= 27 \div 0.001 = 27{,}000\times$ (equivalently 30^3, since concentration multiplies by 30 at each of the three trophic transfers) — a striking illustration of how a near-negligible environmental concentration can become a substantial dose in a top predator.

Bài tập luyện tập

A fish stock estimated at $500{,}000$ tonnes of biomass in 1980 has fallen to $60{,}000$ tonnes by 2010 after decades of intensive fishing. Calculate the percentage decline in biomass over this period.

Lời giải chi tiết

$$\text{Percentage decline} = \frac{500{,}000 - 60{,}000}{500{,}000} \times 100\% = \frac{440{,}000}{500{,}000} \times 100\% = 88\%$$

An 88% collapse in biomass over three decades is consistent with severe, sustained overexploitation, and illustrates why recovery, if it occurs at all, is typically slow: a severely depleted breeding stock produces far fewer offspring even once fishing pressure is reduced.

Bài tập luyện tập

The introduction of the Nile perch to Lake Victoria is a widely cited case study of which threat to biodiversity, and why did the introduced species proliferate so successfully?

Lời giải chi tiết

This is a case study of **invasive (alien) species**. The Nile perch, introduced deliberately for commercial fishing, proliferated because Lake Victoria's native cichlid community had no evolutionary history with a predator of its type, size, or hunting strategy — it therefore faced no effective natural predators or competitors capable of checking its population growth, allowing it to prey heavily on native cichlids and drive many endemic species toward decline or extinction.

Bài tập luyện tập

Explain, using the concept of phenological mismatch, how climate change can reduce breeding success in a migratory bird species even if the birds' own migration timing does not change at all.

Lời giải chi tiết

Many migratory birds time their arrival and breeding using cues such as day length, which do not shift with a warming climate. However, the timing of a key food resource (e.g. peak caterpillar or insect abundance, itself often cued by temperature) can shift earlier as spring temperatures rise. If the birds' migration and breeding timing remains fixed to day length while the food peak shifts earlier, chicks may hatch *after* the food peak has already passed, reducing the food available during the critical nestling period and lowering breeding success — even though the birds' own behaviour and migration timing have not changed at all; it is the *mismatch* between two previously synchronized schedules that causes the harm.

Bài tập luyện tập

A population has declined by an estimated 42% over the last three generations, and the cause of decline (habitat conversion to agriculture) is ongoing. Using the simplified guidelines in this unit, classify the population's most likely IUCN category.

Lời giải chi tiết

A decline of 42% falls within the "roughly 30–50%" band, pointing to **Vulnerable (VU)** — less severe than Endangered (roughly 50–80% decline) but more severe than Near Threatened. The fact that the underlying cause remains active (ongoing habitat conversion) is a warning sign that the decline may continue or worsen if unaddressed.

Bài tập luyện tập

Place the following IUCN Red List categories in order of *increasing* extinction risk: Endangered, Near Threatened, Extinct in the Wild, Vulnerable.

Lời giải chi tiết

In order of increasing risk: **Near Threatened** $<$ **Vulnerable** $<$ **Endangered** $<$ **Extinct in the Wild**. Near Threatened is closest to the "safe" end of the scale; Extinct in the Wild (individuals survive only in captivity) represents a more advanced stage of decline than Critically Endangered or Endangered, where at least some individuals still persist in the wild.

Questions on 3.4 — Conservation of biodiversity

Bài tập luyện tập

A conservation programme moves the last 12 individuals of a critically endangered bird species into a purpose-built breeding facility, with the intention of eventually releasing captive-bred offspring back into restored habitat. Classify this strategy and state one limitation that will remain even if captive breeding is completely successful.

Lời giải chi tiết

This is **ex-situ conservation** (protection outside the species' natural habitat). Even if captive breeding succeeds completely, the strategy does not by itself address whatever originally caused the wild population to collapse (e.g. habitat loss, poaching, disease); unless that underlying cause is also resolved and suitable habitat is available and protected, eventual reintroduction may fail, and the population may also have lost some genetic diversity through the captive-breeding bottleneck.

Bài tập luyện tập

A single square nature reserve measures 200×200 units (area $= 40{,}000$ units^2; perimeter $= 800$ units). A rival proposal instead uses 16 equal-area small square reserves, together covering the same total area. Calculate the side length and perimeter of each small reserve, the combined perimeter of all sixteen, and the factor by which total edge has increased.

Lời giải chi tiết

Area per small reserve $= 40{,}000 \div 16 = 2{,}500$ units^2, so side length $= \sqrt{2{,}500} = 50$ units, and perimeter per small reserve $= 4 \times 50 = 200$ units. Combined perimeter of all sixteen $= 16 \times 200 = 3{,}200$ units.
Total edge increased from 800 to $3{,}200$ units, a factor of $3{,}200 \div 800 = 4\times$ (consistent with the general rule that splitting a square into n equal-area sub-squares multiplies total perimeter by $\sqrt{n} = \sqrt{16} = 4$) — a strong quantitative argument, all else being equal, in favour of a single large reserve where a wide-ranging or edge-sensitive species is the conservation priority.

Bài tập luyện tập

In the Yellowstone wolf-reintroduction case study, wolves are described as a "keystone species". Explain what this term means and why it applies here.

Lời giải chi tiết

A **keystone species** is one whose impact on the structure and functioning of its ecosystem is disproportionately large relative to its own abundance or biomass — its loss or return can trigger a cascade of changes throughout the food web (a **trophic cascade**). Wolves were present in relatively low numbers compared with, say, elk, yet their reintroduction is linked to reduced elk numbers and changed elk grazing behaviour, which in turn is linked to recovery of streamside vegetation, improved riverbank stability, and increased habitat complexity supporting other species (beavers, songbirds) — effects far larger than the wolves' own population size alone would suggest.

Bài tập luyện tập

Distinguish the primary function of CITES from that of the Convention on Biological Diversity (CBD).

Lời giải chi tiết

CITES specifically regulates and restricts *international trade* in endangered species and their derivative products, using a permit system and outright bans for the most threatened listed species. The **CBD** is a much broader framework covering biodiversity conservation, sustainable use of biological resources, and fair sharing of the benefits from genetic resources, and periodically sets global targets (such as the "30 by 30" target under the Kunming-Montreal Global Biodiversity Framework). In short, CITES targets one specific mechanism of biodiversity loss (cross-border trade), while the CBD addresses biodiversity conservation and sustainable use much more broadly.

Bài tập luyện tập

A government must choose between logging a forest for immediate revenue and protecting it. An economist argues the forest should be protected because its calculated ecosystem-service value (water filtration, flood control, ecotourism) exceeds the logging revenue. An ecologist counters that the forest should be protected regardless of any such calculation, because its species have an inherent right to exist. Identify the EVS position underlying each argument.

Lời giải chi tiết

The economist's argument is **anthropocentric/technocentric** (instrumental valuation: the forest is protected because its calculated value to humans exceeds the alternative use). The ecologist's argument is **ecocentric** (intrinsic valuation: protection is justified independent of any human-benefit calculation). This distinction matters practically: the economist's justification could in principle be overturned if a future calculation favoured logging, whereas the ecologist's justification does not depend on any such comparison.

Bài tập luyện tập

Explain why a species reduced to a single small, isolated population is at greater long-term risk than the same total number of individuals spread across several connected populations.

Lời giải chi tiết

A single small, isolated population has lower **genetic diversity** (a smaller gene pool, more vulnerable to genetic drift and inbreeding depression, which lowers fitness and reduces the population's ability to adapt to new diseases or environmental change) and cannot be "rescued" by immigration from other populations if it suffers a local disaster (disease outbreak, poor breeding season, fire). Several smaller but connected populations (e.g. linked by a wildlife corridor) retain more total genetic diversity, allow gene flow that offsets inbreeding, and provide a buffer against total extinction, since a disaster affecting one population does not necessarily affect the others.

Bài tập luyện tập

Which of the following best explains why wildlife corridors are considered valuable in a fragmented landscape?

(A) They convert several small reserves into a single large reserve, eliminating edge effects entirely

(B) They allow gene flow, seasonal migration and recolonization between otherwise isolated habitat patches

(C) They increase the total protected area without any additional cost

(D) They remove the need for in-situ conservation altogether

Lời giải chi tiết

(B). Corridors do not eliminate edge effects or literally merge reserves (A), do not appear at zero cost (C), and do not replace the need for in-situ protection (D). Their specific ecological value is restoring connectivity — allowing individuals, genes, and seasonal movements to flow between patches that would otherwise be fully isolated, partially offsetting the genetic and demographic costs of fragmentation.

Ôn tập nhanh — Unit 3: Đa dạng sinh học: ba cấp độ (gene – loài – sinh cảnh); chỉ số Simpson $D = 1 - \sum(n/N)^2$ kết hợp richness và evenness. Nguồn gốc đa dạng: chọn lọc tự nhiên (4 yếu tố: biến dị, di truyền, sống sót/sinh sản khác biệt, đổi tần số alen); hình thành loài dị vực (có rào cản địa lý) và đồng vực (không có rào cản). Năm mối đe dọa chính: mất/phân mảnh sinh cảnh, loài xâm lấn, ô nhiễm (bao gồm tích lũy/khuếch đại sinh học), khai thác quá mức, biến đổi khí hậu. Thang IUCN tăng dần mức nguy cấp: LC $<$ NT $<$ VU $<$ EN $<$ CR $<$ EW $<$ EX. Bảo tồn: tại chỗ (in-situ, ưu tiên khi khả thi) và chuyển chỗ (ex-situ, "bảo hiểm"); SLOSS và hành lang sinh thái; rewilding và loài chủ chốt; CITES (thương mại) và CBD (khung toàn diện); lập luận kinh tế (instrumental) so với nội tại (intrinsic).

Water and Aquatic Food Production Systems and Societies

> **Mục tiêu Unit:** Chu trình thuỷ văn, thời gian lưu trú (residence time) và tuần hoàn đại dương (dòng bề mặt do gió, tuần hoàn nhiệt–muối); khan hiếm nước vật lý so với khan hiếm nước kinh tế, chất lượng nước, khái niệm nước ảo (virtual water), đánh đổi lợi ích–chi phí của đập/hồ chứa và xung đột nước xuyên biên giới; sản lượng bền vững tối đa (MSY) trong đánh bắt cá, nuôi trồng thuỷ sản, các dấu hiệu đánh bắt quá mức và đánh bắt huỷ diệt; phú dưỡng hoá, ô nhiễm nguồn nước điểm/không điểm, ô nhiễm dầu/nhựa/nhiệt, và nhu cầu oxy sinh hoá (BOD).

4.1 Introduction to water systems

4.1.1 Storages and flows in the hydrological cycle

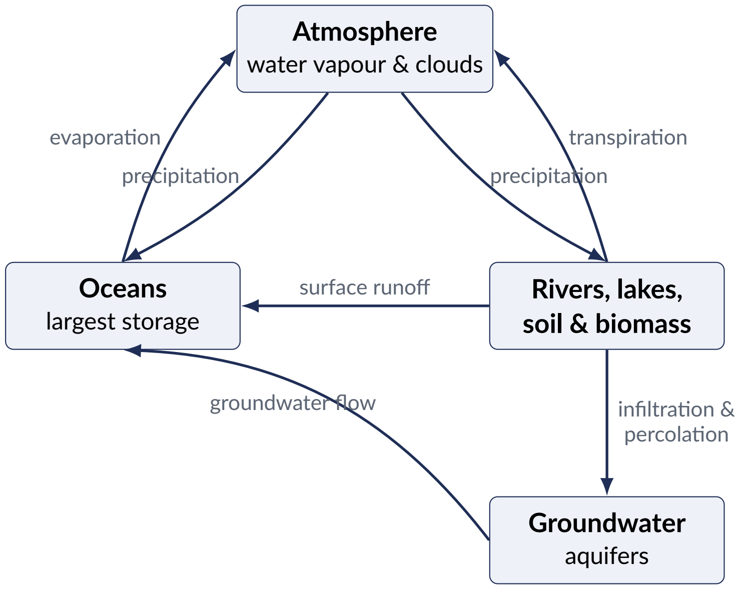
Water is the resource that makes every other environmental system function: it drives weathering and soil formation, transports nutrients through ecosystems, regulates climate, and underpins every food production system studied in this book. Water on Earth does not disappear or get created — it is continuously redistributed among a set of **storages** by physical **flows** (transfers and transformations, in the systems-approach language of Chapter 1). This continuous redistribution is the **hydrological cycle** (water cycle).

The major storages, ranked roughly from largest to smallest, are: the **oceans** (by far the largest, holding an estimated $\approx 97\%$ of all water on Earth, almost all of it saline), **ice caps and glaciers** (the largest reservoir of fresh water), **groundwater** held in the pore spaces and fractures of rock and soil, **lakes and rivers** (surface fresh water), **soil moisture and biomass** (water held in soil and living organisms), and the **atmosphere** (water vapour and cloud droplets) — the smallest storage by volume, but, as Section 4.1.2 shows, the fastest-turnover storage of all.

Water moves between these storages via a recurring set of named flows:

- **Evaporation** — liquid water at the surface (mostly the ocean) changes to water vapour and enters the atmosphere; a transformation driven by solar energy.
- **Transpiration** — water vapour is released to the atmosphere from plant leaves as a by-product of gas exchange; combined with evaporation from soil and open water, the total flux is often termed **evapotranspiration**.
- **Condensation** — water vapour cools and changes back to liquid droplets (or ice crystals), forming clouds.
- **Precipitation** — condensed water falls from the atmosphere to the surface as rain, snow, sleet, or hail.
- **Infiltration** — precipitation soaks into the soil surface.
- **Percolation** — infiltrated water continues moving downward through soil and rock to recharge groundwater storage.
- **Surface runoff (overland flow)** — precipitation that does not infiltrate flows across the land surface into streams, rivers, and eventually the ocean.

- **Groundwater flow** — water stored underground moves slowly through permeable rock (an **aquifer**) and eventually discharges into rivers, wetlands, or the ocean.



The hydrological cycle: major storages (boxes) linked by transfer and transformation processes (arrows). Oceans are the largest storage by far; the atmosphere is the smallest but fastest-turnover storage.

GIẢI THÍCH TIẾNG VIỆT

VN **Chu trình thuỷ văn (hydrological cycle)** mô tả sự luân chuyển liên tục của nước giữa các **kho chứa (storages)**: đại dương (lớn nhất, $\approx 97\%$ lượng nước Trái Đất), băng ở hai cực/sông băng, nước ngầm, sông hồ, đất/sinh khối, và khí quyển (nhỏ nhất nhưng luân chuyển nhanh nhất). Các **dòng chảy (flows)** nối các kho chứa gồm: **bốc hơi (evaporation)**, **thoát hơi nước qua lá cây (transpiration)**, **ngưng tụ (condensation)**, **giáng thuỷ/mưa (precipitation)**, **thấm (infiltration)**, **thấm sâu (percolation)**, **dòng chảy mặt (surface runoff)**, và **dòng chảy ngầm (groundwater flow)**.

4.1.2 Residence time in water storages

Chapter 1 introduced **residence time** (turnover time), τ, as a general quantitative tool for any storage in a system:

$$\tau = \frac{M}{F}$$

where M is the quantity of water held in a storage at a given time and F is the rate at which water flows out of that storage, with M and F expressed in consistent units. A short residence time means water turns over quickly (the storage is a fast, responsive part of the cycle); a long residence time means water, once it enters that storage, stays there for a very long time before leaving.

Because the different hydrological storages have wildly different volumes and outflow rates, their residence times span an enormous range — from days to many thousands of years.

Storage	Relative size	Typical residence time
Oceans	Very large (largest single storage; $\approx 97\%$ of all water on Earth)	Centuries to thousands of years overall — the surface mixed layer exchanges relatively quickly, but the deep ocean turns over far more slowly
Ice caps & glaciers	Large	Centuries to tens of thousands of years
Groundwater	Large	Shallow aquifers: decades to centuries; deep aquifers: centuries to thousands of years
Lakes	Medium	Days to decades (commonly weeks to a few years)
Rivers	Small	Days to weeks
Soil moisture & biomass	Small	Days to weeks
Atmosphere	Smallest	Days ($\approx$ 9–10 days on average) — the fastest-turnover storage of all

Ví dụ mẫu · Residence time of a river channel

A short river channel holds a water volume of $M = 2.0 \times 10^7$ m^3. It discharges water into the sea at a combined rate of $F = 4.0 \times 10^8$ m^3/yr. Calculate the residence time of water in this river, in years and then in days.

$$\tau = \frac{M}{F} = \frac{2.0 \times 10^7 \text{ m}^3}{4.0 \times 10^8 \text{ m}^3/\text{yr}} = 0.05 \text{ years.}$$

Converting to days: 0.05 yr $\times$ 365 days/yr $= 18.25 \approx 18$ days. A parcel of water entering this river remains in the channel, on average, for only about 18 days before reaching the sea — consistent with rivers being one of the fastest-turnover storages in the hydrological cycle.

Ví dụ mẫu · Residence time of a deep groundwater aquifer

A deep aquifer holds a groundwater volume of $M = 6.0 \times 10^{11}$ m^3. Combined natural discharge and recharge through the aquifer occurs at a rate of $F = 3.0 \times 10^8$ m^3/yr. Calculate the residence time of this aquifer, and compare it with the river in the previous example.

$$\tau = \frac{M}{F} = \frac{6.0 \times 10^{11} \text{ m}^3}{3.0 \times 10^8 \text{ m}^3/\text{yr}} = 2{,}000 \text{ years.}$$

This aquifer turns over roughly $2{,}000/(0.05) = 40{,}000$ times more slowly than the river channel in the previous example. The huge difference arises because groundwater moves extremely slowly through dense rock and sediment relative to the enormous volume stored, whereas a river's much smaller storage is flushed quickly by comparatively fast, large flows. The practical consequence is important: a pollutant entering a river will be flushed out within weeks, but the same pollutant entering this aquifer could remain, largely undiluted, for millennia.

(!) Lỗi thường gặp: Residence time is a property of the whole storage, calculated as an *average* from total volume stored divided by total outflow rate — it is not a promise about how long any one specific water molecule stays. It is also only meaningful when a storage is close to steady state (inflow $\approx$ outflow); if a storage is being rapidly drawn down (e.g., an aquifer pumped far faster than it is recharged) or rapidly filled, M is changing and a single $\tau = M/F$ calculated at one moment in time describes only that snapshot, not a stable long-run average.

4.1.3 Ocean circulation and the ocean's role in the climate system

Because oceans are both the largest water storage and the largest store of heat energy at Earth's surface, ocean circulation plays a central role in global climate, moving both water and heat around the planet. Ocean circulation operates through two linked systems.

Surface currents are driven mainly by **wind stress** acting on the top few hundred metres of the ocean, together with the Coriolis effect (Earth's rotation), which deflects moving water into large rotating gyres. Surface currents transport enormous quantities of heat away from the warm tropics toward the cooler poles — the North Atlantic Drift (an extension of the Gulf Stream), for example, carries warm water northeastward across the Atlantic and is a major reason why northwestern Europe has a notably milder climate than other regions at similar latitudes.

Thermohaline circulation (sometimes called the "global ocean conveyor belt") is a much slower, deep-ocean circulation driven not by wind but by **differences in water density**, which in turn arise from differences in **temperature** (*thermo-*) and **salinity** (*-haline*). In parts of the North Atlantic, surface water becomes very cold and, through evaporation and sea-ice formation, unusually salty; cold, salty water is denser than warmer or fresher water, so it sinks to the deep ocean floor and spreads slowly toward the equator and into other ocean basins, eventually upwelling elsewhere to complete a global circuit that is estimated to take on the order of a thousand years to close. This deep circulation is one reason the deep ocean has such a long residence time (Section 4.1.2): once water sinks into this slow, deep loop, it stays there for a very long time before resurfacing.

> The oceans buffer global climate because water has a very high heat capacity: oceans can absorb, store, and slowly redistribute vast quantities of solar heat energy, moderating temperature swings that would otherwise be far more extreme. Surface currents (wind-driven) and thermohaline circulation (density-driven) work together to move this heat around the planet, linking the climates of distant regions.

> VN GIẢI THÍCH TIẾNG VIỆT
>
> **Dòng bề mặt (surface currents)** chủ yếu do **gió** và hiệu ứng Coriolis (do Trái Đất tự quay) tạo ra, di chuyển nhanh và vận chuyển nhiệt từ vùng nhiệt đới về vùng cực (ví dụ dòng Gulf Stream/North Atlantic Drift giúp Tây Bắc Âu ấm hơn các vùng cùng vĩ độ khác). **Tuần hoàn nhiệt–muối (thermohaline circulation)**, còn gọi là "băng chuyền đại dương toàn cầu", là dòng chảy sâu, rất chậm, do **chênh lệch mật độ nước** (từ nhiệt độ và độ mặn) gây ra: nước lạnh, mặn ở Bắc Đại Tây Dương chìm xuống đáy đại dương và di chuyển chậm đi khắp toàn cầu, mất khoảng cỡ một nghìn năm để hoàn thành một vòng — đây cũng là lý do đại dương sâu có thời gian lưu trú rất dài. Đại dương đóng vai trò như "bộ đệm" khí hậu toàn cầu vì nước có nhiệt dung riêng rất cao, hấp thụ và phân phối lại nhiệt lượng mặt trời.

4.2 Access to fresh water

4.2.1 Physical versus economic water scarcity

Although fresh water is a renewable resource (continually resupplied by the hydrological cycle), it is very unevenly distributed in space and time, and a large and growing share of the human population experiences some form of water scarcity. The IB syllabus distinguishes two fundamentally different causes of scarcity.

> **Physical water scarcity** exists where the natural supply of fresh water — from precipitation, rivers, lakes, and groundwater recharge — is genuinely insufficient to meet the demands of the population and ecosystems in a given region, regardless of how much money or infrastructure is available. **Economic water scarcity** exists where adequate fresh water is physically present in the environment, but a lack of infrastructure, investment, technology, or governance prevents people from accessing it reliably and safely.

A commonly cited indicative benchmark for physical scarcity is the **Falkenmark Water Stress Index**, which classifies a country's situation by its renewable freshwater resources per person per year: below roughly $1{,}700$ m^3/person/yr indicates **water stress**; below roughly $1{,}000$ m^3/person/yr indicates **water scarcity**; and below roughly 500 m^3/person/yr indicates **absolute scarcity**. These thresholds are indicative rather than a precise universal law — actual usability also depends on how evenly water is distributed through the year and how efficiently it is used — but they are widely used as a first approximation of physical water availability.

Ví dụ mẫu · Physical or economic water scarcity?

Two hypothetical countries report the following data.

Country A: renewable freshwater resources of approximately 250 m^3 per person per year; rainfall is low and unreliable, and no major river or renewable groundwater source crosses its territory.

Country B: renewable freshwater resources of approximately $2{,}600$ m^3 per person per year (moderate rainfall and a substantial river system), yet a national survey finds that 40% of the rural population has no access to a reliable piped water supply because decades of underinvestment have left water-treatment and distribution infrastructure incomplete.

Classify the type of water scarcity facing each country, and justify each answer.

Country A: 250 m^3/person/yr is far below the 500 m^3/person/yr indicative threshold for absolute scarcity — the underlying renewable resource itself is not large enough to meet demand however well it is managed. This is **physical water scarcity**.

Country B: $2{,}600$ m^3/person/yr is above the $1{,}700$ m^3/person/yr water-stress threshold, so the renewable resource is, in principle, more than adequate. The barrier to access here is not the quantity of water in the environment but the absence of infrastructure and investment needed to treat and deliver it — this is **economic water scarcity**.

(!) Lỗi thường gặp: A very common exam error is to assume that any region reporting low household access to safe water must be physically water-scarce. Always check what is actually limiting: if the renewable resource itself (rainfall, rivers, recharge) is too small, that is physical scarcity; if the resource is adequate but pipelines, treatment plants, storage, or governance are inadequate or underfunded, that is economic scarcity — and the appropriate policy response is completely different in each case (physical scarcity may require desalination, water transfer, or demand reduction; economic scarcity requires investment in infrastructure and institutions, not more water).

VN GIẢI THÍCH TIẾNG VIỆT

Khan hiếm nước vật lý (physical water scarcity): nguồn nước ngọt tự nhiên (mưa, sông, nước ngầm) thực sự không đủ để đáp ứng nhu cầu, bất kể có đầu tư cơ sở hạ tầng đến đâu. **Khan hiếm nước kinh tế (economic water scarcity):** nước có sẵn về mặt vật lý, nhưng thiếu cơ sở hạ tầng, đầu tư, công nghệ hoặc quản trị khiến người dân không tiếp cận được nước an toàn, ổn định. Chỉ số Falkenmark (ngưỡng tham khảo, không phải quy luật tuyệt đối) phân loại: dưới ≈ 1.700 m^3/người/năm là căng thẳng nước (water stress); dưới ≈ 1.000 là khan hiếm nước; dưới ≈ 500 là khan hiếm tuyệt đối.

4.2.2 Water quality and usability

Scarcity is not only a matter of quantity. Even where the *volume* of water available is adequate, its **quality** may make it unsafe or unusable for drinking, agriculture, or industry, effectively creating scarcity of *usable* water:

- **Pathogens** — bacteria, viruses, and parasites from untreated sewage or animal waste contaminate water supplies with disease-causing organisms (e.g., cholera, typhoid, diarrhoeal disease), a leading cause of illness and death in areas lacking sanitation infrastructure.
- **Salinity** — seawater intrusion into coastal aquifers (often worsened by over-pumping groundwater faster than it is recharged), or the build-up of salts in poorly drained irrigated soils and irrigation return-water, can render water too saline for drinking or for most crops.
- **Chemical contamination** — industrial effluent, agricultural runoff (fertilisers, pesticides), heavy metals, or naturally occurring contaminants (e.g., arsenic in some groundwater) can make water unsafe even though it looks and smells clean.

Ví dụ mẫu · When quantity is not the problem

A coastal town over-pumps its shallow aquifer to supply a growing population. As groundwater levels fall below sea level, seawater migrates inland and enters the aquifer, and wells that previously supplied fresh water now yield water too saline to drink, even though the volume of water reaching the wells has not decreased. Which type of water problem does this best illustrate, and why is it a distinct issue from physical or economic scarcity?

This is a **water quality problem reducing usability** (salinisation through saltwater intrusion), not physical scarcity (the volume of water reaching the wells is unchanged) and not, on its own, economic scarcity (the town already has wells and distribution infrastructure). The underlying cause is unsustainable extraction relative to the aquifer's natural recharge rate, allowing denser seawater to intrude — the appropriate response (e.g., reducing extraction rates, relocating wellheads further from the coast, artificial recharge) is different again from the responses appropriate to physical or economic scarcity.

GIẢI THÍCH TIẾNG VIỆT

VN Ngay cả khi **số lượng** nước đủ, **chất lượng** nước kém (mầm bệnh từ nước thải chưa xử lý, nhiễm mặn do khai thác nước ngầm quá mức khiến nước biển xâm nhập, hoặc ô nhiễm hoá chất từ công nghiệp/nông nghiệp) vẫn có thể khiến nước không dùng được — đây là một dạng vấn đề khác, cần giải pháp khác với khan hiếm vật lý hay khan hiếm kinh tế.

4.2.3 Virtual water

A useful concept for understanding global water use is **virtual water** (also called embedded water): the total volume of fresh water actually used, directly and indirectly, in producing a good or service — for example, water used to irrigate the wheat that becomes flour, or water used to grow the feed crops and provide drinking water for livestock that becomes meat. Because goods embedding large amounts of virtual water are traded internationally, virtual water allows water-scarce regions to effectively "import" water indirectly, embedded in food and manufactured products, without physically transporting the water itself.

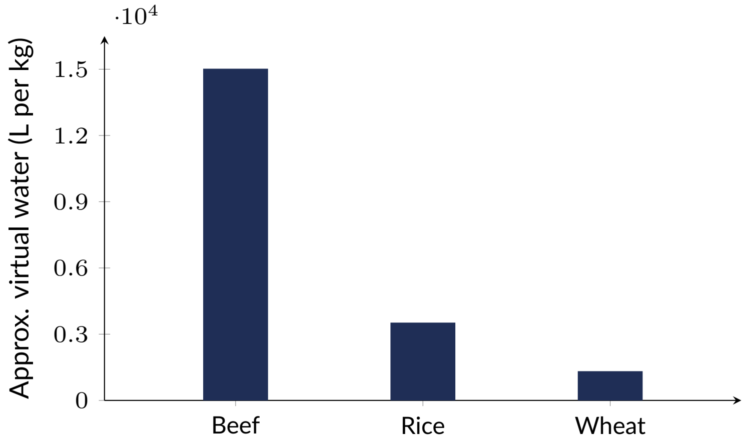
Approximate virtual water content of common foods

Water footprint studies commonly cite the following order-of-magnitude figures (values vary with farming method, climate, and region, so they should be read as illustrative approximations, not exact universal constants):

- Beef: approximately $15{,}000$ L of virtual water per kg — very high, because cattle convert feed to body mass inefficiently and require large quantities of feed crops (themselves grown using irrigation or rainfall) over a long growth period.
- Rice: approximately $3{,}000$–$4{,}000$ L per kg — high, reflecting the large volumes of water used

in flooded paddy cultivation.

- Wheat: approximately $1{,}300$ L per kg — markedly lower than beef or rice.



Approximate virtual (embedded) water content per kilogram of selected foods. The rice figure uses $3{,}500$ L/kg, the midpoint of the commonly cited approximate $3{,}000$–$4{,}000$ L/kg range.

Ví dụ mẫu · Comparing the virtual water of beef and wheat

Using the approximate figures of $15{,}000$ L per kg for beef and $1{,}300$ L per kg for wheat, calculate the virtual water embedded in 1.5 kg of each, and state the ratio between them.

Beef: 1.5 kg $\times$ $15{,}000$ L/kg $= 22{,}500$ L.
Wheat: 1.5 kg $\times$ $1{,}300$ L/kg $= 1{,}950$ L.
Difference: $22{,}500 - 1{,}950 = 20{,}550$ L — producing the beef uses over $20{,}000$ L more virtual water than producing the same mass of wheat.
Ratio: $\dfrac{22{,}500}{1{,}950} \approx 11.5$, so at any quantity, producing beef requires roughly 11.5 times as much virtual water as producing the same mass of wheat (the ratio is set by the per-kg figures and does not change with the quantity chosen).

GIẢI THÍCH TIẾNG VIỆT

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Nước ảo (virtual water) là tổng lượng nước ngọt thực sự được dùng (trực tiếp và gián tiếp) để sản xuất ra một sản phẩm hoặc dịch vụ — ví dụ nước tưới lúa mì, hoặc nước dùng để trồng thức ăn chăn nuôi và cho gia súc uống để tạo ra thịt bò. Nhờ khái niệm này, các vùng khan hiếm nước có thể "nhập khẩu" nước một cách gián tiếp thông qua thực phẩm và hàng hoá. Thịt bò có lượng nước ảo rất cao (≈ 15.000 L/kg) so với lúa mì (≈ 1.300 L/kg) — vì gia súc chuyển hoá thức ăn thành khối lượng cơ thể kém hiệu quả và cần lượng lớn thức ăn thực vật trong thời gian sinh trưởng dài.

4.2.4 Dams, reservoirs, and transboundary water conflict

Large dams and their reservoirs are among the most consequential ways humans manage fresh water, and they involve substantial trade-offs.

Benefits and costs of large dams and reservoirs

Benefits: reliable water storage that evens out natural seasonal and year-to-year variability in river flow; flood control (excess flow can be held back and released gradually); hydroelectric

power generation (a renewable, low-operating-carbon electricity source); and a stable supply of water for irrigation, industry, and domestic use, including during droughts.
Costs: displacement of communities and loss of land, homes, agricultural land, and cultural or archaeological sites flooded by the reservoir; disrupted **sediment transport** — sediment that would naturally travel downstream is instead trapped behind the dam, starving downstream floodplains, deltas, and beaches of the sediment that maintains their fertility and physical extent, and depriving the reservoir itself of storage capacity over time as sediment accumulates; altered **flow regimes** downstream (reduced and less variable flow, changed timing of floods) that can damage river and floodplain ecosystems adapted to the natural flow pattern; and, particularly in tropical reservoirs, **methane** (CH4) **emissions** from the anaerobic decomposition of vegetation and organic matter flooded when the reservoir was filled, a greenhouse gas impact that is often overlooked in assessments of hydropower as a "clean" energy source.

Ví dụ mẫu · Weighing the costs and benefits of a large hydroelectric dam

A government proposes damming a major river to create a reservoir covering 800 km^2 of tropical forest. The project would supply $2{,}000$ MW of hydroelectric generating capacity and irrigation water for $150{,}000$ hectares of farmland, while displacing an estimated $45{,}000$ residents and reducing the natural sediment reaching the river's downstream delta by an estimated 70%. Identify one major benefit and one major cost of the project, and explain one consequence of the sediment reduction for the region downstream.

Benefit: the $2{,}000$ MW of hydroelectric capacity provides a large, renewable, and dispatchable source of electricity, alongside a reliable irrigation supply for $150{,}000$ ha of farmland that would otherwise depend on more variable rainfall.

Cost: displacement of $45{,}000$ residents represents a major social cost — loss of homes, agricultural land, and community structures, often with inadequate or contested compensation and resettlement.

Consequence of reduced sediment delivery: sediment naturally deposited at a river delta builds and maintains the delta's land area and replenishes the fertility of floodplain farmland; a 70% reduction in sediment reaching the delta means the delta will erode faster than it is replenished (a delta already under pressure from rising sea level), and downstream farmland will gradually lose the natural nutrient inputs it previously received from seasonal flooding, likely increasing farmers' dependence on artificial fertiliser over time.

Where a river crosses political borders, decisions made upstream directly affect the water available downstream, creating potential for **transboundary water conflict**: an upstream country building a large dam or withdrawing large volumes for irrigation can significantly reduce flow, timing, or water quality for downstream countries that depend on the same river, with no single government able to unilaterally guarantee the resource for all parties.

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Đập và hồ chứa mang lại lợi ích (trữ nước ổn định, kiểm soát lũ, thuỷ điện, tưới tiêu) nhưng cũng có chi phí lớn: di dời cộng đồng dân cư, gián đoạn vận chuyển **trầm tích (sediment)** khiến vùng đồng bằng/châu thổ hạ lưu bị xói mòn và mất phù sa, thay đổi chế độ dòng chảy gây hại hệ sinh thái hạ lưu, và phát thải khí mê-tan (CH4) từ thực vật ngập nước bị phân huỷ (đặc biệt ở hồ chứa vùng nhiệt đới). Khi một con sông chảy qua nhiều quốc gia, các quyết định ở thượng nguồn (xây đập, rút nước tưới tiêu) có thể gây **xung đột nước xuyên biên giới** với các quốc gia hạ nguồn.

4.3 Aquatic food production systems

4.3.1 Capture fisheries and aquaculture

Aquatic food production takes two broad forms. **Capture fisheries** harvest wild fish and other aquatic organisms directly from oceans, rivers, and lakes — the fish are not owned, bred, or fed by people before capture. **Aquaculture** (fish and shellfish farming) instead breeds and raises aquatic organisms under controlled conditions (in ponds, cages, tanks, or coastal enclosures), in essentially the same way that agriculture "farms" land animals and crops rather than relying on hunting and gathering.

Aspect	Capture fisheries (wild catch)	Aquaculture (farmed)
Yield predictability	Variable; depends on wild stock size, weather, and effort	Higher and more predictable yield per unit area/effort
Pressure on wild stocks	Direct exploitation; overfishing depletes wild populations	Can reduce pressure on wild stocks by substituting farmed supply
Waste & pollution	Dispersed; limited local waste concentration	Concentrated nutrient/waste discharge (uneaten feed, faeces) can cause local eutrophication
Disease & genetic risk	Lower transmission risk in a dispersed wild population	Disease spreads rapidly among crowded stock; escapees can interbreed with, or outcompete, wild and genetically distinct populations
Feed inputs	None (the wild food web supplies growth)	Often high, especially for carnivorous species (e.g., salmon), commonly fed fishmeal/fish oil made from other wild-caught fish
Main management tools	TAC, quotas, mesh size, closed seasons/areas, MPAs	Site licensing, stocking-density limits, effluent/discharge regulation, disease monitoring

Aquaculture advantages: higher and more predictable yield per unit area or effort than wild capture; can relieve fishing pressure on wild stocks by substituting farmed supply for wild-caught product; production can be sited and scaled to meet demand directly.

Aquaculture disadvantages: concentrated nutrient and organic waste output can cause local eutrophication; crowded stocking densities favour rapid disease spread; escaped farmed individuals (which may be non-native, genetically distinct, or selectively bred) can interbreed with, compete with, or introduce disease to wild populations; carnivorous farmed species (e.g., salmon, shrimp) often require large quantities of wild-caught fish converted into feed, which can simply shift fishing pressure onto the wild "feed" species rather than eliminate it.

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Nuôi trồng thuỷ sản (aquaculture) cho năng suất cao và ổn định hơn, giảm áp lực lên quần thể cá tự nhiên, nhưng có nhược điểm: chất thải dinh dưỡng tập trung gây phú dưỡng hoá cục bộ, dễ lây lan dịch bệnh do mật độ nuôi cao, cá thoát ra ngoài có thể lai tạp hoặc cạnh tranh với quần thể hoang dã, và nhiều loài ăn thịt (như cá hồi) cần lượng lớn thức ăn làm từ cá đánh bắt tự nhiên khác.

4.3.2 Logistic growth and maximum sustainable yield

The size of a wild population, in the absence of harvesting, does not grow without limit. In a simple but powerful model, population growth follows the **logistic growth** equation:

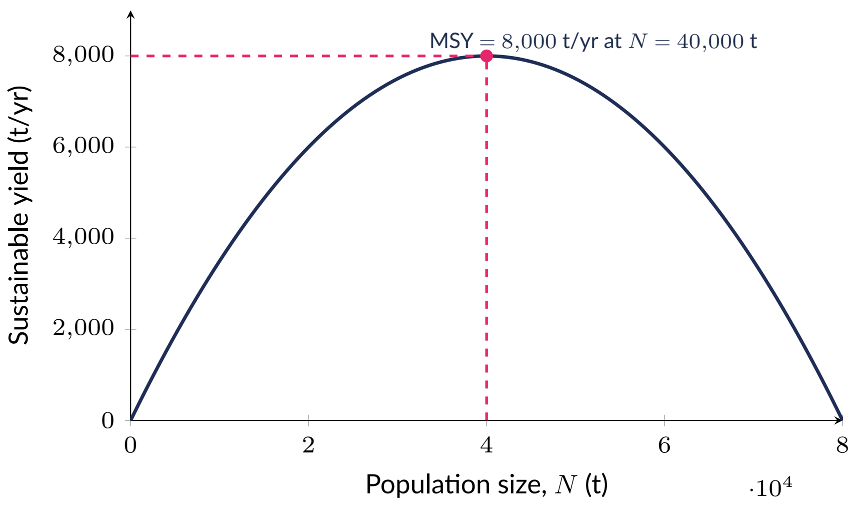
$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

where N is population size, t is time, r is the intrinsic (maximum) growth rate of the population, and K is the **carrying capacity** — the maximum population size the environment can sustain indefinitely. When N is small relative to K, the term $\left(1 - \frac{N}{K}\right)$ is close to 1 and the population grows nearly exponentially; as N approaches K, this term approaches zero and growth slows, halting altogether once $N = K$.

Because the growth rate $\frac{dN}{dt}$ itself depends on N, it is not constant — it is small when the population is very small (few individuals reproducing), rises as the population grows, reaches a maximum, and then falls back to zero as the population approaches K (little room left to grow). Differentiating (or simply testing the algebra) shows that this growth rate is maximized exactly halfway between zero and carrying capacity, at $N = K/2$. This matters directly for fisheries: if a fixed population is harvested at a rate equal to its own natural growth rate, the population size remains stable indefinitely (harvest replaces exactly what is regrown) — so the *largest* harvest that can be sustained forever is the largest possible value of $\frac{dN}{dt}$, which occurs at $N = K/2$.

Maximum sustainable yield (MSY) is the largest catch (harvest) that can be removed from a population indefinitely without depleting the underlying stock, because it exactly matches the population's own maximum rate of natural increase. From the logistic model:

$$N_{MSY} = \frac{K}{2}, \qquad MSY = \frac{rK}{4}$$



Sustainable-yield curve for a fish stock with $r = 0.4$/yr and $K = 80{,}000$ t. Yield $= rN(1 - N/K)$ peaks at $N = K/2 = 40{,}000$ t, giving maximum sustainable yield $MSY = rK/4 = 8{,}000$ t/yr.

Ví dụ mẫu · Calculating maximum sustainable yield

A fish stock has an intrinsic growth rate of $r = 0.4$/yr and a carrying capacity of $K = 80{,}000$ t. (a) Calculate the population size at which sustainable yield is maximized. (b) Calculate the maximum sustainable yield.

(a) $N_{MSY} = \frac{K}{2} = \frac{80{,}000}{2} = 40{,}000$ t.

(b) $MSY = \frac{rK}{4} = \frac{0.4 \times 80{,}000}{4} = \frac{32{,}000}{4} = 8{,}000$ t/yr.

A fishery manager could therefore permit a total allowable catch of up to $8{,}000$ tonnes per year, provided the stock is maintained at approximately $40{,}000$ tonnes, without depleting the underlying population over time.

Ví dụ mẫu · A second maximum sustainable yield calculation

A different, more slowly reproducing fish stock has $r = 0.5$/yr and $K = 60{,}000$ t. Calculate N_{MSY} and the MSY, and comment on how a lower carrying capacity affects the size of the sustainable catch compared with the stock in the previous example.

$N_{MSY} = \frac{K}{2} = \frac{60{,}000}{2} = 30{,}000$ t.

$MSY = \frac{rK}{4} = \frac{0.5 \times 60{,}000}{4} = \frac{30{,}000}{4} = 7{,}500$ t/yr.

Even though this stock has a higher intrinsic growth rate ($r = 0.5$ versus $r = 0.4$ previously), its lower carrying capacity ($K = 60{,}000$ t versus $80{,}000$ t) means its maximum sustainable yield is nonetheless smaller ($7{,}500$ t/yr versus $8{,}000$ t/yr). MSY depends on the *product* rK, so a smaller stock (lower K) can still yield less overall even with faster individual reproduction, unless r is proportionally large enough to compensate.

(!) Lỗi thường gặp: A frequent error is to assume the maximum sustainable yield is harvested at the carrying capacity K, or that harvesting more heavily always increases long-run catch. In fact, sustainable yield is zero at both $N = 0$ (no population left to reproduce) and $N = K$ (the population is already at capacity with a net growth rate of zero, so nothing can be removed without depleting it) — the curve is a peak, not a plateau, and the maximum sustainable catch occurs only at the intermediate point $N = K/2$. Fishing a stock down toward zero, or fishing it while it sits at K, both yield less than fishing it while its population is maintained near $K/2$.

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Tăng trưởng logistic: $\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$, trong đó N là kích thước quần thể, r là tốc độ tăng trưởng nội tại, K là sức chứa môi trường (carrying capacity). Tốc độ tăng trưởng đạt cực đại khi $N = K/2$. **Sản lượng bền vững tối đa (MSY)**: lượng đánh bắt lớn nhất có thể duy trì mãi mãi mà không làm suy giảm quần thể, xảy ra tại $N_{MSY} = K/2$, với $MSY = rK/4$.

4.3.3 Fisheries management tools

Because fish stocks are typically open-access resources vulnerable to the tragedy of the commons (Chapter 1), fisheries are managed using a range of regulatory tools, often used in combination:

- **Total allowable catch (TAC) and quotas** — a regulator sets a maximum total catch for a fishery (ideally near the MSY), divided among fishers or fleets as individual quotas.
- **Individual transferable quotas (ITQs)** — quotas assigned to individual fishers or companies that can be bought, sold, or leased, giving quota holders a direct incentive to conserve the long-term value of the stock (since their quota's future value depends on the stock remaining healthy).
- **Minimum mesh size regulations** — nets must have a minimum mesh size so that smaller, often immature, fish can escape capture, protecting the breeding population and allowing fish to reproduce at least once before being caught.

- **Closed seasons and closed areas** — fishing is banned during breeding/spawning periods, or in specific breeding or nursery grounds, to protect reproduction.
- **Marine protected areas (MPAs)** — designated zones where fishing is restricted or banned entirely, allowing populations (and habitat structure) to recover and, often, "spill over" into adjacent fished areas.

4.3.4 Indicators of overfishing

Overfishing occurs when a stock is harvested faster than it can naturally replace itself, drawing down the population below a sustainable level. Because fish populations cannot be counted directly, fisheries scientists rely on a set of measurable indicators:

- **Declining catch-per-unit-effort (CPUE)** — CPUE (catch divided by a standard measure of fishing effort, e.g., tonnes caught per boat-day) falling over time, especially while total fishing effort stays constant or increases, is the classic signal that the stock available to be caught is shrinking.
- **Declining average size or age of individuals caught** — as larger, older individuals are removed faster than they can be replaced, the average size/age of the catch falls, a sign the stock's age structure is being depleted from the top down.
- **Stock biomass falling below a target reference point** — direct or modelled estimates of total stock biomass dropping below a scientifically defined sustainable reference level (e.g., the biomass associated with MSY).

Ví dụ mẫu · Reading catch-per-unit-effort as an overfishing indicator

A fishery records the following data over five years.

Year	Effort (boat-days)	Catch (t)	CPUE (t/boat-day)
2015	1,000	500	?
2016	1,200	540	?
2017	1,500	600	?
2018	1,800	630	?
2019	2,000	620	?

(a) Calculate CPUE for each year. (b) Describe the trend in effort, catch, and CPUE. (c) State what this pattern indicates about the state of the stock.

(a) CPUE $= \frac{\text{catch}}{\text{effort}}$: 2015: $500/1{,}000 = 0.50$; 2016: $540/1{,}200 = 0.45$; 2017: $600/1{,}500 = 0.40$; 2018: $630/1{,}800 = 0.35$; 2019: $620/2{,}000 = 0.31$ t/boat-day.

(b) Fishing effort rises every year ($1{,}000 \to 2{,}000$ boat-days). Total catch rises from 500 to 630 t but then falls to 620 t in 2019 despite the highest effort of the whole series. CPUE falls every single year, from 0.50 down to 0.31 t/boat-day — a steady, uninterrupted decline.

(c) A continuously falling CPUE, alongside rising effort, is the classic signature of **overfishing**: fishers are having to work harder (more boat-days) for a shrinking catch per unit of that effort, and by 2019 even a record level of effort could not sustain the previous year's total catch. This suggests the stock's abundance is declining and that current effort levels likely exceed what the stock can sustainably support — a fisheries manager would treat this as a strong signal to reduce the total allowable catch.

4.3.5 Destructive fishing methods and bycatch

Some fishing methods cause damage well beyond the target species. **Bottom trawling** drags heavy weighted nets across the seafloor, physically destroying benthic habitat structures such as coral and seagrass beds and disturbing bottom sediment, while also catching almost everything in the net's path largely indiscriminately. **Blast (dynamite) fishing** and **cyanide fishing** kill or stun fish over a wide area (and destroy coral reef structure in the process) in order to make collection easier, causing severe, often long-lasting habitat damage disproportionate to the target catch obtained — these destructive methods connect directly to the habitat destruction and biodiversity loss covered in Chapter 3.

A closely related concern is **bycatch**: non-target species caught incidentally while fishing for a different target species — for example, sea turtles, dolphins, seabirds, sharks, and juvenile fish of non-target species caught by long-line hooks or trawl nets, and often discarded dead or dying. Some shrimp trawl fisheries, for instance, have historically discarded several kilograms of bycatch for every kilogram of shrimp actually landed — a widely cited illustration of how indiscriminate a fishing method can be. Reducing bycatch (e.g., through turtle-excluder devices, circle hooks, or seasonal/area closures around known aggregation sites) is now a standard element of responsible fisheries management.

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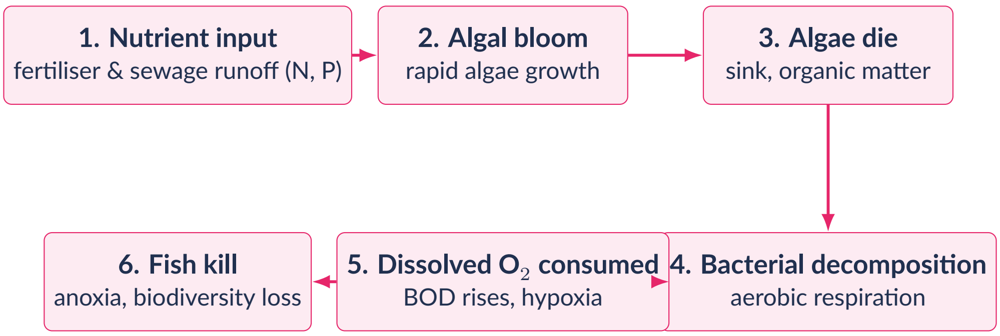
Dấu hiệu đánh bắt quá mức: CPUE (sản lượng trên một đơn vị nỗ lực đánh bắt) giảm dần dù nỗ lực đánh bắt không đổi hoặc tăng; kích thước/tuổi trung bình của cá đánh được giảm dần; sinh khối quần thể giảm xuống dưới mức tham chiếu bền vững. **Đánh bắt huỷ diệt** (giã cào đáy biển, đánh bắt bằng thuốc nổ/xyanua) gây hại môi trường sống đáy biển nghiêm trọng. **Bắt phải loài không mục tiêu (bycatch)**: các loài không phải mục tiêu (rùa biển, cá heo, chim biển, cá con) bị bắt phải và thường bị vứt bỏ — liên hệ trực tiếp đến mất môi trường sống và đa dạng sinh học đã học ở Chương 3.

4.4 Water pollution

4.4.1 Eutrophication

Eutrophication is the enrichment of a body of water with excess nutrients — principally nitrogen (as $NO3^{-}$) and phosphorus (as $PO4^{3}$—) — usually originating from agricultural fertiliser runoff and untreated or partially treated sewage. This nutrient enrichment sets off a well-defined chain of consequences:

> Nutrient input (fertiliser/sewage runoff, excess N and P) → rapid algal growth (**algal bloom**) → algae die (their lifespan is short, and the bloom eventually exhausts light or nutrients) → dead algae sink and are decomposed by aerobic **bacteria**, whose respiration consumes dissolved oxygen from the water, raising the **biochemical oxygen demand (BOD)** → dissolved oxygen concentration falls, producing **hypoxia** (low oxygen) or **anoxia** (no oxygen) → fish and other oxygen-dependent aquatic organisms die (a **fish kill**), and biodiversity in the water body collapses.



The eutrophication chain: excess nutrient input drives an algal bloom; algae die and are decomposed by bacteria, whose aerobic respiration consumes dissolved oxygen (raising biochemical oxygen demand), producing hypoxia/anoxia that kills fish and other aquatic organisms.

Ví dụ mẫu · Tracing the eutrophication chain

A lake downstream of intensively fertilised farmland experiences a sudden, extensive fish kill in late summer. Trace the most likely chain of cause and effect that led to this fish kill, starting from the fertiliser applied to the farmland.

Fertiliser applied to farmland is not fully taken up by crops; rainfall washes the surplus nitrogen and phosphorus into field drains and streams that feed the lake (**nutrient runoff**). The nutrient-enriched lake water supports an **algal bloom** — algae, no longer limited by nutrient availability, grow explosively. As the bloom ages (nutrients become depleted, or light is blocked for algae lower in the water column), large numbers of algae **die** and sink. Aerobic **bacteria** decomposing this sudden surplus of dead organic matter multiply rapidly and consume large quantities of **dissolved oxygen** through respiration, sharply raising the water's **biochemical oxygen demand**. Oxygen concentration falls faster than it can be replenished (by diffusion from air or photosynthesis), producing **hypoxic or anoxic** conditions, especially in summer when warm water already holds less dissolved oxygen — and fish, unable to obtain enough oxygen to survive, die in large numbers.

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Phú dưỡng hoá (eutrophication): nước bị phú dưỡng do dư thừa dinh dưỡng (N, P) từ phân bón/nước thải chảy tràn, gây bùng nổ tảo (algal bloom); tảo chết, bị vi khuẩn phân huỷ hiếu khí tiêu thụ oxy hoà tan (làm tăng BOD), gây thiếu oxy (hypoxia/anoxia) và làm cá chết hàng loạt.

4.4.2 Point source and non-point source pollution

Point source versus non-point (diffuse) source

A **point source** is a single, identifiable, localized origin of pollution — for example, a factory's discharge pipe or a sewage treatment plant's outfall — that can be directly monitored, measured, and regulated, and whose responsible party is clearly identifiable.
A **non-point (diffuse) source** arises from numerous, dispersed origins spread across a wide area — for example, fertiliser and pesticide runoff from many separate farms across a river catchment, or urban stormwater runoff carrying oil and litter from thousands of streets and driveways. Because no single actor can be clearly and solely identified as responsible, and the pollution enters the water body at many scattered points rather than one, non-point sources are far harder to monitor, regulate, and hold accountable than point sources.

(!) Lỗi thường gặp: Do not classify a source as "point" or "non-point" based simply on whether more than one pipe or location is involved — the real distinction is whether the pollution can be traced to a small number of clearly identifiable, individually regulable origins (point source, even if there happen to be several such pipes) or whether it is genuinely diffuse and scattered across many contributors that cannot be individually singled out or monitored (non-point source). Ten identified factory outfalls along a river are still, in principle, ten point sources; fertiliser washing off thousands of unmonitored fields is a non-point source.

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Nguồn điểm (point source): nguồn ô nhiễm đơn lẻ, xác định rõ vị trí (ống xả nhà máy, cống thải), dễ giám sát và quy trách nhiệm. **Nguồn không điểm/phân tán (non-point source)**: nhiều nguồn rải rác trên diện rộng (nước chảy tràn mang phân bón từ nhiều cánh đồng), khó xác định và quy trách nhiệm cho một chủ thể cụ thể, nên khó kiểm soát hơn nhiều.

4.4.3 Other categories of water pollution

Beyond nutrient enrichment, several other categories of water pollutant are important in ESS:

- **Oil pollution** — from tanker spills, offshore drilling accidents, or chronic small leaks and runoff — coats the water surface and the feathers/fur of animals, blocking gas exchange and insulation, smothers intertidal and shoreline organisms, and breaks down only slowly in the environment, with some heavier fractions persisting for years.
- **Plastic and marine debris** — plastic waste is extremely persistent (resisting biological decomposition for decades to centuries), causing direct harm through ingestion (blocking digestive tracts) and entanglement, and gradually breaking down through UV exposure and wave action into **microplastics**, tiny particles now found throughout marine food webs with poorly understood long-term effects.
- **Thermal pollution** — heated water discharged into a river or lake, commonly from the cooling systems of power plants and industrial facilities, raises the receiving water's temperature. Because warmer water holds *less* dissolved oxygen (oxygen solubility decreases as temperature rises), thermal pollution reduces the oxygen available to aquatic organisms and can stress or kill species adapted to cooler, more oxygen-rich conditions, even without adding any new chemical substance to the water.

Ví dụ mẫu · Comparing pollutant mechanisms

A power station discharges cooling water into a river at $32\,^{\circ}$C, several degrees warmer than the river's natural temperature. Explain, in terms of dissolved oxygen, why this discharge can harm aquatic life even though it introduces no new chemical substance into the water.

Dissolved oxygen (O2) solubility in water falls as water temperature rises — warm water can physically hold less dissolved oxygen than cold water at the same pressure. By raising the river's temperature, the thermal discharge lowers the maximum amount of oxygen the water can hold, reducing the oxygen available to fish and invertebrates. This effect is often compounded because higher temperatures also raise the metabolic (and hence oxygen-demand) rate of aquatic organisms at exactly the moment the oxygen supply is reduced — a double stress that can push sensitive species beyond their tolerance even without any toxic chemical being present.

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Ô nhiễm dầu: phủ lên mặt nước, gây ngạt và mất khả năng cách nhiệt cho động vật, phân huỷ chậm. **Ô nhiễm nhựa/rác biển**: rất bền, gây hại qua việc bị nuốt phải hoặc mắc kẹt, và phân rã thành vi nhựa (microplastics). **Ô nhiễm nhiệt**: nước làm mát từ nhà máy điện làm tăng nhiệt độ nước nhận, làm giảm khả năng hoà tan oxy của nước, gây stress cho sinh vật thuỷ sinh dù không thêm hoá chất mới.

4.4.4 Measuring and monitoring water quality

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen consumed by microorganisms as they decompose organic matter in a water sample, measured over a set period at a set temperature — conventionally over 5 days at $20\,^\circ$C (often written BOD$_5$). It is calculated as the difference between the dissolved oxygen concentration measured at the start of the incubation period and the dissolved oxygen concentration measured at the end:

$$\text{BOD} = \text{DO}_{\text{initial}} - \text{DO}_{\text{after 5 days}}$$

A **higher BOD** indicates a greater quantity of biodegradable organic matter in the sample (more organic pollution), because more oxygen is being consumed by decomposer respiration — meaning *less* oxygen remains available for fish and other aquatic organisms. Clean, unpolluted water typically has a low BOD (a few mg/L or less); water heavily polluted with sewage or organic waste can have a BOD many times higher.

Ví dụ mẫu · Calculating biochemical oxygen demand

A water sample is collected and its dissolved oxygen (DO) concentration is measured immediately at 8.5 mg/L. The same sample, kept in the dark at $20\,^\circ$C, is re-measured after 5 days and found to have a DO concentration of 3.0 mg/L. (a) Calculate the BOD$_5$ of this sample. (b) Explain what this value suggests about the level of organic pollution in the water body sampled.

(a) BOD$_5$ $=$ DO$_{\text{initial}}$ $-$ DO$_{\text{after 5 days}}$ $= 8.5 - 3.0 = 5.5$ mg/L.

(b) A BOD$_5$ of 5.5 mg/L is well above the low values (typically under about 2–3 mg/L) expected of clean, unpolluted water, indicating a moderate-to-high load of biodegradable organic matter — consistent with input from sewage, agricultural runoff, or another organic waste source — and correspondingly less dissolved oxygen remaining available to support fish and other aquatic life in that water body.

(!) Lỗi thường gặp: Do not reverse the logic of BOD: a *high* BOD does not mean the water currently contains a lot of oxygen — quite the opposite. A high BOD means the water contains a lot of organic matter that is actively consuming (depleting) dissolved oxygen as it decomposes, so a high BOD is associated with *low* oxygen availability for aquatic organisms, not high.

In addition to BOD, water quality is routinely monitored using several simpler, complementary tools: **indicator organisms** (the presence or absence of species with known, narrow tolerance ranges for pollution or oxygen level — e.g., certain aquatic invertebrates that only survive in well-oxygenated, unpolluted water — gives a quick biological signal of water quality without needing full laboratory chemical analysis); **turbidity** (a measure of water cloudiness caused by suspended sediment or particles, which can smother habitat, block light needed for photosynthesis, and often correlates with runoff-related pollution); and direct chemical testing for **nitrate and phosphate concentrations**, which gives an early warning of nutrient enrichment before a full eutrophication event and fish kill actually occur.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhu cầu oxy sinh hoá (BOD) là lượng oxy hoà tan bị vi sinh vật tiêu thụ khi phân huỷ chất hữu cơ trong một mẫu nước, đo trong một khoảng thời gian và nhiệt độ xác định (thường là 5 ngày ở $20\,^\circ$C). **BOD càng cao** nghĩa là nước càng ô nhiễm hữu cơ và càng ít oxy hoà tan sẵn có cho sinh vật thuỷ sinh — không phải ngược lại. Ngoài BOD, người ta còn dùng **sinh vật chỉ thị (indicator organisms)**, **độ đục (turbidity)**, và xét nghiệm nồng độ **nitrat/photphat** để theo dõi chất lượng nước.

4.5 Problem Bank

4.5.1 Practice: the hydrological cycle, residence time, and ocean circulation

Bài tập luyện tập

Which storage holds the largest volume of water on Earth?

(A) Groundwater
(B) Ice caps and glaciers
(C) Oceans
(D) Rivers and lakes

Lời giải chi tiết

Oceans hold an estimated $\approx 97\%$ of all water on Earth, making them by far the largest single storage in the hydrological cycle. **(C)**.

Bài tập luyện tập

A lake holds a water volume of $M = 1.2 \times 10^{10}$ m^3. Water leaves the lake (outflow plus evaporation) at a combined rate of $F = 6.0 \times 10^8$ m^3/yr. Calculate the residence time of water in this lake.

Lời giải chi tiết

$$\tau = \frac{M}{F} = \frac{1.2 \times 10^{10}\ \text{m}^3}{6.0 \times 10^8\ \text{m}^3/\text{yr}} = 20\ \text{years}.$$

Bài tập luyện tập

Which water storage has the shortest (fastest) residence time on average?

(A) Deep groundwater
(B) The atmosphere
(C) Ice caps and glaciers
(D) The deep ocean

Lời giải chi tiết

The atmosphere holds only a small volume of water vapour relative to the very large, fast flows of evaporation and precipitation moving through it, giving it an average residence time of only around 9–10 days — far shorter than any other major storage. **(B)**.

Bài tập luyện tập

Lake A holds $M = 5 \times 10^9$ m^3 and loses water at $F = 1 \times 10^9$ m^3/yr. Lake B holds $M = 8 \times 10^{10}$ m^3 and loses water at $F = 2 \times 10^8$ m^3/yr. (a) Calculate the residence time of each lake. (b) A pollutant spill of equal severity occurs in both lakes on the same day. Which lake would you expect to take longer to naturally flush out the pollutant, and why?

Lời giải chi tiết

(a) Lake A: $\tau = \dfrac{5 \times 10^9}{1 \times 10^9} = 5$ years. Lake B: $\tau = \dfrac{8 \times 10^{10}}{2 \times 10^8} = 400$ years.

(b) Lake B, with a residence time of 400 years compared with Lake A's 5 years, would take vastly longer to flush out the pollutant. A longer residence time means water (and anything dissolved or suspended in it, including a pollutant) leaves the storage much more slowly on average, so contamination introduced into Lake B would persist, largely undiluted by fresh inflow, for centuries, whereas Lake A's much faster turnover would dilute and remove the pollutant within a matter of years.

Bài tập luyện tập

The deep-ocean "conveyor belt" (thermohaline) circulation is primarily driven by:

(A) Wind stress acting on the ocean surface

(B) Differences in water density caused by temperature and salinity

(C) Tidal forces exerted by the Moon

(D) Atmospheric pressure differences alone

Lời giải chi tiết

Thermohaline circulation is driven by density differences: cold, salty (and therefore dense) water sinks in regions such as the North Atlantic and flows slowly along the deep ocean floor, in contrast to wind-driven surface currents. **(B)**.

Bài tập luyện tập

A hydrologist records the following hypothetical data for three water storages.

Storage	M	F
X	1.5×10^{13} kg	5.5×10^{14} kg/yr
Y	5×10^{11} m^3	2.5×10^{10} m^3/yr
Z	2×10^{14} m^3	2×10^{11} m^3/yr

Calculate τ for each storage (X in days, Y and Z in years), and match each storage to the type it most likely represents: the atmosphere, a lake, or deep groundwater.

Lời giải chi tiết

Storage X: $\tau = \dfrac{1.5 \times 10^{13}}{5.5 \times 10^{14}} = 0.0273$ yr $\times 365 \approx 10.0$ days — consistent with the **atmosphere** (fast turnover, small storage relative to its huge flux).

Storage Y: $\tau = \dfrac{5 \times 10^{11}}{2.5 \times 10^{10}} = 20$ years — consistent with a **lake** (medium storage, moderate turnover).

Storage Z: $\tau = \dfrac{2 \times 10^{14}}{2 \times 10^{11}} = 1{,}000$ years — consistent with **deep groundwater** (very large storage relative to its slow flux, giving a very long residence time).

4.5.2 Practice: access to fresh water

Bài tập luyện tập

A region receives moderate rainfall and has an adequate river flowing through it, giving it a reasonable per-capita freshwater resource. However, decades of underinvestment mean pipelines and treatment plants have never been built to bring that water to most residents. This region is best described as experiencing:

(A) Physical water scarcity
(B) Economic water scarcity
(C) A water quality problem only
(D) No form of water scarcity

Lời giải chi tiết

The underlying renewable resource is adequate, but a lack of infrastructure and investment prevents access — this is the defining feature of economic water scarcity. **(B)**.

Bài tập luyện tập

A desert nation has renewable freshwater resources of only 180 m^3 per person per year, well below the indicative threshold for absolute scarcity, regardless of how well any available water is managed or distributed. This nation's situation is best classified as:

(A) Physical water scarcity
(B) Economic water scarcity
(C) Virtual water surplus
(D) Thermal pollution

Lời giải chi tiết

The renewable resource itself is too small to meet demand, independent of infrastructure or investment — this is physical water scarcity. **(A)**.

Bài tập luyện tập

A household buys 4 kg of beef and 10 kg of wheat flour in one month. Using the approximate figures of $15{,}000$ L/kg for beef and $1{,}300$ L/kg for wheat, estimate the virtual water embedded in each purchase, and the combined total.

Lời giải chi tiết

Beef: 4 kg $\times$ $15{,}000$ L/kg $= 60{,}000$ L.
Wheat: 10 kg $\times$ $1{,}300$ L/kg $= 13{,}000$ L.
Combined total: $60{,}000 + 13{,}000 = 73{,}000$ L of virtual water embedded in this month's purchases.

Bài tập luyện tập

Over-pumping of a coastal aquifer causes seawater to migrate inland, and wells that previously supplied fresh drinking water now yield water too saline to drink, even though the volume reaching the wells has not fallen. This scenario best illustrates:

(A) Physical water scarcity

(B) Economic water scarcity

(C) A water quality problem reducing usability

(D) Virtual water trade

Lời giải chi tiết

The quantity of water reaching the wells is unchanged; the problem is that saltwater intrusion has made the water unusable — a water quality issue, distinct from either physical or economic scarcity. **(C)**.

Bài tập luyện tập

Outline two benefits and two costs of constructing a large hydroelectric dam and reservoir.

Lời giải chi tiết

Benefits (any two): reliable water storage that evens out seasonal/annual variability in river flow; flood control through regulated release of stored water; generation of renewable hydroelectric power; a stable water supply for irrigation, industry, and domestic use even during droughts.

Costs (any two): displacement of communities and loss of homes/farmland/cultural sites under the reservoir; disrupted sediment transport, starving downstream floodplains and deltas of sediment and reducing their fertility and physical extent; altered downstream flow regimes that damage river and floodplain ecosystems; methane (CH_4) emissions from decomposing flooded vegetation, especially in tropical reservoirs.

Bài tập luyện tập

Which situation is most likely to create transboundary tension over shared water resources?

(A) A river's entire course, from source to sea, lies within a single country

(B) A major river flows through several countries, and the upstream country builds a large dam that reduces downstream flow

(C) A country meets all its needs through desalination of seawater

(D) A lake lies entirely within the borders of one province of a single country

Lời giải chi tiết

When a shared river crosses political borders, an upstream country's unilateral decisions (such as damming the river) can directly reduce the water available to downstream countries, creating potential for transboundary conflict. **(B)**.

Bài tập luyện tập

A household follows Diet A for one week: 3 kg of beef and 5 kg of wheat. A neighbouring household follows Diet B for the same week: no beef, 5 kg of wheat, and 2 kg of rice. Using approximate virtual water figures of $15{,}000$ L/kg (beef), $1{,}300$ L/kg (wheat), and $3{,}500$ L/kg (rice, the midpoint of the commonly cited $3{,}000$–$4{,}000$ L/kg range), calculate the total weekly virtual water footprint of each diet and the difference between them.

Lời giải chi tiết

Diet A: beef $3 \times 15{,}000 = 45{,}000$ L; wheat $5 \times 1{,}300 = 6{,}500$ L; total $= 45{,}000 + 6{,}500 = 51{,}500$ L.

Diet B: wheat $5 \times 1{,}300 = 6{,}500$ L; rice $2 \times 3{,}500 = 7{,}000$ L; total $= 6{,}500 + 7{,}000 = 13{,}500$ L.

Difference: $51{,}500 - 13{,}500 = 38{,}000$ L — Diet B (no beef) embeds $38{,}000$ L less virtual water per week than Diet A, illustrating how substituting meat with plant-based staples can substantially reduce a diet's virtual water footprint.

4.5.3 Practice: aquatic food production and fisheries

Bài tập luyện tập

A fish stock has an intrinsic growth rate of $r = 0.6$/yr and a carrying capacity of $K = 50{,}000$ t. (a) Calculate the population size at which sustainable yield is maximized. (b) Calculate the maximum sustainable yield.

Lời giải chi tiết

(a) $N_{MSY} = \dfrac{K}{2} = \dfrac{50{,}000}{2} = 25{,}000$ t.

(b) $MSY = \dfrac{rK}{4} = \dfrac{0.6 \times 50{,}000}{4} = \dfrac{30{,}000}{4} = 7{,}500$ t/yr.

Bài tập luyện tập

Which of the following is the strongest evidence that a fish stock is being overfished?

(A) Catch-per-unit-effort (CPUE) declining steadily while fishing effort stays constant or rises

(B) Total catch fluctuating randomly from year to year with no clear trend

(C) The fishing fleet switching to larger, more comfortable boats

(D) Aquaculture production increasing in a neighbouring region

Lời giải chi tiết

A steady decline in CPUE despite constant or rising effort directly indicates that the abundance of fish available to be caught is shrinking — the standard quantitative signature of overfishing. **(A)**.

Bài tập luyện tập

A fish stock has $r = 0.3$/yr and $K = 90{,}000$ t. Calculate N_{MSY} and the MSY.

Lời giải chi tiết

$$N_{MSY} = \frac{K}{2} = \frac{90{,}000}{2} = 45{,}000 \text{ t.}$$

$$MSY = \frac{rK}{4} = \frac{0.3 \times 90{,}000}{4} = \frac{27{,}000}{4} = 6{,}750 \text{ t/yr.}$$

Bài tập luyện tập

Which of the following is a genuine disadvantage of aquaculture compared with capture fisheries?

(A) Aquaculture yield is generally lower and less predictable

(B) Aquaculture always increases pressure on wild fish stocks

(C) Concentrated waste output and high stocking density increase the risk of nutrient pollution and disease transmission

(D) Aquaculture cannot be regulated by any management tools

Lời giải chi tiết

Confined, high-density aquaculture concentrates nutrient/organic waste in a small area (risking local eutrophication) and allows disease to spread rapidly among crowded stock — a genuine disadvantage relative to dispersed wild capture. **(C)**.

Bài tập luyện tập

Explain what is meant by bycatch, and outline why bottom trawling is considered a particularly destructive fishing method.

Lời giải chi tiết

Bycatch is the incidental capture of non-target species while fishing for a different target species — for example, turtles, dolphins, seabirds, sharks, or juvenile fish of other species caught in nets or on hooks intended for a different catch, often discarded dead or dying.

Bottom trawling drags heavy, weighted nets across the seafloor. This physically destroys benthic habitat structures such as coral and seagrass beds and disturbs bottom sediment, while the net itself catches almost everything in its path largely indiscriminately, producing high rates of bycatch relative to the target catch obtained — making it damaging both to habitat and to non-target species, echoing the habitat destruction and biodiversity concerns covered in Chapter 3.

Bài tập luyện tập

A fishery records: 2015 — effort $1{,}000$ boat-days, catch 500 t; 2016 — effort $1{,}200$ boat-days, catch 540 t; 2017 — effort $1{,}500$ boat-days, catch 600 t; 2018 — effort $1{,}800$ boat-days, catch 630 t; 2019 — effort $2{,}000$ boat-days, catch 620 t. Calculate CPUE for 2015 and 2019 only, and state what the change indicates.

Lời giải chi tiết

2015: CPUE $= \dfrac{500}{1{,}000} = 0.50$ t/boat-day.

2019: CPUE $= \dfrac{620}{2{,}000} = 0.31$ t/boat-day.

CPUE fell from 0.50 to 0.31 t/boat-day (a decline of about 38%) even though effort nearly doubled — indicating the stock's abundance has declined substantially, a strong indicator of overfishing.

Bài tập luyện tập

A regulation closes a known spawning ground to all fishing activity during the breeding season each year. This is best classified as which fisheries management tool?

(A) An individual transferable quota (ITQ)

(B) A minimum mesh size regulation

(C) A closed area/closed season

(D) A total allowable catch (TAC)

Lời giải chi tiết

Banning fishing in a specific location during a specific breeding period is precisely the definition of a closed area/closed season measure. **(C)**.

Bài tập luyện tập

Give one advantage and one disadvantage of capture fisheries, and one advantage and one disadvantage of aquaculture.

Lời giải chi tiết

Capture fisheries — advantage: no feed input is required, since the wild food web supplies growth. **Disadvantage:** yield is variable and harvesting directly depletes wild stocks if not carefully managed.

Aquaculture — advantage: yield per unit area/effort is higher and more predictable, and can relieve pressure on wild stocks. **Disadvantage:** waste is concentrated (risking local eutrophication) and disease spreads readily among densely stocked individuals.

4.5.4 Practice: water pollution

Bài tập luyện tập

Place the following stages of eutrophication in the correct causal order: (i) dead algae are decomposed by bacteria, consuming dissolved oxygen; (ii) excess nitrogen and phosphorus enter the water body; (iii) hypoxia/anoxia develops and fish die; (iv) an algal bloom occurs.

(A) ii, iv, i, iii

(B) iv, ii, i, iii

(C) ii, i, iv, iii

(D) iii, ii, iv, i

Lời giải chi tiết

The correct causal chain is: nutrient input (ii) → algal bloom (iv) → bacterial decomposition consumes oxygen (i) → hypoxia/anoxia and fish kill (iii). **(A)**.

Bài tập luyện tập

Fertiliser runoff enters a river from hundreds of separate, unmonitored farms scattered across the watershed. This pollution is best classified as:

(A) Point source, and comparatively easy to regulate

(B) Non-point (diffuse) source, and comparatively difficult to regulate

(C) Thermal pollution

(D) Virtual water

Lời giải chi tiết

Pollution arising from numerous scattered, individually unidentifiable sources across a wide area is a non-point (diffuse) source, which is inherently harder to monitor and regulate than a single identifiable discharge. **(B)**.

Bài tập luyện tập

A water sample has a very high biochemical oxygen demand (BOD) compared with a nearby unpolluted sample. This indicates:

(A) Low organic matter content and high dissolved oxygen availability

(B) High organic matter content and reduced dissolved oxygen available to aquatic organisms

(C) High salinity only, with no effect on oxygen

(D) The presence of plastic debris only

Lời giải chi tiết

A high BOD means more oxygen is being consumed by microorganisms decomposing organic matter in the sample, which is only possible if the sample contains substantial organic pollution — and it directly implies less dissolved oxygen remains available for aquatic organisms. **(B)**.

Bài tập luyện tập

Two water samples are tested for BOD_5. Upstream of a sewage outfall: initial DO $= 9.0$ mg/L, DO after 5 days $= 7.8$ mg/L. Downstream of the outfall: initial DO $= 9.0$ mg/L, DO after 5 days $= 2.1$ mg/L. (a) Calculate the BOD_5 of each sample. (b) Interpret the difference.

Lời giải chi tiết

(a) Upstream: $BOD_5 = 9.0 - 7.8 = 1.2$ mg/L. Downstream: $BOD_5 = 9.0 - 2.1 = 6.9$ mg/L.

(b) The downstream BOD_5 (6.9 mg/L) is nearly six times higher than upstream (1.2 mg/L), indicating that the sewage outfall has introduced a substantial load of biodegradable organic matter into the river at that point, sharply increasing oxygen consumption by decomposer microorganisms and correspondingly reducing the dissolved oxygen available to fish and other aquatic life downstream of the discharge.

Bài tập luyện tập

A power plant discharges heated cooling water into a river. This thermal pollution primarily harms aquatic ecosystems because warmer water:

(A) Increases the solubility of dissolved oxygen, causing over-oxygenation

(B) Decreases the water's capacity to hold dissolved oxygen, stressing organisms adapted to cooler conditions

(C) Directly poisons fish with heavy metals

(D) Causes eutrophication by adding phosphorus to the water

Lời giải chi tiết

Dissolved oxygen solubility falls as water temperature rises, so heated discharge reduces the maximum oxygen the water can hold, stressing species adapted to cooler, more oxygen-rich conditions — without necessarily adding any new chemical substance. **(B)**.

Bài tập luyện tập

Classify each of the following as a point source or a non-point (diffuse) source of water pollution, and justify each answer: (a) a factory's single discharge pipe into a river; (b) fertiliser runoff from many separate farms across a watershed; (c) leaking septic tanks scattered across a large suburban area; (d) a municipal sewage treatment plant's outfall.

Lời giải chi tiết

(a) Point source — a single, identifiable, localized discharge that can be directly monitored and regulated.
(b) Non-point source — pollution arises from numerous, dispersed farms across a wide area, none individually identifiable as solely responsible, making regulation far harder.
(c) Non-point source — many scattered, individually small and hard-to-detect origins spread across a wide area, similar in character to diffuse agricultural runoff.
(d) Point source — a single, identifiable outfall from one facility, even though the facility itself serves many households; the discharge point itself is singular and directly regulable.

Bài tập luyện tập

Dissolved oxygen (DO) is measured at increasing distances downstream of a sewage outfall: 0 km: 8.0 mg/L; 2 km: 4.5 mg/L; 4 km: 2.0 mg/L; 6 km: 3.0 mg/L; 8 km: 5.5 mg/L; 10 km: 7.0 mg/L. (a) Identify the distance at which DO is lowest. (b) Explain why DO falls after the outfall and then gradually recovers further downstream.

Lời giải chi tiết

(a) DO is lowest at 4 km downstream (2.0 mg/L).

(b) Immediately after the sewage outfall, the sudden input of organic matter causes bacterial decomposition (aerobic respiration) to intensify, consuming dissolved oxygen faster than it can be replenished, so DO falls sharply over the first few kilometres, reaching a minimum (here at 4 km) — this pattern is often called an oxygen sag curve. Further downstream, the organic matter is progressively broken down and diluted, decomposer activity slows as the organic load is used up, and oxygen is continuously replenished by reaeration (mixing with air at the water surface, turbulence) and by photosynthesis from aquatic plants and algae — so DO gradually rises again, recovering toward its original upstream level as the river moves further from the source of pollution.

Soil Systems and Terrestrial Food Production Systems and Societies

Mục tiêu Unit: Đất như một hệ thống với đầu vào, đầu ra, kho chứa và các dòng chuyển hoá; phẫu diện đất và các tầng (O, A, B, C, R), mùn, phong hoá (vật lý, hoá học, sinh học) và vật liệu mẹ; thành phần đất (khoáng, chất hữu cơ, nước, không khí) và tam giác kết cấu đất (soil texture triangle) — cách đọc và ảnh hưởng của kết cấu đến năng suất sơ cấp, thoát nước, thấm, khả năng giữ nước, thoáng khí và giữ dưỡng chất; so sánh đất cát, sét và mùn (loam), độ phì và trao đổi cation; các hệ thống sản xuất lương thực trên cạn (tự cung tự cấp so với thương mại, thâm canh so với quảng canh), hiệu suất hệ thống, lựa chọn thực phẩm và ăn thấp trên chuỗi thức ăn; so sánh hiệu quả năng lượng và tác động môi trường của sản xuất trên cạn với dưới nước; suy thoái đất (xói mòn, mặn hoá, sa mạc hoá, mất cấu trúc, nhiễm độc) và các biện pháp bảo tồn đất.

5.1 Soil as a system

Soil is the thin, biologically active layer at the interface of the lithosphere, atmosphere, hydrosphere, and biosphere. It is far more than inert ground: soil is a dynamic, open **system** that can be analysed with exactly the systems vocabulary introduced in Chapter 1 — **inputs**, **outputs**, **storages**, and the **transfers** and **transformations** that move and change matter and energy within it.

5.1.1 Inputs, outputs, storages, transfers and transformations

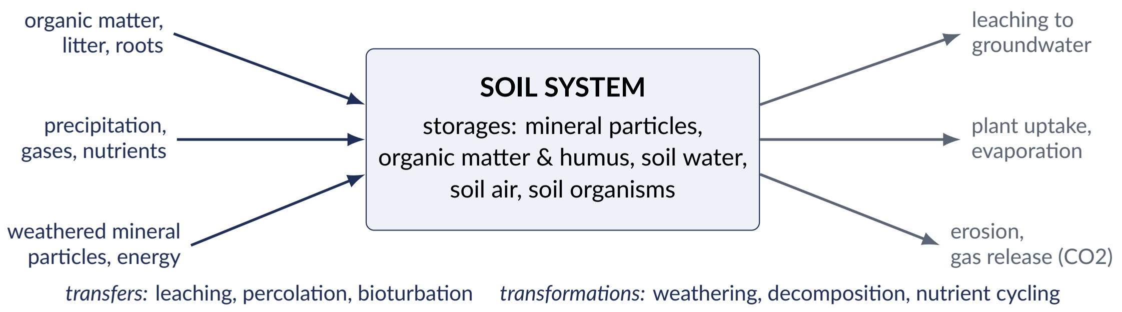
The soil system receives a set of characteristic **inputs**: organic matter (leaf litter, dead roots, animal remains, faeces), mineral particles derived from the weathering of **parent material**, precipitation and the dissolved gases and nutrients it carries, energy (solar heat and the chemical energy locked in organic matter), and living organisms that colonise it.

Its **outputs** include leaching losses of dissolved nutrients to groundwater, soil erosion (the physical removal of particles by wind and water), uptake of water and nutrients by plants, evaporation of water, and the release of gases such as CO2 and N2O from respiration and decomposition.

Between input and output, matter is held in **storages**: mineral particles, organic matter and humus, soil water (the soil solution), soil air in the pore spaces, and the pool of living organisms (the soil biota).

Material moves and changes through **transfers** (movement without a change of state or chemical form) and **transformations** (a change of state or chemical form):

- **Transfers:** leaching (downward washing of soluble material), the movement of water by infiltration and percolation, the biological mixing of particles by earthworms (bioturbation), and mass movement on slopes.
- **Transformations:** weathering of rock into mineral particles, decomposition of organic matter into humus, nutrient cycling (e.g. nitrogen fixation and nitrification), and the reactions that release nutrients into the soil solution.



The soil as an open system: inputs (left) and outputs (right) linked to internal storages; transfers move matter, transformations change it.

> **GIẢI THÍCH TIẾNG VIỆT**
> VN
> **Đất là một hệ thống mở.** **Đầu vào (inputs):** chất hữu cơ, mưa, khí, dưỡng chất, hạt khoáng từ phong hoá, và năng lượng. **Đầu ra (outputs):** rửa trôi (leaching), xói mòn, cây hấp thụ, bốc hơi, và khí thoát ra (CO_2). **Kho chứa (storages):** hạt khoáng, chất hữu cơ và mùn, nước đất, không khí trong đất, sinh vật đất. **Chuyển giao (transfers)** là di chuyển không đổi trạng thái (rửa trôi, thấm); **chuyển hoá (transformations)** là đổi trạng thái/dạng hoá học (phong hoá, phân huỷ, tuần hoàn dưỡng chất).

5.1.2 The soil ecosystem

A single teaspoon of fertile soil can contain billions of organisms. These **decomposers** (bacteria, fungi, actinomycetes) and **detritivores** (earthworms, mites, nematodes, insect larvae) break down dead organic matter, releasing nutrients back into the soil solution where plants can absorb them. This makes soil the engine of terrestrial nutrient cycling. Soil organisms also physically structure the soil: earthworm burrows increase aeration and drainage, and the sticky secretions of fungi and bacteria bind particles into stable **aggregates**, creating the crumb structure of a healthy soil.

> Soil forms extremely slowly. Under natural conditions it may take 100 years or more to form 1 cm of topsoil (roughly 200 years–1000 years per centimetre in many climates). For practical purposes soil is a **non-renewable resource** on a human timescale, which is why soil degradation is so serious.

5.2 The soil profile and horizons

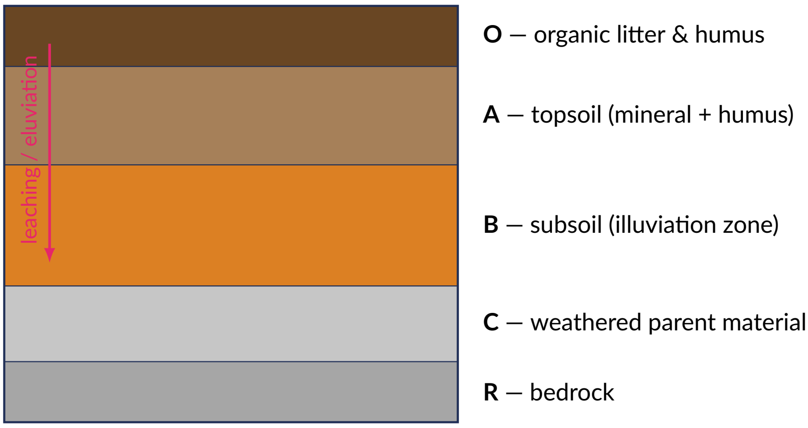
If you dig a pit through soil down to bedrock and look at the exposed vertical face, you see a sequence of roughly horizontal layers called **horizons**. The full sequence from surface to bedrock is the **soil profile**. Each horizon differs in colour, texture, and organic content because of the way material is added at the top, weathered from below, and washed downward by water.

5.2.1 The main horizons: O, A, B, C, R

- **O horizon (organic):** the surface layer of litter and partly decomposed organic matter — leaves, twigs, and **humus**. Dark, spongy, and rich in nutrients.
- **A horizon (topsoil):** a mixture of mineral particles and humus, dark and biologically active. Most root activity and biological life occur here. This is the layer lost first to erosion.
- **B horizon (subsoil):** the zone of **illuviation** — material leached (washed down) from above, such as clay, iron, and aluminium oxides, accumulates here. Usually lighter in colour, denser, and lower in organic matter.
- **C horizon:** weathered and broken **parent material** (regolith) that has not yet developed soil structure; the transition to solid rock.

- **R horizon (bedrock):** the unweathered solid rock (parent material) at the base of the profile.

The downward washing of soluble and fine material out of the A horizon is called **eluviation** (or **leaching**); its deposition lower down in the B horizon is **illuviation**.



A generalised soil profile. Organic matter is added at the top; water leaches fine and soluble material from the A horizon (eluviation) and deposits it in the B horizon (illuviation).

GIẢI THÍCH TIẾNG VIỆT

VN **Phẫu diện đất (soil profile)** gồm các tầng: **O** (chất hữu cơ, mùn), **A** (tầng đất mặt — khoáng trộn mùn, nhiều rễ và sinh vật, dễ bị xói mòn nhất), **B** (tầng tích tụ — nơi vật liệu bị rửa trôi từ trên xuống lắng lại), **C** (vật liệu mẹ đã phong hoá), và **R** (đá gốc). **Rửa trôi ra khỏi tầng A** gọi là eluviation; **lắng đọng ở tầng B** gọi là illuviation. **Mùn (humus)** là chất hữu cơ đã phân huỷ hoàn toàn, màu sẫm, giàu dưỡng chất, giữ nước và kết dính hạt đất.

5.2.2 Humus, weathering and parent material

Humus is the dark, colloidal end-product of the decomposition of organic matter. It is chemically stable, retains water, holds nutrients on its surface (it carries a negative charge), and binds mineral particles into aggregates. High humus content is a hallmark of fertile soil.

Parent material is the underlying rock or deposit from which the mineral fraction of the soil is derived. It is broken down by **weathering**, the in-situ breakdown of rock, which occurs by three mechanisms:

- **Physical (mechanical) weathering:** breaks rock into smaller pieces without changing its chemistry — e.g. freeze–thaw (frost shattering), thermal expansion and contraction, and abrasion.
- **Chemical weathering:** alters the chemical composition of minerals — e.g. carbonation (CO2 dissolved in rain forms weak carbonic acid that dissolves limestone), hydrolysis, and oxidation.
- **Biological weathering:** the breakdown of rock by living organisms — e.g. tree roots prising cracks apart, and organic acids from lichens and microbes dissolving minerals.

Carbonation of limestone, a classic chemical weathering reaction:

$$\mathrm{CaCO3} + \mathrm{H2O} + \mathrm{CO2} - > \mathrm{Ca}(\mathrm{HCO3})2$$

Calcium carbonate reacts with carbonic acid to form soluble calcium hydrogencarbonate, which is then washed away in solution.

5.3 Soil composition and texture

5.3.1 The four components of soil

A fertile mineral topsoil is, by volume, roughly **45% mineral particles**, **25% water**, **25% air**, and **5% organic matter**. The water and air share the **pore space** between solid particles; because they compete for the same space, a soil that is saturated with water is starved of air (and vice versa). The balance between water and air in the pore space is one of the most important properties of a soil for plant growth, because roots need both water and oxygen.

5.3.2 Mineral particle size: sand, silt and clay

The mineral fraction is classified by particle diameter:

- **Sand:** 0.05 mm–2.0 mm — large particles, large pore spaces.
- **Silt:** 0.002 mm–0.05 mm — intermediate.
- **Clay:** < 0.002 mm — microscopic particles, tiny pore spaces, huge total surface area.

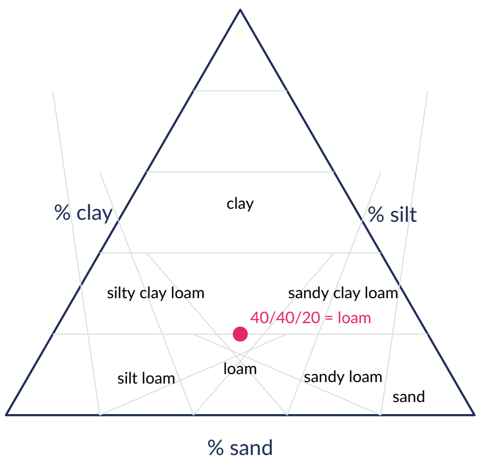
The relative proportions of sand, silt, and clay define a soil's **texture**. Texture governs almost every physical behaviour of a soil: how fast water infiltrates and drains, how much water it can hold for plants, how well it is aerated, and how well it retains nutrients.

> **Why particle size matters.** Small clay particles pack tightly, giving many *small* pores: slow drainage, high water-holding capacity, poor aeration, but a very large surface area that holds nutrients well. Large sand particles give few *large* pores: fast drainage and good aeration, but low water-holding capacity and poor nutrient retention.

5.3.3 Reading the soil texture triangle

The **soil texture triangle** is a chart used to name a soil's texture class from the percentages of sand, silt, and clay in its mineral fraction. Because the three percentages must sum to 100%, only two are independent, and any soil plots as a single point inside the triangle. To read it:

1. Each side of the triangle is a scale from 0 to 100% for one component: % clay up the left, % silt down the right, % sand along the base.
2. From the measured % clay, follow the grid line running *horizontally* across the triangle.
3. From the measured % sand, follow its grid line (running parallel to the right-hand side).
4. The point where the two lines cross falls inside a named region (e.g. "loam", "sandy clay", "silt loam"); read off that name. The third value (% silt) is fixed automatically because the three must total 100%.



Simplified soil texture triangle. Read % clay across horizontally, % sand along its own grid direction; where they cross gives the texture class. The marked point (40% sand, 40% silt, 20% clay) classifies as *loam*.

VN GIẢI THÍCH TIẾNG VIỆT

Tam giác kết cấu đất dùng để đặt tên loại đất theo % cát (sand), % limon/thịt (silt) và % sét (clay), tổng luôn bằng 100%. Đọc: theo % sét kẻ đường **ngang**; theo % cát kẻ đường song song với cạnh phải; giao điểm rơi vào vùng có tên (ví dụ "loam" — đất mùn/thịt pha). **Kết cấu** quyết định: năng suất sơ cấp, thoát nước (drainage), thấm (infiltration), khả năng giữ nước (water-holding capacity), thoáng khí (aeration) và giữ dưỡng chất (nutrient retention). Hạt sét nhỏ ⇒ lỗ nhỏ, giữ nước và dưỡng chất tốt nhưng thoát nước và thoáng khí kém; hạt cát lớn ⇒ ngược lại.

5.3.4 How texture affects soil behaviour

- **Drainage and infiltration:** large sand pores let water infiltrate and drain quickly; clay's tiny pores drain slowly and can waterlog.
- **Water-holding capacity:** clay holds the most water (large surface area, small pores retain water against gravity); sand holds the least.
- **Aeration:** sandy soils are well aerated; waterlogged clay soils are poorly aerated, starving roots of oxygen.
- **Nutrient retention:** clay and humus carry negative surface charges that hold positively charged nutrient ions (cations); sand retains few nutrients and loses them to leaching.
- **Primary productivity:** highest in soils that balance these properties — enough water and nutrient retention plus enough drainage and aeration. This is why **loam** (a balanced mix) generally supports the greatest plant growth.

5.4 Comparison of sand, clay and loam

Property	Sandy soil	Clay soil	Loam	Reason
Particle size	Large (0.05–2 mm)	Very small (< 0.002 mm)	Balanced mix	Defines pore size
Porosity	Moderate–high, large pores	High, tiny pores	Moderate, mixed	Packing of particles
Permeability / drainage	High (fast)	Low (waterlogs)	Moderate–good	Pore size controls flow
Infiltration rate	Fast	Slow	Moderate	Large pores admit water
Water-holding capacity	Low	High	Moderate–high	Small pores retain water
Aeration	Good	Poor when wet	Good	Air needs open pores
Nutrient retention	Poor (leaches)	High	High	Charged surfaces hold cations
Workability	Easy (light)	Hard (heavy, sticky)	Easy	Cohesion of clay

Comparison of the three reference soil types. Loam combines the drainage and aeration of sand with the water and nutrient retention of clay.

Why loam is best for agriculture. Loam — typically around 40% sand, 40% silt, 20% clay — holds enough water and nutrients for crops (from its clay and silt) while draining freely and staying well aerated (from its sand). It is also easy to work. It therefore supports the highest sustained primary productivity of the three and is the preferred soil for most arable farming.

VN GIẢI THÍCH TIẾNG VIỆT

Đất cát: thoát nước nhanh, thoáng khí tốt, dễ cày, nhưng giữ nước và dưỡng chất kém. **Đất**

sét: giữ nước và dưỡng chất tốt, nhưng thoát nước kém, dễ úng, khó cày. **Đất mùn (loam):** cân bằng cả hai — giữ đủ nước và dưỡng chất mà vẫn thoát nước và thoáng khí tốt, dễ canh tác, nên là loại đất nông nghiệp tốt nhất.

5.4.1 Soil fertility, nutrient cycling and cation exchange

Soil fertility is the capacity of a soil to supply the nutrients required for plant growth. It depends on the store of nutrients, the store of organic matter and humus, soil structure, pH, and the activity of soil organisms. Nutrients cycle through the soil: plants absorb ions from the soil solution, incorporate them into biomass, and return them when litter and dead organisms are decomposed by soil biota — the **soil nutrient cycle**.

Clay and humus particles (collectively the soil **colloids**) carry **negative** surface charges. These attract and hold positively charged nutrient ions — **cations** such as $K+$, Ca^2+, Mg^2+, and $NH4+$ — preventing them from leaching away. Plant roots release $H+$ ions that swap places with these held cations, releasing them into the soil solution for uptake. This process is **cation exchange**, and the total quantity a soil can hold is its **cation exchange capacity (CEC)**. Soils rich in clay and humus have a high CEC and therefore a high nutrient-holding capacity; sandy soils have a low CEC.

5.5 Terrestrial food production systems

A **food production system** (like any system) has inputs, outputs, storages, and flows, and can be judged by its **efficiency**. Terrestrial (land-based) systems vary enormously along two axes.

5.5.1 Subsistence versus commercial; intensive versus extensive

- **Subsistence farming:** food is grown mainly to feed the farmer's own family and local community, with little sold. Inputs are typically low (family labour, few purchased chemicals). Example: a smallholding growing rice, cassava, and vegetables.
- **Commercial farming:** food is produced to sell for profit, often for distant markets. Inputs of capital, machinery, fertiliser, and fossil-fuel energy are high. Example: a large cereal estate or a feedlot beef operation.
- **Intensive systems:** high inputs (of labour, capital, fertiliser, pesticides, or energy) per unit area to achieve a high yield per hectare. Example: intensive glasshouse horticulture, feedlot beef, battery poultry.
- **Extensive systems:** low inputs spread over a large area; yield per hectare is low but total output can be large. Example: extensive cattle ranching or nomadic pastoralism on rangeland.

System efficiency of a food production system compares useful output with the inputs required:

$$\text{energy efficiency} = \frac{\text{energy output (food energy produced)}}{\text{energy input (fuel, feed, fertiliser, labour)}}$$

A high value means much food energy is obtained per unit of energy invested. Traditional subsistence systems often have high *energy* efficiency (little fossil energy is used) but low yield per hectare; industrial systems have high yield per hectare but often low energy efficiency because of heavy fossil-fuel subsidies.

5.5.2 Commercial versus subsistence: a worked comparison

Consider **intensive commercial beef** in a feedlot versus **cereal farming**. The feedlot maximises meat output per animal using large inputs of grain, water, veterinary chemicals, and fossil energy; it has high yields per animal but low energy efficiency and a large environmental footprint per kilogram of food. Cereal farming converts sunlight, soil nutrients, and fertiliser directly into edible grain, feeding far more people per hectare for far less energy input. The contrast illustrates a general rule: **producing food further up the food chain (meat) is far more resource-costly than producing food lower down (crops).**

> **GIẢI THÍCH TIẾNG VIỆT**
> VN
> Hệ thống **tự cung tự cấp (subsistence)** trồng để ăn, đầu vào thấp, năng suất/ha thấp nhưng hiệu quả năng lượng cao. Hệ thống **thương mại (commercial)** trồng để bán, đầu vào (vốn, máy móc, phân bón, nhiên liệu) cao, năng suất/ha cao nhưng hiệu quả năng lượng thường thấp. **Thâm canh (intensive)** = đầu vào cao trên diện tích nhỏ; **quảng canh (extensive)** = đầu vào thấp trải trên diện tích lớn. Hiệu suất năng lượng = năng lượng thực phẩm thu được ÷ năng lượng đầu vào.

5.6 Food choice and efficiency

Recall from Chapter 2 that only about **10%** of the energy at one trophic level is passed to the next. When we eat plants (crops) directly we are feeding at the **second** trophic level; when we eat meat from animals that ate plants we feed at the **third** level, so roughly **90% of the original plant energy has already been lost** before it reaches us.

> **Eating lower on the food chain** (crops rather than meat) supports far more people per unit area and per unit energy, because it avoids the large energy loss between trophic levels. The same hectare that produces grain to feed people directly would feed far fewer people if the grain were first fed to livestock and the livestock then eaten.

The resource cost of meat is high on every measure:

- **Land:** producing 1 kg of beef protein can require *tens of times* more land than 1 kg of plant protein such as pulses.
- **Energy / feed:** beef typically needs on the order of 7 kg–10 kg of grain feed per 1 kg of live weight gain; poultry is far more efficient (roughly 2 kg–3 kg feed per kg).
- **Water:** producing 1 kg of beef can require thousands of litres of water — roughly ten times as much as 1 kg of cereal.

These are strong environmental arguments for diets richer in plants and lower in meat, especially ruminant meat.

5.7 Energy subsidies in food production

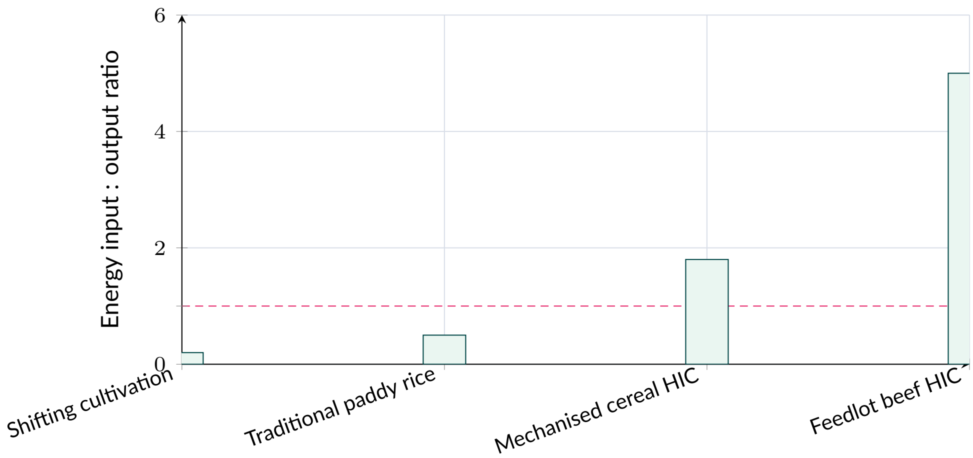
5.7.1 The energy-input-to-output ratio

Every food production system requires an **energy subsidy** — energy invested beyond the sunlight captured by the crop itself — to prepare land, plant, irrigate, protect against pests, harvest, process, and transport food. Systems differ enormously in how large this subsidy is relative to the food energy produced.

The **energy-input-to-output ratio** of a food production system is

$$\text{ratio} = \frac{\text{energy input (human/animal labour, fuel, fertiliser, machinery, transport, etc.)}}{\text{food energy output}}$$

A ratio *below* 1 means the system produces more food energy than the energy invested in it (an energy-positive system, typical of traditional, low-input agriculture); a ratio *above* 1 means more energy is invested than is recovered as food energy (an energy-subsidised system, typical of modern industrialised agriculture, where the "extra" energy comes overwhelmingly from fossil fuels used in machinery, synthetic fertiliser manufacture, irrigation pumping, processing, and transport).



Illustrative energy-input-to-output ratios (schematic). Traditional low-input systems fall below the ratio-1 line (energy-positive); industrialised systems, especially livestock produced further up the food chain, fall well above it (heavily energy-subsidised, chiefly by fossil fuels).

VN **GIẢI THÍCH TIẾNG VIỆT**

Trợ cấp năng lượng (energy subsidy) là năng lượng đầu tư thêm ngoài ánh sáng mặt trời mà cây trồng tự thu (nhiên liệu, phân bón, máy móc, tưới tiêu, vận chuyển). **Tỉ số năng lượng đầu vào/đầu ra** < 1: hệ thống tạo ra nhiều năng lượng thực phẩm hơn năng lượng bỏ vào (thường gặp ở nông nghiệp truyền thống, đầu vào thấp); > 1: đầu tư nhiều năng lượng hơn thu lại (thường gặp ở nông nghiệp công nghiệp hoá, phần năng lượng "thêm vào" chủ yếu đến từ nhiên liệu hoá thạch). Hệ thống thâm canh hiện đại có năng suất/ha rất cao nhưng thường có tỉ số này lớn hơn nhiều so với 1, đặc biệt với chăn nuôi (bậc dinh dưỡng cao).

Ví dụ mẫu · Comparing energy-input-to-output ratios

A traditional rice paddy system requires 3.2 MJ of human/animal labour and simple inputs per square metre per season and produces 6.4 MJ of food energy (rice grain) from the same area. A mechanised industrial cereal farm requires 18.0 MJ per square metre (fuel, machinery, synthetic fertiliser manufacture, irrigation pumping) and produces 10.0 MJ of food energy from the same area. Calculate the energy-input-to-output ratio for each system and state which is energy-positive.

Traditional paddy: ratio $= \dfrac{3.2}{6.4} = 0.5$. Since $0.5 < 1$, this system is **energy-positive**: it yields twice as much food energy as the energy invested.

Mechanised cereal farm: ratio $= \dfrac{18.0}{10.0} = 1.8$. Since $1.8 > 1$, this system is **energy-subsidised**: it invests almost twice as much energy (overwhelmingly fossil-fuel-derived) as it recovers as food energy, even though its food energy output per square metre is higher in absolute terms (10.0 vs 6.4 MJ m^{-2}).

This is the central paradox of industrialised agriculture: far higher yield per unit area is achieved only by supplying a large, mostly fossil-fuel energy subsidy, so that yield per hectare and energy efficiency move in *opposite* directions as farming intensifies.

GIẢI THÍCH TIẾNG VIỆT

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Nghịch lý trung tâm của nông nghiệp công nghiệp hoá: năng suất/ha cao hơn nhiều chỉ đạt được nhờ một lượng lớn năng lượng trợ cấp (chủ yếu từ nhiên liệu hoá thạch) — nghĩa là năng suất/ha và hiệu quả năng lượng thường **đi ngược chiều nhau** khi canh tác càng thâm canh.

5.8 Strategies for sustainable food production

Because industrial agriculture's high yields depend on a large, largely fossil-fuel energy subsidy and often accelerate soil degradation (Section 5.6), a range of alternative and complementary strategies aim to maintain productivity while reducing these environmental costs.

Organic farming avoids synthetic fertilisers and pesticides, relying instead on compost, manure, crop rotation, and biological pest control to maintain fertility and manage pests; it typically has a lower energy subsidy and less nutrient runoff than conventional farming, but often at a lower yield per hectare, so it requires more land to produce the same total output. **Integrated pest management (IPM)** combines biological control (natural predators/parasites of pests), resistant crop varieties, crop rotation, and *targeted*, minimal pesticide use only when needed, reducing both cost and the ecological damage (e.g. to pollinators and non-target species) associated with routine, broad-spectrum spraying. **Agroforestry** deliberately integrates trees or shrubs with crops or livestock on the same land, providing shade, wind protection, nitrogen fixation (where legume trees are used), and additional products (fruit, timber, fodder), while trees roots also reduce soil erosion.

GIẢI THÍCH TIẾNG VIỆT

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Nông nghiệp hữu cơ (organic farming): không dùng phân bón/thuốc trừ sâu tổng hợp, dựa vào phân hữu cơ, luân canh và kiểm soát sinh học — trợ cấp năng lượng thấp hơn, ít gây ô nhiễm dòng chảy hơn, nhưng năng suất/ha thường thấp hơn nên cần nhiều đất hơn để đạt cùng sản lượng. **Quản lí dịch hại tổng hợp (IPM)**: kết hợp kiểm soát sinh học, giống kháng sâu bệnh, luân canh và chỉ phun thuốc khi thực sự cần thiết — giảm chi phí và tác hại sinh thái (ví dụ với loài thụ phấn). **Nông lâm kết hợp (agroforestry)**: trồng cây gỗ/cây bụi xen với cây trồng/vật nuôi — che bóng, chắn gió, cố định đạm (nếu dùng cây họ đậu), giảm xói mòn và tạo thêm sản phẩm phụ.

Genetically modified (GM) crops have had their DNA directly altered (e.g. to resist a pest, tolerate a herbicide, or resist drought), with proponents citing higher and more reliable yields, reduced pesticide use for some pest-resistant varieties, and increased resilience to climate stress, and critics raising concerns about reduced crop genetic diversity (large areas planted with a single modified variety), the risk of modified genes spreading to wild relatives, corporate control over seed supply, and uncertain long-term ecological effects — an unresolved debate that mixes genuine scientific uncertainty with differing environmental value systems (Chapter 1).

Ví dụ mẫu · Comparing organic and conventional yield and land use

A conventional farm produces 8.0 tonnes of wheat per hectare using synthetic fertiliser and pesticides. A neighbouring organic farm, on otherwise identical land, produces 5.6 tonnes per hectare. To supply a fixed regional demand of $2{,}800$ tonnes of wheat, calculate the land area required under each system, and comment on the land-use trade-off this illustrates.

Conventional: area $= \dfrac{2{,}800}{8.0} = 350$ hectares. Organic: area $= \dfrac{2{,}800}{5.6} = 500$ hectares.
Meeting the same demand organically requires $500 - 350 = 150$ additional hectares (43% more land). This illustrates a genuine trade-off in sustainable food-production policy: organic farming reduces the energy subsidy and chemical runoff *per hectare*, but — at lower yield — requires proportionally more land to produce the same total food, which can in turn place greater pressure on natural habitat if that additional land is newly cleared.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ví dụ trên minh hoạ đánh đổi thực sự trong chính sách sản xuất thực phẩm bền vững: canh tác hữu cơ giảm trợ cấp năng lượng và ô nhiễm dòng chảy *trên mỗi ha*, nhưng do năng suất thấp hơn nên cần nhiều đất hơn để đạt cùng tổng sản lượng — có thể gây thêm áp lực lên môi trường tự nhiên nếu phần đất thêm đó phải khai hoang mới.

5.9 Terrestrial versus aquatic food production

Terrestrial and aquatic systems differ sharply in energy efficiency and environmental impact.

- **Trophic level harvested:** much terrestrial food is produced at the *second* trophic level (crops, and herbivorous livestock). Much marine food (e.g. tuna, salmon, cod) is harvested at the *third, fourth, or higher* trophic level — carnivorous fish — so far more of the original solar energy has been lost, making wild marine capture of top predators energetically inefficient as a way of feeding people.
- **Productivity per area:** the open ocean has low net primary productivity, but coastal upwellings and continental shelves are highly productive. On land, agriculture concentrates productivity through fertiliser and irrigation.
- **Environmental impact:** terrestrial systems drive deforestation, soil degradation, and fertiliser runoff; aquatic systems risk overfishing, bycatch, habitat destruction (e.g. trawling), and eutrophication from aquaculture. Aquaculture of *herbivorous* fish (e.g. carp, tilapia) is relatively efficient; farming *carnivorous* fish requires large inputs of wild-caught fishmeal, undermining the apparent efficiency.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ăn **thấp trên chuỗi thức ăn** (cây trồng thay vì thịt) nuôi được nhiều người hơn trên mỗi ha vì tránh mất ~90% năng lượng giữa các bậc dinh dưỡng. Thịt bò tốn nhiều đất, thức ăn (khoảng 7 kg–10 kg ngũ cốc/kg) và nước hơn cây trồng rất nhiều. Nhiều thực phẩm **trên cạn** thu ở bậc dinh dưỡng thấp (bậc 2), trong khi nhiều cá **biển** là loài ăn thịt ở bậc 3–4, nên đánh bắt kém hiệu quả về năng lượng. Nuôi cá ăn cỏ (rô phi, chép) hiệu quả hơn nuôi cá ăn thịt (cần bột cá từ cá đánh bắt).

5.10 Soil degradation

Soil degradation is the decline in soil quality and productivity caused by physical, chemical, or biological damage. Its main forms are:

- **Erosion:** the removal of topsoil by **water** (rain-splash, sheet, rill, and gully erosion) and **wind** (especially on bare, dry, flat land). Erosion strips away the nutrient-rich A horizon first.
- **Salinization:** the accumulation of salts in the topsoil, mainly from **over-irrigation** in hot climates — irrigation water rises by capillary action and evaporates, leaving salts behind that poison crops.
- **Desertification:** the degradation of drylands into desert-like conditions through a combination of overgrazing, deforestation, drought, and poor management, causing loss of vegetation and productive capacity.
- **Structure loss and compaction:** loss of aggregate structure and pore space (e.g. from heavy machinery or loss of organic matter), reducing infiltration and aeration.
- **Toxification:** the build-up of toxic substances — heavy metals, excess salts, or pesticide residues — that harm soil organisms and crops.

Causes are largely human: **overgrazing** (removes protective vegetation), **deforestation** (exposes soil to rain and wind), **over-irrigation** (salinization and waterlogging), and **monoculture** with intensive tillage (depletes nutrients and organic matter, leaving soil bare and structureless). **Consequences** include falling crop yields, food insecurity, sedimentation and eutrophication of rivers, loss of biodiversity, and, ultimately, land abandonment.

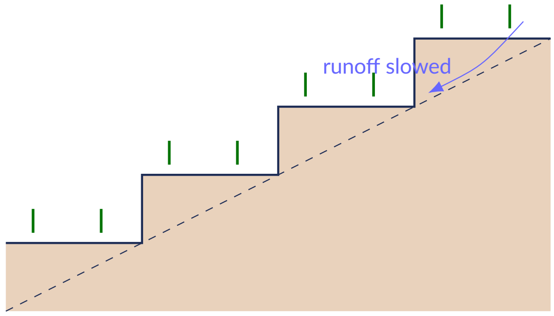
(!) Lỗi thường gặp: Do not confuse **leaching** (natural downward washing of soluble nutrients, part of normal soil function) with **erosion** (physical removal of whole soil particles from the surface). Both cause nutrient loss, but by different mechanisms. Likewise, **salinization** is a build-*up* of salt, not a washing-away.

5.11 Soil conservation

Soil conservation techniques counter degradation by protecting the surface, slowing water flow, and maintaining organic matter and structure:

- **Contour ploughing:** ploughing along the contours (across the slope, not up and down) so each furrow traps water and slows runoff, reducing water erosion.
- **Terracing:** cutting a steep slope into a staircase of level platforms, dramatically reducing slope length and runoff velocity on hillsides.
- **Wind breaks (shelter belts):** rows of trees or hedges that reduce wind speed at ground level, cutting wind erosion of exposed fields.
- **Cover crops:** planting a crop (e.g. clover, rye) to keep the soil covered between main crops, protecting it from rain and wind and adding organic matter.
- **Crop rotation:** alternating crops (especially including nitrogen-fixing legumes) to maintain fertility and reduce pest build-up and nutrient depletion.
- **No-till (conservation tillage):** leaving crop residues on the surface and not ploughing, preserving structure, organic matter, and soil life.

- **Bunds:** low earth or stone ridges built along contours to trap water and sediment.
- **Maintaining organic matter:** adding manure, compost, and residues to raise humus content, improving structure, water-holding capacity, and CEC.



Terracing: a steep slope (dashed) is cut into level platforms. Each terrace shortens the slope, slows runoff, and traps water and sediment, greatly reducing erosion.

GIẢI THÍCH TIẾNG VIỆT

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Bảo tồn đất: **cày theo đường đồng mức (contour ploughing)** và **ruộng bậc thang (terracing)** làm chậm dòng chảy, giảm xói mòn nước; **đai chắn gió (wind breaks)** giảm xói mòn gió; **cây che phủ (cover crops)**, **luân canh (crop rotation, gồm cây họ đậu cố định đạm)**, **không cày (no-till)**, **bờ chắn (bunds)** và **duy trì chất hữu cơ** giữ cấu trúc, độ phì và khả năng giữ nước của đất.

5.12 Worked examples

Ví dụ mẫu · Classifying a soil from the texture triangle

A soil sample's mineral fraction is measured as 40% sand, 40% silt, and 20% clay. Classify its texture.

Solution. First check the percentages sum to 100%: $40 + 40 + 20 = 100$ ✓ (so only two are independent). On the triangle, follow the 20% clay line horizontally and the 40% sand line; their intersection lies in the central region. A soil that is roughly two-fifths sand, two-fifths silt, one-fifth clay is a balanced mix and classifies as a **loam** — the texture generally best for agriculture.

Ví dụ mẫu · Reading a clay-rich sample

A sample contains 20% sand and 60% clay. What is the % silt, and roughly what class is it?

Solution. Silt $= 100 - 20 - 60 = 20\,\%$. With 60% clay dominating, the point sits high in the triangle in the **clay** region. Expect slow drainage, high water-holding capacity, poor aeration when wet, and high nutrient retention.

Ví dụ mẫu · Soil-loss (erosion) rate

A field of area 2.5 ha loses an estimated 30 tonnes of topsoil to erosion in one year. Express the erosion rate in tonnes per hectare per year, and compare it with a typical soil-formation rate of about 1 tonne per hectare per year.

Solution.

$$\text{rate} = \frac{30\ \text{t}}{2.5\ \text{ha}} = 12\ \text{t ha}^{-1}\ \text{yr}^{-1}.$$

This is about **12 times** faster than soil is formed, so the soil is being lost roughly an order of magnitude faster than it can be replaced — clearly unsustainable, and a case for conservation measures such as contour ploughing or cover crops.

Ví dụ mẫu · Depth of soil eroded

The eroded topsoil above has a bulk density of 1.2 tonnes per cubic metre. If 12 tonnes per hectare are lost in a year, what depth of soil is removed? (1 ha $= 10000\,\mathrm{m}^2$.)

Solution. Volume lost per hectare $= \dfrac{12\text{ t}}{1.2\text{ t m}^{-3}} = 10\text{ m}^3$. Spread over $10000\,\mathrm{m}^2$:

$$\text{depth} = \frac{10\text{ m}^3}{10000\text{ m}^2} = 0.001\text{ m} = 1\text{ mm}.$$

Losing 1 mm of topsoil per year is severe when 1 cm may take centuries to form.

Ví dụ mẫu · Feed-conversion efficiency of beef

A steer eats 7200 kg of grain over its life and yields 900 kg of live weight. Calculate the feed conversion ratio (FCR, kg feed per kg gain) and the conversion efficiency as a percentage.

Solution.

$$\text{FCR} = \frac{7200}{900} = 8\text{ kg feed per kg gain.}$$

Efficiency $= \dfrac{900}{7200} \times 100\% = 12.5\,\%$. Only about one-eighth of the feed mass ends up as animal, illustrating the large loss between trophic levels — consistent with the $\sim$10% rule.

Ví dụ mẫu · Comparing beef and poultry feed efficiency

Poultry has an FCR of about 2.0 while the beef above has FCR 8.0. How many kilograms of grain are needed to produce 50 kg of each meat, and which is more efficient?

Solution. Beef: $50 \times 8.0 = 400$ kg grain. Poultry: $50 \times 2.0 = 100$ kg grain. Poultry needs only one-quarter of the grain, so it is **four times more feed-efficient** than beef. Choosing poultry (or plants) over beef greatly reduces the land, feed, and energy cost of protein.

Ví dụ mẫu · Energy efficiency ratio of a food system

An intensive maize system yields 80 GJ of food energy per hectare but requires 25 GJ of fossil-fuel energy input (fuel, fertiliser, machinery). A subsistence maize plot yields 15 GJ using only 1.5 GJ of input (mostly human labour). Compare their energy efficiencies.

Solution.

$$\text{intensive: } \frac{80}{25} = 3.2; \qquad \text{subsistence: } \frac{15}{1.5} = 10.$$

The subsistence plot returns **10 units** of food energy per unit invested versus **3.2** for the intensive farm — it is far more energy-efficient, even though the intensive farm's yield *per hectare* is much higher (80 GJ vs 15 GJ). High yield and high energy efficiency are not the same thing.

Ví dụ mẫu · People supported per hectare — crops vs livestock

A hectare of land produces 12000 kg of grain per year. Route A: humans eat the grain directly, needing 200 kg grain-equivalent per person per year. Route B: the grain is fed to cattle at FCR 10 (10 kg grain per kg beef), and each person needs 40 kg of beef per year. How many people does each route feed?

Solution. Route A: $12000/200 =$ **60** people. Route B: beef produced $= 12000/10 = 1200$ kg; people fed $= 1200/40 =$ **30** people. Eating the grain directly feeds **twice** as many people from the same land, because feeding grain to cattle first wastes about 90% of its energy.

Ví dụ mẫu · Water cost of a diet choice

Producing 1 kg of beef uses about 15000 L of water; 1 kg of wheat uses about 1500 L. A person's weekly protein could come from 1 kg beef or 5 kg wheat. Which choice uses less water, and by how much?

Solution. Beef: $1 \times 15000 = 15000$ L. Wheat: $5 \times 1500 = 7500$ L. The wheat option uses **half** the water. Even after accounting for the larger mass of wheat needed, the plant source is far less water-intensive per unit of nutrition.

Ví dụ mẫu · Water-holding capacity comparison

Two 1 kg dry soil samples are saturated then drained. The sandy sample retains 150 g of water; the clay sample retains 450 g. Express each as gravimetric water content (% of dry mass) and interpret.

Solution.

$$\text{sand: } \frac{150}{1000} \times 100 = 15\,\%; \qquad \text{clay: } \frac{450}{1000} \times 100 = 45\,\%.$$

The clay holds three times as much water because its tiny pores retain water against gravity. However, much of that water is held so tightly it may be unavailable to plants, and the poor drainage risks waterlogging — which is why a *loam* (intermediate value) is usually preferred.

Ví dụ mẫu · Trophic energy loss and food choice

A crop fixes 10000 kJ of energy per square metre per year. Compare the food energy available to humans if they (a) eat the crop directly, or (b) eat herbivores that ate the crop, assuming 10% transfer efficiency between levels.

Solution. (a) Eating the crop, roughly 10% of 10000 kJ is passed on as usable production ≈ 1000 kJ. (b) Eating herbivores adds another 10% step: $10000 \times 0.10 \times 0.10 = 100$ kJ. The meat route delivers only **one-tenth** as much food energy, confirming that eating lower on the food chain supports far more people per unit area.

5.13 Practice problems

Bài tập luyện tập

Which soil horizon is the topsoil, richest in a mixture of humus and mineral particles and most vulnerable to erosion?

(A) O horizon
(B) A horizon
(C) B horizon
(D) C horizon

Lời giải chi tiết

(B) The A horizon is the topsoil: a dark, biologically active mix of mineral particles and humus, with most roots and soil life. It is the first layer removed by erosion. (The O horizon above is purely organic litter; the B horizon is the subsoil illuviation zone.)

Bài tập luyện tập

A soil sample is 30% sand, 50% silt, and 20% clay. Show that these are self-consistent and state which single measurement would have been enough to deduce the third value.

Lời giải chi tiết

The three sum to $30 + 50 + 20 = 100\%$, as they must. Because the total is fixed at 100%, only *two* of the three are independent; measuring any two (say sand and clay) fixes the third automatically (silt $= 100 -$ sand $-$ clay). This is exactly why a two-dimensional triangle can represent three variables.

Bài tập luyện tập

Define the terms **transfer** and **transformation** as applied to a soil system, giving one example of each.

Lời giải chi tiết

A **transfer** moves matter without changing its state or chemical form — e.g. leaching of dissolved ions from the A to the B horizon, or earthworms mixing particles. A **transformation** changes the state or chemical form of matter — e.g. weathering of rock into mineral particles, or decomposition of litter into humus.

Bài tập luyện tập

Which statement about clay soils is correct?

(A) They drain quickly and are well aerated
(B) They have large pores and low water-holding capacity
(C) They retain water and nutrients well but drain poorly
(D) They have a low cation exchange capacity

Lời giải chi tiết

(C) Clay's tiny particles create many small pores and a large charged surface area, giving high water-holding capacity, high nutrient retention (high CEC), but slow drainage and poor aeration when wet. Options A, B, and D describe sandy soils.

Bài tập luyện tập

A 4 ha field loses 48 tonnes of topsoil in a year. Calculate the erosion rate in tonnes per hectare per year and state whether it exceeds a formation rate of 1 tonne per hectare per year.

Lời giải chi tiết

rate $= 48/4 = 12$ t ha^{-1} yr^{-1}, which is 12 times the formation rate of 1 tonne per hectare per year. The soil is being lost far faster than it forms — unsustainable.

Bài tập luyện tập

Explain, using the 10% rule, why a hectare of land feeds more people if it grows grain for humans than if the grain is fed to cattle for beef.

Lời giải chi tiết

Only about 10% of the energy at one trophic level passes to the next. Eating grain directly puts humans one step from the producers, so most of the crop's energy is available. Feeding grain to cattle first, then eating the cattle, adds a trophic step at which $\sim$90% of the energy is lost to respiration, movement, and inedible tissue. Hence the land supports far more people (roughly ten times) when crops are eaten directly.

Bài tập luyện tập

Distinguish between **intensive** and **extensive** food production systems, giving one example of each.

Lời giải chi tiết

Intensive systems use high inputs (labour, capital, fertiliser, or energy) per unit area for a high yield per hectare — e.g. feedlot beef or glasshouse tomatoes. **Extensive** systems use low inputs spread over a large area, giving low yield per hectare but potentially large total output — e.g. extensive cattle ranching or nomadic pastoralism.

Bài tập luyện tập

A pig farm feeds 300 kg of feed to gain 100 kg of live weight. Calculate the feed conversion ratio and the percentage conversion efficiency.

Lời giải chi tiết

FCR $= 300/100 = 3.0$ kg feed per kg gain. Efficiency $= 100/300 \times 100\% = 33.3\,\%$. Pigs are more efficient than beef (FCR ≈ 8) but less than the theoretical direct consumption of crops.

Bài tập luyện tập

Which weathering process is described by the reaction CaCO3 $+$ H2O $+$ CO2$-$ $>$ Ca(HCO3)2?

(A) Physical (freeze–thaw)

(B) Chemical (carbonation)

(C) Biological (root action)

(D) Erosion by wind

Lời giải chi tiết

(B) This is chemical weathering by **carbonation**: CO2 dissolved in rain forms weak carbonic acid that reacts with calcium carbonate in limestone to form soluble calcium hydrogencarbonate, which is washed away.

Bài tập luyện tập

Define **soil salinization** and explain how over-irrigation in a hot climate causes it.

Lời giải chi tiết

Salinization is the accumulation of soluble salts in the topsoil. Irrigation water contains dissolved salts. In a hot climate, water applied in excess raises the water table and is drawn upward by capillary action to the surface, where it evaporates and leaves its salts behind. Over time salt concentrates in the root zone, damaging crops and lowering fertility.

Bài tập luyện tập

An intensive farm produces 60 GJ of food energy per hectare using 20 GJ of input energy. A traditional farm produces 12 GJ using 2 GJ. Calculate each energy efficiency ratio and comment.

Lời giải chi tiết

Intensive: $60/20 = 3.0$. Traditional: $12/2 = 6.0$. The traditional farm is twice as energy-efficient (6 units out per unit in) even though the intensive farm yields five times more food energy per hectare. High yield does not imply high energy efficiency; industrial systems are subsidised by large fossil-fuel inputs.

Bài tập luyện tập

Why is loam generally the best soil texture for arable agriculture? Refer to at least three specific properties.

Lời giải chi tiết

Loam is a balanced mix of sand, silt, and clay, so it combines the best of each: (i) good drainage and aeration (from sand) so roots get oxygen and the soil does not waterlog; (ii) high water-holding capacity (from silt and clay) so crops have a reserve of moisture; (iii) high nutrient retention and CEC (from clay and humus) so fertiliser is not leached away; and (iv) it is easy to work. These together give the highest sustained primary productivity.

Bài tập luyện tập

Which soil conservation technique is best suited to reducing **water** erosion on a steep hillside?

(A) Wind breaks

(B) Terracing

(C) Adding sand

(D) Deep ploughing up and down the slope

Lời giải chi tiết

(B) Terracing cuts a steep slope into level platforms, shortening the slope length and slowing runoff so that water infiltrates rather than eroding. Wind breaks address wind erosion; ploughing up and down a slope *increases* water erosion.

Bài tập luyện tập

Explain what **cation exchange capacity (CEC)** is and why sandy soils have a low CEC.

Lời giải chi tiết

CEC is the total quantity of exchangeable cations (K$+$, Ca$^2+$, Mg$^2+$, NH4$+$) that a soil can hold on its negatively charged colloid surfaces (clay and humus). These held cations are protected from leaching and released to plant roots by exchange with H$+$. Sandy soils contain little clay or humus, so they have little negatively charged surface area and therefore a low CEC — they retain few nutrients and leach easily.

Bài tập luyện tập

Producing 1 kg of beef uses about 15000 L of water; 1 kg of potatoes uses about 290 L. How many times more water does the beef require, per kilogram?

Lời giải chi tiết

$15000/290 \approx 51.7$. Beef requires roughly **52 times** more water per kilogram than potatoes, one of many reasons plant foods have a smaller environmental footprint.

Bài tập luyện tập

List the four components of a fertile mineral topsoil by volume, with approximate percentages, and explain why water and air percentages are inversely related.

Lời giải chi tiết

Approximately 45% mineral particles, 25% water, 25% air, and 5% organic matter. Water and air both occupy the *pore space* between solids, so they compete for the same volume: when the soil is wetter, water fills more pores and displaces air (risking anaerobic, waterlogged conditions); when drier, air fills them. Hence their percentages vary inversely.

Bài tập luyện tập

A hectare produces 9000 kg of grain. If eaten directly, each person needs 180 kg per year; if converted to beef at FCR 12 and each person needs 25 kg beef per year, how many people does each route feed?

Lời giải chi tiết

Direct: $9000/180 =$ **50** people. Beef route: beef $= 9000/12 = 750$ kg; people $= 750/25 =$ **30** people. Eating grain directly feeds 20 more people (67% more) from the same land.

Bài tập luyện tập

Why is harvesting large carnivorous marine fish (e.g. tuna) an energetically inefficient way to feed people compared with harvesting crops on land?

Lời giải chi tiết

Tuna feed at the third, fourth, or higher trophic level. Because only ~10% of energy passes between levels, by the time energy reaches a top marine predator, well over 99% of the original solar energy captured by phytoplankton has been lost. Crops are harvested at the second trophic level, so far more of the fixed solar energy remains, making crop production a far more energy-efficient way to feed people per unit of primary production.

Bài tập luyện tập

Distinguish between **eluviation (leaching)** and **illuviation** in a soil profile.

Lời giải chi tiết

Eluviation (leaching) is the downward washing of soluble and fine material (clay, ions, iron/aluminium oxides) *out of* the upper (A) horizon by percolating water. **Illuviation** is the *deposition* of that material lower down, in the B horizon. Together they explain why the B horizon accumulates clay and oxides while the A horizon can become depleted.

Bài tập luyện tập

Identify two human causes of desertification and outline one consequence.

Lời giải chi tiết

Causes (any two): **overgrazing** (livestock strip protective vegetation), **deforestation** (removes tree cover), **over-cultivation/monoculture** (exhausts soil and leaves it bare), and **poor irrigation** (salinization). A consequence: loss of vegetation and topsoil lowers productivity and water retention, so the land can no longer support crops or people, leading to food insecurity and abandonment or migration.

Bài tập luyện tập

A clay soil retains 500 g of water per 1 kg dry soil; a loam retains 300 g; a sand retains 120 g. Rank them by gravimetric water content and explain why loam is nonetheless often preferred by farmers.

Lời giải chi tiết

Water contents: clay $= 50\%$, loam $= 30\%$, sand $= 12\%$; ranking clay $>$ loam $>$ sand. Although clay holds the most water, much is bound too tightly for plants to use and it drains poorly and waterlogs. Loam holds a good reserve of *plant-available* water while still draining freely and staying aerated, so it usually gives better crop growth — water-holding capacity alone is not the whole story.

Bài tập luyện tập

Which of the following best explains why maintaining soil organic matter improves soil quality?

(A) It increases particle size to sand

(B) It lowers the cation exchange capacity

(C) It improves structure, water-holding capacity, and nutrient retention

(D) It speeds up erosion

Lời giải chi tiết

(C) Organic matter (humus) binds particles into stable aggregates (better structure and aeration), holds water, and provides negatively charged surfaces that retain nutrient cations (raising CEC). It therefore improves structure, water-holding capacity, and nutrient retention — the opposite of options A, B, and D.

Bài tập luyện tập

Compare the environmental impacts of intensive terrestrial livestock farming with those of intensive aquaculture of carnivorous fish. Give one shared and one distinct impact.

Lời giải chi tiết

Shared: both cause nutrient pollution/eutrophication — runoff of manure and fertiliser from livestock, and waste and uneaten feed from fish cages, enriching water with N and P. **Distinct:** intensive livestock drives land-based impacts such as deforestation and soil/land degradation and high greenhouse-gas emissions (methane from ruminants), whereas carnivorous aquaculture depends on wild-caught fishmeal, adding pressure on wild fish stocks and marine food webs. Both undermine their own apparent efficiency.

Bài tập luyện tập

Explain how contour ploughing and cover crops each reduce soil erosion, and why combining them with maintaining organic matter is especially effective.

Lời giải chi tiết

Contour ploughing runs furrows across the slope so each furrow acts as a small barrier that traps water and slows runoff, cutting water erosion. **Cover crops** keep a living plant canopy and root network over the soil between main crops, shielding the surface from rain-splash and wind and binding particles with roots. Combined with **maintaining organic matter**, which builds stable aggregates and raises water-holding capacity and infiltration, the three reinforce one another: less runoff, better-protected and better-bound soil, and a structure that resists detachment — so erosion is minimised while fertility is preserved.

Bài tập luyện tập

A traditional shifting-cultivation plot requires 1.5 MJ of human labour per square metre per season and yields 4.5 MJ of food energy. A neighbouring mechanised plantation requires 22.0 MJ per square metre (fuel, machinery, fertiliser) and yields 13.2 MJ of food energy. Calculate the energy-input-to-output ratio for each and state which is energy-positive.

Lời giải chi tiết

Shifting cultivation: ratio $= 1.5/4.5 = 0.33$ — since below 1, this system is **energy-positive**, producing three times more food energy than the energy invested. Mechanised plantation: ratio $= 22.0/13.2 = 1.67$ — since above 1, this system is **energy-subsidised**, consuming more energy than it yields as food, despite a much higher absolute food output per square metre (13.2 vs 4.5 MJ m^{-2}).

Bài tập luyện tập

State one advantage and one disadvantage of integrated pest management (IPM) compared with routine, broad-spectrum pesticide spraying.

Lời giải chi tiết

Advantage: IPM applies pesticide only when a pest population actually threatens the crop (using biological control, resistant varieties and monitoring first), so it reduces both cost and collateral ecological damage — for example, to pollinators and other non-target species that are killed by routine spraying regardless of whether a pest outbreak is actually occurring. **Disadvantage:** IPM requires more monitoring, expertise, and management time than simply spraying on a fixed schedule, and biological control agents can take longer to bring an outbreak under control than an immediate chemical application.

Bài tập luyện tập

Explain why genetically modified (GM) crops remain a debated strategy for sustainable food production, referring to both a potential benefit and a potential concern.

Lời giải chi tiết

A potential **benefit**: GM crops can be engineered for pest resistance, herbicide tolerance, or drought tolerance, potentially raising and stabilising yields (and, for some pest-resistant varieties, reducing pesticide applications). A potential **concern**: planting large areas with a single modified variety can reduce crop genetic diversity (Chapter 3), modified genes may spread to wild relative populations through cross-pollination, and control over seed supply can become concentrated among a small number of companies. The debate is not purely a factual/scientific one — it also reflects differing environmental value systems (Chapter 1) about acceptable levels of human intervention in agricultural genetics.

Atmospheric Systems and Society

Mục tiêu Unit: Cấu trúc và thành phần của khí quyển ($N_2 \approx 78\%$, $O_2 \approx 21\%$, argon, CO_2, khí vết, hơi nước) và các tầng khí quyển (đối lưu, bình lưu, trung lưu, nhiệt lưu) cùng hồ sơ nhiệt độ theo độ cao; khí quyển như một hệ động và một kho chứa, thời gian lưu trú (residence time) của chất ô nhiễm; sự hình thành và phá huỷ tầng ôzôn bình lưu (chu trình Chapman), vai trò chắn tia UV, chất phá huỷ ôzôn (CFC, halon), chu trình xúc tác của clo, lỗ thủng ôzôn và thành công của Nghị định thư Montreal; phân biệt ôzôn bình lưu bảo vệ với ôzôn tầng đối lưu gây ô nhiễm; khói quang hoá (chất ô nhiễm sơ cấp so với thứ cấp, vai trò của NO_x, VOC và ánh sáng mặt trời, hiện tượng nghịch nhiệt); và lắng đọng axit (khô và ướt) — nguồn SO_2 và NO_x, tác động lên đất, nước ngọt, thực vật, công trình, và các chiến lược quản lí.

6.1 Structure and composition of the atmosphere

6.1.1 Composition of dry air

The **atmosphere** is the thin envelope of gases held to the Earth by gravity. It is a comparatively small store of matter — its entire mass is a millionth of the Earth's mass — yet it regulates surface temperature, filters harmful radiation, and supplies the gases on which life depends. Treated in the systems language of Chapter 1, the atmosphere is a **store** through which materials continually **flow**: gases enter and leave through biological, chemical, and human processes.

By volume, **dry air** near the surface has a remarkably constant composition:

- **Nitrogen** (N_2) — $\approx 78\%$; a relatively inert gas that dilutes oxygen and is fixed by lightning and micro-organisms into biologically useful forms.
- **Oxygen** (O_2) — $\approx 21\%$; the product of photosynthesis and the reactant of aerobic respiration and combustion.
- **Argon** (Ar) — $\approx 0.93\%$; a chemically inert noble gas.
- **Carbon dioxide** (CO_2) — $\approx 0.04\%$ (about 420 ppm and rising); a trace greenhouse gas central to the carbon cycle and to climate (Chapter 7).
- **Trace gases** — neon, helium, methane (CH_4), krypton, hydrogen, nitrous oxide (N_2O), and ozone (O_3), each present in tiny amounts but several of which are radiatively or chemically important.

Superimposed on this dry mixture is **water vapour** (H_2O), whose concentration is *variable* — from almost zero over cold deserts to about 4% by volume in warm, humid air. Because water vapour condenses and precipitates, it is excluded when the "fixed" percentages above are quoted; those figures describe dry air.

Roughly 99% of dry air is just two gases: nitrogen ($\approx 78\%$) and oxygen ($\approx 21\%$). Everything else — argon, carbon dioxide, and all the trace gases combined — makes up only about 1%, yet this last 1% contains the greenhouse gases and ozone that dominate the atmosphere's environmental behaviour.

GIẢI THÍCH TIẾNG VIỆT

VN

Không khí khô có thành phần gần như cố định theo thể tích: **nitơ** (N_2) $\approx 78\%$, **oxi** (O_2) $\approx 21\%$,

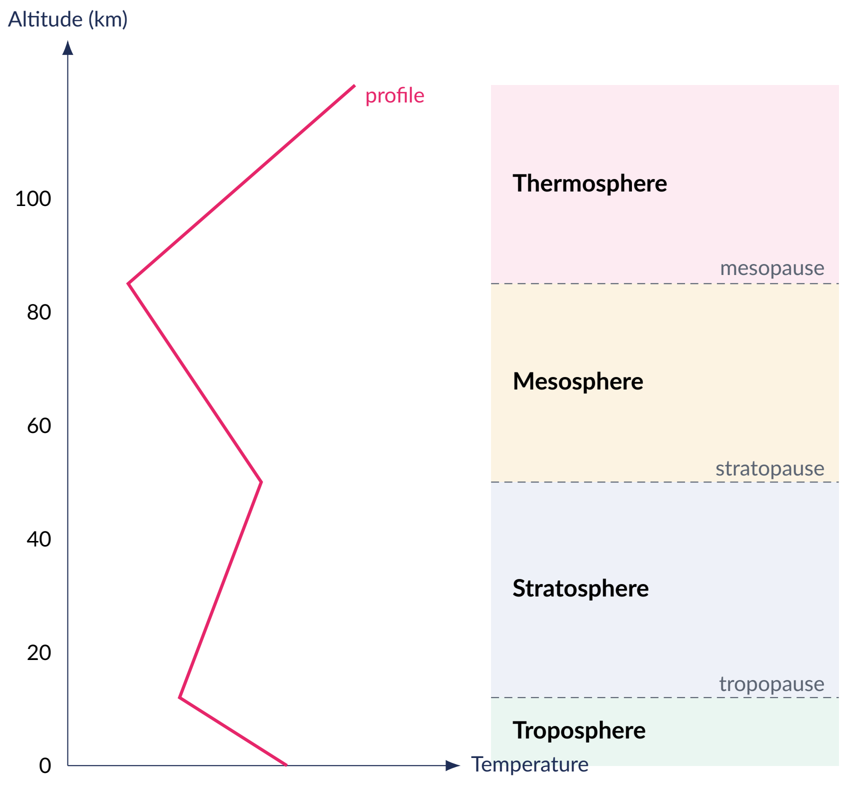
argon $\approx 0{,}93\%$, $CO_2 \approx 0{,}04\%$ (khoảng 420 ppm), cùng các **khí vết** (metan, N_2O, ôzôn, neon, heli...). **Hơi nước** (H_2O) thay đổi từ gần 0 đến $\approx 4\%$ nên không được tính vào các phần trăm "cố định". Hai khí N_2 và O_2 chiếm $\approx 99\%$; nhưng 1% còn lại chứa các khí nhà kính và ôzôn — những khí quyết định hành vi môi trường của khí quyển.

6.1.2 Vertical structure: the four layers

Because gas is compressible and gravity pulls it downward, the atmosphere is densest at the surface and thins rapidly with height — about half of its entire mass lies below 5.5 km. It is divided into four principal **layers**, distinguished not by composition (which is well mixed up to about 80 km) but by how **temperature changes with altitude**. At each boundary the temperature trend reverses; the boundaries are named with the suffix *-pause*.

- **Troposphere** (0 to ≈ 12 km) — the lowest layer, where nearly all weather and almost all water vapour occur. Temperature *falls* with height (the environmental lapse rate, on average about $6.5\,^{\circ}$C per km) because the layer is heated from below by the sun-warmed surface. Its upper boundary is the **tropopause**.
- **Stratosphere** (≈ 12 to 50 km) — temperature *rises* with height. This inversion is caused by the **ozone layer** absorbing ultraviolet radiation and releasing heat. The stable, non-convecting air makes this the cruising altitude of jet aircraft. Its top is the **stratopause**.
- **Mesosphere** (≈ 50 to 85 km) — temperature *falls* again, reaching the coldest temperatures in the atmosphere (below $-90\,^{\circ}$C). Meteors burn up here. Its top is the **mesopause**.
- **Thermosphere** (≈ 85 km upward) — temperature *rises* steeply as the sparse gas absorbs high-energy solar X-rays and UV. The aurorae and low-orbit satellites occur here; it grades into space.

The **tropopause** matters especially: it acts as a lid on convection, trapping weather and pollutants within the troposphere and preventing tropospheric water vapour from reaching the stratosphere.



Vertical structure of the atmosphere. The pink line is the temperature profile: temperature falls through the troposphere, rises through the stratosphere (ozone heating), falls through the mesosphere, and rises through the thermosphere. Each reversal marks a *-pause* boundary. Altitude and temperature axes are schematic.

GIẢI THÍCH TIẾNG VIỆT

VN

Khí quyển chia thành bốn tầng theo **cách nhiệt độ biến đổi theo độ cao**: **tầng đối lưu (troposphere,** 0–12 **km)** nhiệt độ *giảm* theo độ cao (chứa hầu hết thời tiết và hơi nước); **tầng bình lưu (stratosphere,** 12–50 **km)** nhiệt độ *tăng* do tầng ôzôn hấp thụ UV; **tầng trung lưu (mesosphere,** 50–85 **km)** nhiệt độ *giảm* (lạnh nhất, $< -90\,^\circ$C); **tầng nhiệt lưu (thermosphere,** > 85 **km)** nhiệt độ *tăng* mạnh. Ranh giới giữa các tầng có đuôi *-pause*; **tropopause** là "nắp" giữ thời tiết và chất ô nhiễm trong tầng đối lưu.

6.1.3 The atmosphere as a dynamic system and a store

The atmosphere is a **dynamic system**: energy from the Sun drives convection, winds, and the water cycle, so the atmosphere continually mixes and redistributes heat, moisture, and gases around the planet. It is also a **store** for gases that enter from natural and human sources and leave through sinks such as photosynthesis, dissolution in the ocean, chemical reaction, and deposition.

For any substance in the atmospheric store, its **residence time** τ measures how long, on average, a molecule remains before it is removed:

$$\tau = \frac{M}{F}$$

where M is the total mass (or amount) of the substance stored in the atmosphere and F is the rate at which it is removed (or, at steady state, the rate at which it is added). Substances with *long* residence times spread globally and their effects are shared worldwide (for example CO_2 and long-lived CFCs); substances with *short* residence times stay near their sources and cause local or regional problems (for example ground-level ozone and many particulates).

Residence time is the single most useful idea for understanding *where* a pollutant does damage. A gas that survives for decades is carried around the globe by winds long before it is removed, so it becomes a **global** problem; a gas removed within hours or days cannot travel far and remains a **local** or at most **transboundary** (regional) problem.

GIẢI THÍCH TIẾNG VIỆT

VN

Khí quyển vừa là **hệ động** (năng lượng Mặt Trời tạo ra gió, đối lưu, chu trình nước), vừa là **kho chứa** khí. **Thời gian lưu trú (residence time)** $\tau = M/F$ cho biết một phân tử tồn tại bao lâu trước khi bị loại bỏ. Chất có τ *dài* (như CO_2, CFC) lan ra toàn cầu ⇒ vấn đề toàn cầu; chất có τ *ngắn* (như ôzôn tầng thấp) ở gần nguồn ⇒ vấn đề địa phương/khu vực.

Ví dụ mẫu · Residence time and scale of impact

A pollutant is emitted into the atmosphere at a steady rate. At steady state the atmospheric store holds $M = 5.4 \times 10^6$ tonnes and the removal rate is $F = 1.8 \times 10^6$ tonnes per year. (a) Find the residence time. (b) A second pollutant has $M = 8.0 \times 10^3$ t and $F = 2.9 \times 10^6$ t yr^{-1}; find its residence time in days. (c) State which is more likely to be a *global* problem.

Solution. (a) $\tau = \dfrac{M}{F} = \dfrac{5.4 \times 10^6}{1.8 \times 10^6} = 3.0$ years.

(b) $\tau = \dfrac{8.0 \times 10^3}{2.9 \times 10^6} = 2.76 \times 10^{-3}$ yr $\times\ 365 \approx 1.0$ day.

(c) The first pollutant ($\tau = 3$ yr) survives long enough for winds to spread it worldwide, so it is the more likely **global** problem. The second ($\tau \approx 1$ day) is removed near its source and causes

local pollution.

6.2 Global atmospheric circulation

6.2.1 Unequal heating and the drive for circulation

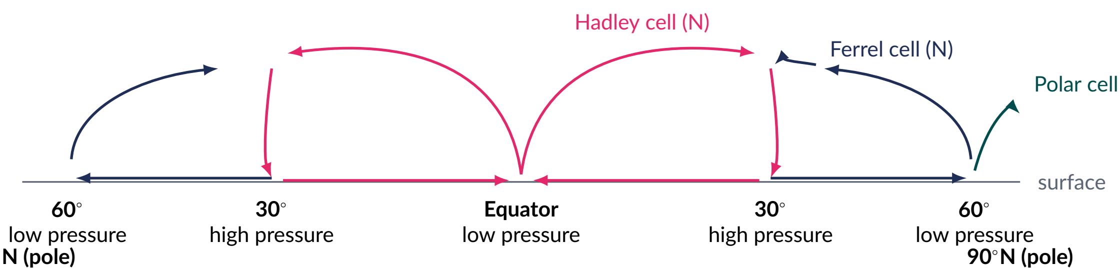
The atmosphere circulates because the Sun heats the Earth's surface **unevenly**. Near the equator, sunlight strikes the surface almost directly and travels through less atmosphere, so equatorial regions receive far more solar energy per unit area, averaged over the year, than the poles, where sunlight arrives at a shallow angle, is spread over a larger surface area, and (for part of the year) does not arrive at all. This latitudinal imbalance in incoming solar energy (**insolation**) would, if uncorrected, make the tropics ever hotter and the poles ever colder. Instead, the atmosphere (together with ocean currents) continuously transports surplus heat from the tropics toward the poles, acting as a giant heat-redistribution engine and preventing runaway divergence in temperature between latitudes.

> The basic physical principle is simple: warm air is less dense and rises (creating a region of relatively **low pressure** at the surface below it); cool air is denser and sinks (creating relatively **high pressure** at the surface below it). Because air moves from high pressure to low pressure, these rising and sinking columns of air, linked by surface and upper-level winds, organise into large, repeating circulation cells rather than one simple pole-to-equator flow.

6.2.2 The three-cell model

The simplified **three-cell model** divides atmospheric circulation in each hemisphere into three linked cells:

- **Hadley cell** (0–30°): intense heating at the equator causes strong convective uplift, producing a belt of low pressure and heavy convectional rainfall (driving the equatorial/tropical rainforest biome of Chapter 2). The risen air spreads poleward at high altitude, cools, and sinks back to the surface at about 30° latitude, creating a belt of high pressure, descending, warming, drying air — explaining why most of the world's major hot deserts (Sahara, Arabian, Australian) sit close to 30°N/S.
- **Ferrel cell** (30–60°): a weaker, indirectly driven mid-latitude cell, sandwiched between and partly dragged along by the Hadley and Polar cells. Surface air flows poleward from the 30° high-pressure belt toward 60°, where it meets cold polar air at the **polar front** and is forced to rise, producing a belt of low pressure and the changeable, frontal rainfall typical of temperate latitudes.
- **Polar cell** (60–90°): cold, dense air sinks at the poles (a belt of high pressure), flows toward 60° at the surface, rises at the polar front, and returns poleward aloft.



The three-cell circulation model (Northern Hemisphere half shown schematically): Hadley cells (equator–30°), Ferrel cells (30–60°) and Polar cells (60–90°) link belts of alternating low and high surface pressure.

VN GIẢI THÍCH TIẾNG VIỆT

Khí quyển tuần hoàn vì Mặt Trời sưởi ấm bề mặt Trái Đất **không đều** theo vĩ độ — xích đạo nhận nhiều năng lượng hơn hai cực. Không khí ấm bốc lên tạo áp thấp; không khí lạnh chìm xuống tạo áp cao. **Mô hình ba tế bào**: **tế bào Hadley** (0–$30°$) — không khí bốc lên mạnh ở xích đạo (áp thấp, mưa nhiều, rừng mưa nhiệt đới), di chuyển về $30°$ rồi chìm xuống (áp cao, khô — giải thích vì sao các sa mạc lớn nằm gần $30°$B/N); **tế bào Ferrel** (30–$60°$) — tế bào trung gian yếu hơn, không khí bề mặt di chuyển từ $30°$ về $60°$, gặp front cực và bốc lên (áp thấp, mưa front ôn đới); **tế bào cực** (60–$90°$) — không khí lạnh chìm ở cực (áp cao), di chuyển về $60°$ rồi bốc lên.

Ví dụ mẫu · Linking pressure belts to biome distribution

Using the three-cell model, explain why the Sahara Desert (roughly 23–$30°$N) is extremely dry, while equatorial rainforest of the Congo Basin (close to $0°$) is extremely wet, even though both regions receive strong, near-year-round sunshine.

Both regions lie within the tropics and receive intense solar heating, but their position within the Hadley cell differs decisively. The **Congo Basin** sits near the equator, in the zone of strongest convective uplift: intense heating causes warm, moist air to rise rapidly, cool, and condense, producing the persistent, heavy convectional rainfall that sustains rainforest. The **Sahara** sits near $30°$N, where that same air — having lost most of its moisture through condensation and rainfall near the equator — descends back to the surface as part of the Hadley cell. This descending air **warms adiabatically as it sinks** (increasing its capacity to hold moisture rather than release it) and produces a persistent belt of high pressure with almost no rainfall. The two regions differ not because one receives more sunlight than the other, but because of where each sits relative to the rising (wet) or sinking (dry) limb of the same Hadley circulation.

VN GIẢI THÍCH TIẾNG VIỆT

Rừng mưa Congo và sa mạc Sahara đều nhận nắng mạnh quanh năm, nhưng khác nhau ở vị trí trong tế bào Hadley: Congo nằm ở **nhánh bốc lên** (xích đạo) — không khí ẩm bốc lên, ngưng tụ, mưa nhiều; Sahara nằm ở **nhánh chìm xuống** ($\approx 30°$B) — không khí đã mất ẩm lại chìm xuống, nóng lên đoạn nhiệt, khô hanh. Khác biệt không phải do lượng nắng mà do vị trí trong cùng một vòng tuần hoàn Hadley.

(!) Lỗi thường gặp: Do not describe descending air within a high-pressure belt (e.g. at $30°$ latitude) as "cold air sinking". The air sinking at $30°$ is air that rose at the equator and has already lost most of its moisture; as it descends, it is compressed and **warms** (adiabatic warming), which is precisely why $30°$ high-pressure belts are hot, dry deserts rather than cold ones — the "high pressure" here refers to a stable, subsiding air mass, not necessarily to a region of stable cold air as in mid-latitude weather forecasts.

6.3 Stratospheric ozone

6.3.1 Formation and destruction: the Chapman cycle

About 90% of all atmospheric ozone lies in the **stratosphere**, forming the **ozone layer** (peak concentration ≈ 20–30 km up). Ozone (O_3) is continuously *created* and *destroyed* by ultraviolet radiation. The set of natural reactions was worked out by Sydney Chapman and is called the **Chapman cycle**:

1. **Photodissociation of oxygen** — high-energy UV splits an oxygen molecule into two free oxygen atoms:

$$O_2 + UV \rightarrow O + O$$

2. **Ozone formation** — each free atom combines with an oxygen molecule (with a third body M carrying away excess energy) to form ozone:

$$O + O_2 \rightarrow O_3$$

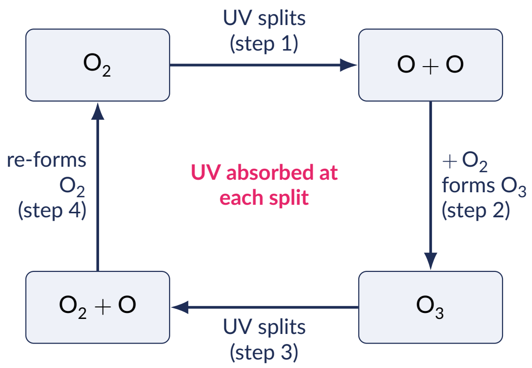
3. **Ozone destruction** — UV is absorbed by ozone, splitting it back into a molecule and an atom:

$$O_3 + UV \rightarrow O_2 + O$$

4. **Recombination** — a free atom and an ozone molecule may react to give two oxygen molecules:

$$O + O_3 \rightarrow 2\,O_2$$

In an unpolluted stratosphere, formation (steps 1–2) and destruction (steps 3–4) are in **dynamic equilibrium**, so a steady amount of ozone is maintained. Crucially, both step 1 and step 3 *absorb ultraviolet radiation*: it is this continual making and breaking of ozone that removes harmful UV before it reaches the surface.



The Chapman cycle. Oxygen and ozone are continually interconverted; the two UV-absorbing steps (1 and 3) are what shield the surface. Under natural conditions creation and destruction balance, holding ozone at a steady level.

> **GIẢI THÍCH TIẾNG VIỆT**
> VN
> **Chu trình Chapman** mô tả sự tạo thành và phá huỷ ôzôn bình lưu: (1) $O_2 + UV \rightarrow O + O$; (2) $O + O_2 \rightarrow O_3$; (3) $O_3 + UV \rightarrow O_2 + O$; (4) $O + O_3 \rightarrow 2\,O_2$. Ở khí quyển sạch, tạo thành và phá huỷ **cân bằng động**, giữ lượng ôzôn ổn định. Hai bước hấp thụ UV (1 và 3) chính là cơ chế **chắn tia cực tím** cho bề mặt Trái Đất.

6.3.2 The ozone layer as a UV shield

Ultraviolet radiation is divided by wavelength into UV-A, UV-B, and the most energetic UV-C. The Chapman reactions absorb essentially all UV-C and most UV-B. This matters because UV-B is absorbed by **DNA**: it causes mutations that lead to **skin cancers** (including malignant melanoma), **cataracts** (clouding of the eye lens), suppression of the immune system, and damage to the surface tissues of plants and to phytoplankton at the base of marine food chains. A thinner ozone layer therefore means more UV-B at the surface and measurably higher rates of these harms.

> The ozone layer is beneficial because it absorbs ultraviolet radiation — especially UV-B, which damages DNA. Reduced stratospheric ozone increases surface UV-B, raising the incidence of skin cancer and cataracts and harming plants and phytoplankton.

6.3.3 Ozone-depleting substances and the catalytic chlorine cycle

The natural balance is upset by **ozone-depleting substances (ODS)** — most importantly **chlorofluorocarbons (CFCs)**, once used as refrigerants, aerosol propellants, foam-blowing agents, and solvents, and **halons** (bromine-containing fire-extinguishing agents). CFCs are chemically inert and insoluble, so they are *not* removed in the troposphere; they have very long residence times and drift up into the stratosphere over years.

There, intense UV finally breaks them apart, liberating a **chlorine atom** (Cl). This atom destroys ozone **catalytically**: it is regenerated at the end of each cycle and so destroys ozone molecule after ozone molecule.

$$\mathrm{Cl} + \mathrm{O_3} \rightarrow \mathrm{ClO} + \mathrm{O_2}$$

$$\mathrm{ClO} + \mathrm{O} \rightarrow \mathrm{Cl} + \mathrm{O_2}$$

Adding the two steps, the net reaction is $O_3 + O \rightarrow 2\,O_2$: the ozone and a free oxygen atom are consumed, but the Cl atom emerges *unchanged*, ready to attack another O_3. A single chlorine atom can destroy on the order of 10^5 ozone molecules before it is finally removed (for example by forming stable "reservoir" species such as HCl). This catalytic amplification is why tiny concentrations of CFCs cause large ozone losses.

> **(!) Lỗi thường gặp:** Do not say the chlorine atom is "used up." It is a **catalyst** — consumed in step 1 but *regenerated* in step 2, so it is available again. That regeneration is exactly why one Cl atom destroys so many O_3 molecules.

> VN **GIẢI THÍCH TIẾNG VIỆT**
> **Chất phá huỷ ôzôn (ODS): CFC** (chất làm lạnh, chất đẩy bình xịt) và **halon** (chữa cháy). CFC trơ, không tan nên có τ rất dài, trôi lên bình lưu; UV tách ra **nguyên tử clo (Cl)**. Cl phá huỷ ôzôn theo cơ chế **xúc tác**: $\mathrm{Cl} + \mathrm{O_3} \rightarrow \mathrm{ClO} + \mathrm{O_2}$ rồi $\mathrm{ClO} + \mathrm{O} \rightarrow \mathrm{Cl} + \mathrm{O_2}$. Nguyên tử Cl được *tái tạo* nên một nguyên tử có thể phá $\sim 10^5$ phân tử O_3.

Ví dụ mẫu · Net effect of the chlorine catalytic cycle

Write the two steps of the chlorine catalytic cycle and add them to find the net reaction. Explain what happens to the Cl atom and estimate how many ozone molecules 2.0×10^{-3} mol of Cl atoms could destroy if each atom cycles 1.0×10^5 times.

Solution. Step 1: $\mathrm{Cl} + \mathrm{O_3} \rightarrow \mathrm{ClO} + \mathrm{O_2}$. Step 2: $\mathrm{ClO} + \mathrm{O} \rightarrow \mathrm{Cl} + \mathrm{O_2}$.
Adding, ClO cancels and Cl appears on both sides and cancels:

$$\mathrm{O_3} + \mathrm{O} \rightarrow 2\,\mathrm{O_2}.$$

The Cl atom is a **catalyst**: consumed then regenerated, so it is not used up. Number of Cl atoms $= 2.0 \times 10^{-3} \times 6.02 \times 10^{23} = 1.20 \times 10^{21}$. Multiplying by 1.0×10^5 cycles gives $\approx 1.2 \times 10^{26}$ ozone molecules destroyed — illustrating the enormous catalytic leverage of a small amount of chlorine.

6.3.4 The ozone hole and the Montreal Protocol

Each Antarctic spring, a severe seasonal thinning — the **ozone hole** — appears over the South Pole. It forms because the extreme cold of the polar winter creates **polar stratospheric clouds** on whose ice surfaces chlorine is converted into forms that, when sunlight returns in spring, release a burst of ozone-destroying Cl. The isolated **polar vortex** concentrates the effect.

The international response was the **Montreal Protocol** (1987), which set a binding, staged **phase-out** of CFCs and other ODS, with financial and technical support to help developing countries switch to substitutes (initially HCFCs and HFCs). It is widely regarded as the **most successful global environmental agreement**: production of the main ODS has fallen by over 98%, atmospheric chlorine loading has peaked and is declining, and the ozone layer is projected to recover to its 1980 levels around the middle of the 21st century. Its success rested on strong scientific consensus, the availability of substitutes, near-universal ratification, and its flexible, tightening structure.

> The Montreal Protocol succeeded because: (i) the science was clear and agreed; (ii) affordable substitutes existed; (iii) it bound almost every nation and tightened over time; and (iv) it helped poorer nations comply. The ozone layer is now recovering — direct evidence that coordinated international action can reverse an atmospheric problem.

VN **GIẢI THÍCH TIẾNG VIỆT**

Lỗ thủng ôzôn xuất hiện trên Nam Cực vào mùa xuân do mây bình lưu vùng cực (polar stratospheric clouds) và xoáy cực (polar vortex) làm giải phóng ồ ạt Cl. **Nghị định thư Montreal (1987)** quy định lộ trình **loại bỏ** CFC/halon, hỗ trợ nước đang phát triển chuyển sang chất thay thế. Đây là hiệp định môi trường **thành công nhất**: sản lượng ODS giảm $> 98\%$, tầng ôzôn đang phục hồi (dự kiến về mức 1980 vào giữa thế kỉ 21).

6.4 Tropospheric ozone: ``good up high, bad nearby"

The same molecule, O_3, plays opposite roles at different altitudes. In the **stratosphere** it is a natural, protective UV shield. But at **ground level (in the troposphere)** ozone is a harmful **secondary pollutant**: a strong oxidising gas that irritates the respiratory system, aggravates asthma and bronchitis, damages plant leaves and reduces crop yields, and is itself a greenhouse gas. Ground-level ozone is not emitted directly; it is manufactured by sunlight from other pollutants (Section 6.4). Hence the memorable summary: ozone is **"good up high, bad nearby."**

	Stratospheric ozone	Tropospheric (ground-level) ozone
Altitude	≈ 15–30 km (ozone layer)	0–≈ 12 km, at the surface
Origin	Natural (Chapman cycle)	Secondary pollutant from NO_x + VOCs + sunlight
Role	Beneficial — absorbs UV-B	Harmful — respiratory & plant damage
Concern	Its *depletion* (too little)	Its *formation* (too much)
Value judgement	"Good up high"	"Bad nearby"

Same molecule, opposite significance: stratospheric ozone protects; tropospheric ozone pollutes.

VN **GIẢI THÍCH TIẾNG VIỆT**

Cùng một phân tử O_3 nhưng ý nghĩa trái ngược theo độ cao. Ở **tầng bình lưu**: tự nhiên, **có lợi** (chắn UV-B). Ở **mặt đất (tầng đối lưu)**: **chất ô nhiễm thứ cấp có hại**, gây kích ứng hô hấp và hại cây trồng. Khẩu quyết: "good up high, bad nearby" — trên cao thì tốt, dưới thấp thì hại.

6.5 Photochemical smog

6.5.1 Primary and secondary pollutants

A **primary pollutant** is emitted *directly* from a source into the atmosphere in a harmful form. A **secondary pollutant** is *not* emitted directly; it forms in the atmosphere when primary pollutants react, often driven by sunlight. **Photochemical smog** is a brown haze of secondary pollutants formed over cities on warm, sunny days.

The key ingredients are **primary** pollutants from combustion, chiefly in vehicle engines:

- **Nitrogen oxides** (NO_x, **i.e.** NO **and** NO_2) — formed when the high temperature of combustion makes atmospheric N_2 and O_2 react.
- **Volatile organic compounds (VOCs)** — unburnt or partly burnt hydrocarbons from fuel and solvents.

Given **sunlight**, these react to produce the harmful **secondary** pollutants: **ground-level ozone** (O_3) and **peroxyacetyl nitrates (PANs)**, together with aldehydes and fine particulates.

6.5.2 The reaction chain

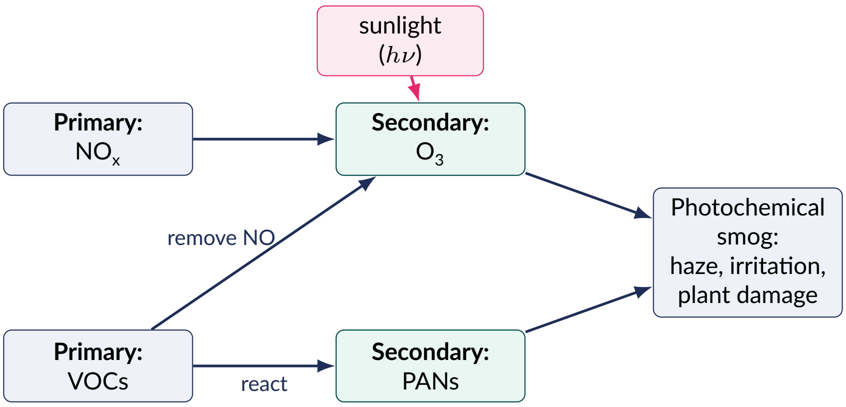
The essential photochemistry can be summarised in three linked steps. Sunlight (hν) splits nitrogen dioxide:

$$NO_2 + h\nu \rightarrow NO + O$$

the free oxygen atom then makes ozone:

$$O + O_2 \rightarrow O_3$$

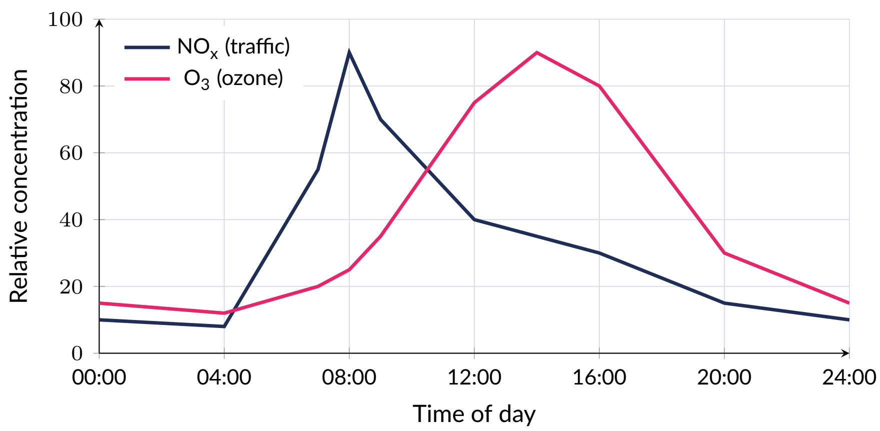
On its own this ozone would quickly be destroyed by NO ($NO + O_3 \rightarrow NO_2 + O_2$), giving no net build-up. The role of the **VOCs** is to react with and remove the NO by other pathways, regenerating NO_2 *without* consuming ozone. This lets O_3 accumulate and also produces **PANs**, powerful eye irritants. The result is high daytime ozone that peaks in the afternoon when sunlight is strongest.



Photochemical-smog reaction chain. Primary pollutants (NO_x, VOCs) plus sunlight generate secondary pollutants (O_3, PANs); VOCs let ozone accumulate by removing the NO that would otherwise destroy it.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chất ô nhiễm sơ cấp (primary) thải trực tiếp; **thứ cấp (secondary)** hình thành trong khí quyển do phản ứng. **Khói quang hoá (photochemical smog)** = NO_x + VOC + **ánh sáng mặt trời** → O_3 và **PAN** (chất thứ cấp). VOC loại bỏ NO nên ôzôn tích tụ lại. Smog gây mù nâu, kích ứng mắt/hô hấp, hại cây trồng, mạnh nhất vào buổi chiều nắng.



Schematic diurnal pattern in a smog-prone city: NO_x peaks sharply with the morning traffic rush (≈08:00), while O_3 peaks later (≈14:00), after sunlight has had time to drive the photochemical reactions that consume NO_x and generate ozone.

Ví dụ mẫu · Explaining the time lag between NO_x and O_3 peaks

Using the figure, explain why the ozone concentration peaks several hours *after* the morning NO_x peak, rather than at the same time.

Lời giải chi tiết

NO_x is a **primary** pollutant, emitted directly by morning rush-hour traffic, so its concentration rises and peaks quickly, tracking traffic volume almost immediately. Ozone, however, is a **secondary** pollutant that must first be *manufactured* by a chain of sunlight-driven reactions (Section 6.4) acting on the NO_x and VOCs already present. This photochemistry takes time to proceed and requires strong sunlight, which itself increases through the morning and peaks around midday to early afternoon. The ozone concentration therefore lags behind the primary NO_x peak, reaching its own maximum only once several hours of intense sunlight have driven the reaction chain far enough — a graph-reading pattern (primary pollutant peaks early, secondary pollutant peaks later in the same day) that is common to many photochemical smog datasets.

VN **GIẢI THÍCH TIẾNG VIỆT**

NO_x là chất ô nhiễm **sơ cấp**, thải trực tiếp từ giao thông giờ cao điểm buổi sáng nên tăng và đạt đỉnh gần như ngay lập tức. Ôzôn là chất ô nhiễm **thứ cấp**, cần thời gian để hình thành qua chuỗi phản ứng quang hoá dưới ánh nắng — ánh nắng mạnh nhất vào khoảng giữa trưa đến đầu giờ chiều, nên đỉnh ôzôn luôn xuất hiện **trễ hơn** đỉnh NO_x vài giờ. Đây là một dạng đọc đồ thị thường gặp trong đề thi IB về khói quang hoá.

6.5.3 Temperature inversions and geography

Normally, air temperature falls with height, so warm surface air (carrying pollutants) rises and disperses. A **temperature inversion** reverses this: a layer of warm air sits *above* cooler surface air. Because the cool surface air is denser, it cannot rise through the warm lid, so pollutants are **trapped** near the ground and their concentrations climb — often to hazardous levels overnight and in the early morning.

Inversions and smog are worst where **topography** and **climate** conspire: cities in **basins or valleys** ringed by hills (Los Angeles, Mexico City, Santiago) where cool air pools and stagnant high-pressure, sunny weather prevents mixing. Dense traffic supplies the NO_x and VOCs; abundant sunshine drives the photochemistry.

Ví dụ mẫu · Reasoning about a temperature inversion

On a calm, clear night a rising weather balloon records $8\,^\circ$C at the surface, $11\,^\circ$C at 200 m, and $9\,^\circ$C at 600 m. (a) Between which heights is there an inversion? (b) Explain, in terms of air density, why this traps pollutants. (c) State one topographic setting that worsens the effect.

Solution. (a) Temperature *rises* from $8\,^\circ$C (surface) to $11\,^\circ$C (200 m): an **inversion** exists between the surface and ≈ 200 m. Above 200 m temperature falls again ($11 \to 9\,^\circ$C), which is normal.
(b) In the inversion layer, cooler surface air is **denser** than the warm air above it. Denser air cannot rise through the lighter warm "lid," so vertical mixing stops and pollutants emitted at the surface accumulate instead of dispersing.

(c) A **valley or basin** surrounded by hills, where cold dense air drains and pools and hills block horizontal winds, intensifies and prolongs the inversion.

6.5.4 Effects and management

Photochemical smog harms **health** (eye irritation, coughing, reduced lung function, aggravated asthma and cardiovascular disease) and **plants** (ozone damages leaf tissue, reduces photosynthesis, and cuts crop yields), while reducing visibility. Management follows the general model of altering human activity, then regulating the pollutant, then cleaning up:

- **Alter the activity** (most effective) — reduce vehicle use through public transport, cycling, congestion charging, and urban planning; switch to electric vehicles and cleaner fuels.
- **Regulate the release** — emissions standards and **catalytic converters** that reduce NO_x and unburnt hydrocarbons at source; fuel-vapour controls on VOCs.
- **Clean up / adapt** (least effective) — smog alerts, restricting activity on high-ozone days, planting tolerant vegetation.

GIẢI THÍCH TIẾNG VIỆT
VN
Nghịch nhiệt (temperature inversion): lớp không khí ấm nằm *trên* lớp lạnh sát mặt đất; không khí lạnh đặc hơn không bốc lên được nên chất ô nhiễm bị **giữ lại**. Nặng nhất ở các thành phố nằm trong **thung lũng/bồn địa** nắng nhiều. Quản lí theo thứ tự ưu tiên: **thay đổi hoạt động** (giảm xe cá nhân, xe điện) > **kiểm soát phát thải** (bộ chuyển đổi xúc tác) > **khắc phục** (cảnh báo smog).

6.6 Acid deposition

6.6.1 Sources and formation

Acid deposition is the return to the surface of acidifying pollutants originally released as **sulfur dioxide** (SO_2) and **nitrogen oxides** (NO_x). The main sources are the **combustion of fossil fuels**: SO_2 from burning sulfur-bearing coal and oil (power stations, smelters) and NO_x from high-temperature combustion in power stations and vehicle engines.

In the atmosphere these gases are oxidised and dissolve in water to form strong acids:

$$\mathrm{SO_2} + \tfrac{1}{2}\,\mathrm{O_2} + \mathrm{H_2O} \rightarrow \mathrm{H_2SO_4} \quad \text{(sulfuric acid)}$$

$$2\,\mathrm{NO_2} + \tfrac{1}{2}\,\mathrm{O_2} + \mathrm{H_2O} \rightarrow 2\,\mathrm{HNO_3} \quad \text{(nitric acid)}$$

Deposition takes two forms. **Wet deposition** is the acids falling dissolved in rain, snow, or fog ("acid rain," typically pH 4–5, versus about 5.6 for natural rain made slightly acidic by dissolved CO_2). **Dry deposition** is the acidic gases and particles settling directly onto surfaces, later dissolving when wetted — this dominates near the source, while wet deposition carries the problem far downwind.

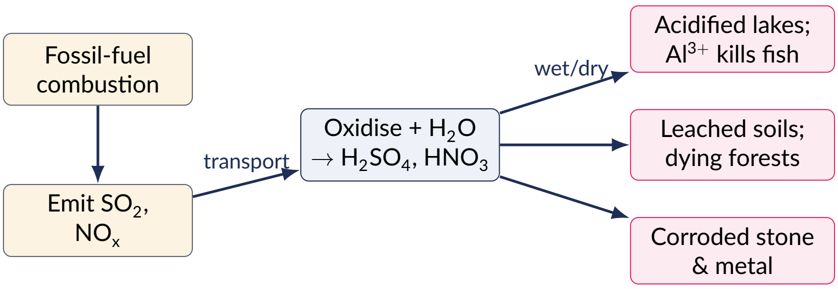
Natural rain is already mildly acidic ($\approx$ pH 5.6) because CO_2 dissolves to form carbonic acid. "Acid rain" means rain made *more* acidic (pH below ≈ 5) by H_2SO_4 and HNO_3 derived from SO_2 and NO_x.

6.6.2 Effects: direct and indirect

Acid deposition acts both **directly** (damaging what it lands on) and **indirectly** (changing soil and water chemistry, which then harms organisms):

- **Freshwater** — lakes and streams acidify; below about pH 5 fish eggs fail and populations collapse. Crucially, acidity **mobilises aluminium** from soils and rock into the water; dissolved Al^{3+} clogs fish gills and is toxic — an *indirect* effect often more lethal than the acidity itself.
- **Soils** — acids leach away essential nutrient cations (calcium, magnesium, potassium), lowering fertility, and release toxic aluminium and heavy metals.
- **Vegetation** — *direct* damage to leaf cuticles and needles, plus *indirect* damage as nutrient-poor, aluminium-rich soils weaken and kill trees (notably conifer forests).
- **Buildings and materials** — acids react with and dissolve **limestone and marble** ($CaCO_3$) and corrode metals, damaging buildings and monuments.

Because the pollutants can travel hundreds of kilometres before deposition, acid deposition is a **transboundary** problem: emissions in one country fall as acid in another, so it requires international cooperation (for example between countries in Europe and in North America).



Acid deposition from source to effect. SO_2 and NO_x from combustion are oxidised to H_2SO_4 and HNO_3, transported across borders, then deposited (wet or dry) — acidifying water and soil, mobilising toxic aluminium, damaging forests, and corroding buildings.

> VN **GIẢI THÍCH TIẾNG VIỆT**
>
> **Lắng đọng axit** bắt nguồn từ SO_2 (đốt than/dầu chứa lưu huỳnh) và NO_x (đốt cháy nhiệt độ cao), bị oxi hoá và hoà tan thành H_2SO_4 và HNO_3. **Ướt (wet)** = mưa/tuyết/sương axit; **khô (dry)** = khí/hạt lắng trực tiếp. Tác động *trực tiếp* (hại lá, ăn mòn đá vôi $CaCO_3$) và *gián tiếp* (axit hoá nước hồ, **giải phóng nhôm** Al^{3+} độc giết cá, rửa trôi dưỡng chất trong đất, làm chết rừng). Đây là vấn đề **xuyên biên giới**.

6.6.3 Management

Management again follows three levels: **alter human activity** (energy conservation, renewable energy, and low-sulfur fuels reduce the pollutants at the root — the most effective); **clean or regulate the release** (**flue-gas desulfurisation**/scrubbers on power-station chimneys, catalytic converters on vehicles, international emission-reduction treaties); and **restore/clean up** (liming acidified lakes and soils with powdered limestone to neutralise acidity — treating the symptom, not the cause).

Ví dụ mẫu · Interpreting the pH of acid rain

Natural rainwater has pH 5.6. A sample of polluted rain has pH 4.0. (a) Find the hydrogen-ion concentration $[H^+]$ of each. (b) By what factor is the polluted rain more acidic? (c) Name the two acids chiefly responsible and their precursor gases.

Solution. (a) Using $[H^+] = 10^{-\text{pH}}$: natural rain $[H^+] = 10^{-5.6} = 2.5 \times 10^{-6}$ mol dm^{-3}; polluted rain $[H^+] = 10^{-4.0} = 1.0 \times 10^{-4}$ mol dm^{-3}.

(b) Ratio $= \dfrac{10^{-4.0}}{10^{-5.6}} = 10^{5.6-4.0} = 10^{1.6} \approx 40$. The polluted rain has about **40 times** the hydrogen-ion concentration.

(c) **Sulfuric acid** (H_2SO_4) from SO_2, and **nitric acid** (HNO_3) from NO_x.

Ví dụ mẫu · pH change from one unit

Acid rain of pH 4 falls into a lake buffered at pH 6. (a) How many times more acidic (in $[H^+]$) is the rain than the lake? (b) If the lake's pH drops to 5, by what factor did its acidity increase?

Solution. (a) $\dfrac{10^{-4}}{10^{-6}} = 10^2 = 100$ times more acidic.
(b) From pH 6 to pH 5 is a decrease of one pH unit, so $[H^+]$ increases by a factor of $10^1 =$ **10**. Each whole pH unit is a tenfold change in acidity.

Ví dụ mẫu · Balancing the sulfuric-acid formation reaction

Show that the equation $SO_2 + \frac{1}{2} O_2 + H_2O \rightarrow H_2SO_4$ is balanced, and rewrite it with whole-number coefficients.

Solution. Count atoms. Left: S $= 1$; O $= 2 + 1 + 1 = 4$; H $= 2$. Right (H_2SO_4): S $= 1$; O $= 4$; H $= 2$. All balance. Doubling to clear the fraction:

$$2\,SO_2 + O_2 + 2\,H_2O \rightarrow 2\,H_2SO_4.$$

Check — Left: S $= 2$, O $= 4 + 2 + 2 = 8$, H $= 4$; Right: S $= 2$, O $= 8$, H $= 4$. Balanced.

Ví dụ mẫu · Classifying primary and secondary pollutants

Classify each as a primary or secondary pollutant and justify: (i) NO from a car exhaust; (ii) unburnt hydrocarbons (VOCs); (iii) ground-level O_3; (iv) PANs; (v) SO_2 from a coal power station.

Solution. (i) **Primary** — emitted directly from combustion. (ii) **Primary** — released directly (unburnt fuel/solvent). (iii) **Secondary** — not emitted; formed in air from NO_x + VOCs + sunlight. (iv) **Secondary** — formed in the same photochemical reactions. (v) **Primary** — emitted directly from burning sulfur-bearing coal. (The secondary acid H_2SO_4 it later forms would be a secondary pollutant.)

Ví dụ mẫu · Interpreting the Chapman equilibrium

Explain why, in an unpolluted stratosphere, the amount of ozone stays roughly constant even though ozone is being destroyed all the time. What quantity does the addition of CFCs change?

Solution. In clean stratosphere the **rate of ozone formation** (Chapman steps 1–2: $O_2 + UV \rightarrow 2O$ then $O + O_2 \rightarrow O_3$) equals the **rate of destruction** (steps 3–4). Because creation and destruction are balanced, a **dynamic equilibrium** holds a steady ozone concentration. CFCs add an *extra*, catalytic destruction pathway (chlorine cycle) that raises the destruction rate without changing formation, so the balance shifts and the steady-state ozone level **falls**.

Ví dụ mẫu · Residence time and global vs local pollution

CFC-12 has an atmospheric residence time of about 100 years; ground-level ozone lasts hours to a few days. Use residence time to explain why one caused a *global* ozone problem while the other is a *local* pollutant.

Solution. A long residence time (~ 100 yr) means CFC molecules survive far longer than the time winds need to mix them worldwide, so they reach the stratosphere everywhere and deplete ozone **globally**. Ground-level ozone is destroyed within hours to days, far too quickly to travel far, so its high concentrations stay near where its precursors are emitted — a **local/urban** problem.

Ví dụ mẫu · Comparing wet and dry deposition distances

Explain why dry deposition of SO_2 is concentrated near a power station, whereas wet deposition of the resulting acid affects regions hundreds of kilometres downwind.

Solution. **Dry deposition** is the settling of SO_2 gas and particles directly onto surfaces; this happens quickly, so it dominates **close to the source**. **Wet deposition** requires the SO_2 first to be oxidised and dissolved into H_2SO_4 in cloud water, which takes time — during which prevailing winds carry the pollution **far downwind** before it falls as acid rain. Hence wet deposition creates the **transboundary** pattern.

6.7 Practice problems

Bài tập luyện tập

1. Which two gases together make up about 99% of dry air?

(A) Oxygen and carbon dioxide
(B) Nitrogen and oxygen
(C) Nitrogen and argon
(D) Oxygen and water vapour

Lời giải chi tiết

(B). Nitrogen ($\approx 78\%$) and oxygen ($\approx 21\%$) sum to $\approx 99\%$; argon (0.93%), CO_2 (0.04%) and trace gases make up the rest. Water vapour is variable and excluded from "dry air."

Bài tập luyện tập

2. In which atmospheric layer does temperature *increase* with altitude because of ozone?

(A) Troposphere
(B) Stratosphere
(C) Mesosphere
(D) Thermosphere (due to ozone)

Lời giải chi tiết

(B). In the **stratosphere** the ozone layer absorbs UV and warms the layer, so temperature rises with height. (The thermosphere also warms with height, but from X-ray/UV absorption by O_2/O, not ozone.)

Bài tập luyện tập

3. State the name and approximate altitude of the boundary between the troposphere and the stratosphere, and describe what happens to temperature there.

Lời giải chi tiết

The **tropopause**, at about 12 km (higher over the equator, lower over the poles). Below it temperature falls with height; above it temperature begins to rise. The tropopause acts as a lid that traps weather and pollutants in the troposphere.

Bài tập luyện tập

4. Write, in order, the four reactions of the Chapman cycle.

Lời giải chi tiết

(1) $O_2 + UV \rightarrow O + O$; (2) $O + O_2 \rightarrow O_3$; (3) $O_3 + UV \rightarrow O_2 + O$; (4) $O + O_3 \rightarrow 2\,O_2$. Steps 1–2 create ozone; steps 3–4 destroy it; at equilibrium they balance.

Bài tập luyện tập

5. Which type of UV radiation is most strongly linked to DNA damage and skin cancer, and is largely absorbed by the ozone layer?

(A) UV-A
(B) UV-B
(C) Infrared
(D) Visible light

Lời giải chi tiết

(B). UV-B is energetic enough to be absorbed by DNA, causing mutations that lead to skin cancer and cataracts; the ozone layer absorbs most UV-B (and essentially all UV-C).

Bài tập luyện tập

6. Write the two steps of the chlorine catalytic cycle and state the net reaction. Explain why one Cl atom can destroy many ozone molecules.

Lời giải chi tiết

$Cl + O_3 \rightarrow ClO + O_2$ and $ClO + O \rightarrow Cl + O_2$; net $O_3 + O \rightarrow 2\,O_2$. The Cl atom is a **catalyst** — regenerated in step 2 — so it is free to attack another O_3, on the order of 10^5 times before removal.

Bài tập luyện tập

7. A CFC molecule releases 1 chlorine atom, and each Cl destroys about 1.0×10^5 ozone molecules. How many ozone molecules could 3.0×10^{15} CFC molecules destroy?

Lời giải chi tiết

Each CFC $\rightarrow$ 1 Cl $\rightarrow 1.0 \times 10^5$ O_3. Total $= 3.0 \times 10^{15} \times 1.0 \times 10^5 =$ **3.0×10^{20}** ozone molecules — showing the catalytic amplification of a small number of CFCs.

Bài tập luyện tập

8. Explain two reasons the Montreal Protocol is considered the most successful international environmental agreement.

Lời giải chi tiết

Any two: (i) the underlying science was clear and agreed, giving political momentum; (ii) affordable substitutes for CFCs existed, so compliance was feasible; (iii) it achieved near-universal ratification and *tightened* over time; (iv) it provided funds/technology for developing countries. Result: ODS production fell $> 98\%$ and the ozone layer is recovering.

Bài tập luyện tập

9. Contrast stratospheric and tropospheric ozone in terms of origin and impact, and give the phrase that summarises the distinction.

Lời giải chi tiết

Stratospheric ozone is natural (Chapman cycle) and *beneficial* — it absorbs UV-B. **Tropospheric** (ground-level) ozone is a *secondary pollutant* formed from NO_x + VOCs + sunlight and is *harmful* to health and plants. The phrase: **"good up high, bad nearby."**

Bài tập luyện tập

10. Which statement about a secondary pollutant is correct?

(A) It is emitted directly from a source

(B) It forms in the atmosphere from primary pollutants

(C) It is always less harmful than a primary pollutant

(D) Ground-level ozone is a primary pollutant

Lời giải chi tiết

(B). A secondary pollutant forms in the atmosphere by reaction of primary pollutants (often driven by sunlight); ground-level ozone and PANs are examples, so options (A) and (D) are wrong, and (C) is false.

Bài tập luyện tập

11. Name the two classes of primary pollutant and the energy input required to form photochemical smog.

Lời giải chi tiết

Primary pollutants: **nitrogen oxides** (NO_x) and **volatile organic compounds (VOCs)**, mostly from vehicle combustion. The energy input is **sunlight** (UV/visible), which drives the photochemistry — hence "photochemical."

Bài tập luyện tập

12. Explain the role of VOCs in allowing ground-level ozone to accumulate.

Lời giải chi tiết

Sunlight splits NO_2 to give O, which makes O_3. Normally NO would immediately destroy that ozone ($NO + O_3 \rightarrow NO_2 + O_2$). VOCs react with and remove NO by other routes, regenerating NO_2 *without* using up ozone, so O_3 builds up (and PANs form).

Bài tập luyện tập

13. A sounding gives $6\,^{\circ}$C at the surface, $10\,^{\circ}$C at 150 m, and $7\,^{\circ}$C at 500 m. Identify the inversion layer and explain why it worsens smog.

Lời giải chi tiết

Temperature rises from 6 to $10\,^{\circ}$C between the surface and 150 m — an **inversion** there. The warm “lid” stops the cooler, denser surface air from rising, so pollutants cannot disperse and their concentrations climb, intensifying smog.

Bài tập luyện tập

14. Why are cities such as Los Angeles, Mexico City, and Santiago especially prone to photochemical smog?

Lời giải chi tiết

They lie in **basins/valleys ringed by mountains**, so cool dense air pools and hills block dispersing winds, favouring frequent temperature inversions. Combined with heavy traffic (NO_x, VOCs) and abundant sunshine to drive the photochemistry, smog forms readily and persists.

Bài tập luyện tập

15. State one management strategy for photochemical smog at each level: altering activity, regulating release, and cleaning up.

Lời giải chi tiết

Alter activity: promote public transport/cycling or switch to electric vehicles (most effective). **Regulate release:** fit catalytic converters and enforce emission standards. **Clean up/adapt:** issue smog alerts and restrict activity on high-ozone days (least effective).

Bài tập luyện tập

16. Write balanced equations for the formation of sulfuric acid from SO_2 and nitric acid from NO_2 in the atmosphere.

Lời giải chi tiết

$SO_2 + \frac{1}{2}O_2 + H_2O \rightarrow H_2SO_4$ (or $2\,SO_2 + O_2 + 2\,H_2O \rightarrow 2\,H_2SO_4$); and $2\,NO_2 + \frac{1}{2}O_2 + H_2O \rightarrow 2\,HNO_3$.

Bài tập luyện tập

17. Distinguish wet and dry acid deposition, and state which dominates near the source.

Lời giải chi tiết

Wet deposition: acids fall dissolved in rain, snow, or fog. **Dry deposition**: acidic gases and particles settle directly onto surfaces. **Dry** deposition dominates *near the source*; wet deposition carries the problem far downwind, making it transboundary.

Bài tập luyện tập

18. Rain has pH 3.0; pure water has pH 7.0. How many times greater is the hydrogen-ion concentration of the rain?

(A) 4 times
(B) 40 times
(C) 10^3 times
(D) 10^4 times

Lời giải chi tiết

(D). $\frac{10^{-3.0}}{10^{-7.0}} = 10^4$. Each pH unit is a factor of 10, and there are 4 units difference, so $10^4 = 10{,}000$ times.

Bài tập luyện tập

19. Explain, with the relevant ion, why acidified lakes kill fish even when the fish could tolerate the acidity itself.

Lời giải chi tiết

Acidity **mobilises aluminium**, dissolving Al^{3+} out of soils and rock into the water. Al^{3+} damages and clogs fish gills, causing suffocation. This **indirect** effect is often more lethal than the low pH itself.

Bài tập luyện tập

20. Give one direct and one indirect effect of acid deposition on forests.

Lời giải chi tiết

Direct: acid damages leaf cuticles/needles, harming the tree surface. **Indirect:** acid leaches nutrient cations (Ca, Mg, K) from soil and releases toxic aluminium, so the impoverished, toxic soil weakens and kills trees.

Bài tập luyện tập

21. Why is acid deposition described as a "transboundary" problem, and what does this imply for its management?

Lời giải chi tiết

The SO_2/NO_x can travel hundreds of kilometres before being deposited, so emissions in one country fall as acid in another. Because the source and the damage are in different jurisdictions, effective management requires **international cooperation and treaties** to cut emissions, not action by a single state.

Bài tập luyện tập

22. What material in buildings and statues is chemically attacked by acid deposition, and why?

Lời giải chi tiết

Limestone and marble, which are **calcium carbonate** ($CaCO_3$). The acids react with and dissolve carbonate, eroding stonework and monuments; acids also corrode metals.

Bài tập luyện tập

23. A power station reduces its SO_2 emissions by fitting scrubbers, and a lake is treated with powdered limestone. Classify each strategy by management level and state which addresses the cause.

Lời giải chi tiết

Scrubbers (**flue-gas desulfurisation**) *clean the release* — reducing SO_2 at source; this addresses the **cause**. Liming the lake is **restoration/clean-up**: it neutralises acidity but treats only the *symptom* and must be repeated. Altering activity (less fossil-fuel use) would be the most fundamental.

Bài tập luyện tập

24. A pollutant has an atmospheric store of $M = 2.4 \times 10^6$ t and a removal rate of $F = 6.0 \times 10^5$ t yr^{-1}. Find its residence time and state whether it is more likely a global or local problem.

Lời giải chi tiết

$\tau = M/F = \dfrac{2.4 \times 10^6}{6.0 \times 10^5} = \mathbf{4.0}$ years. Four years is long enough for global mixing by winds, so it is more likely a **global** problem.

Bài tập luyện tập

25. Explain why CFCs, though emitted at the surface, deplete ozone tens of kilometres up in the stratosphere.

Lời giải chi tiết

CFCs are chemically **inert and insoluble**, so they are not broken down or washed out in the troposphere. Their very long residence time lets them slowly mix and rise into the stratosphere, where finally intense UV splits them and releases the Cl atoms that catalyse ozone destruction.

Bài tập luyện tập

26. Classify each pollutant as primary (P) or secondary (S): (i) SO_2, (ii) H_2SO_4 in rain, (iii) NO from exhaust, (iv) ground-level O_3, (v) PANs.

Lời giải chi tiết

(i) SO_2 — **P** (emitted directly); (ii) H_2SO_4 — **S** (formed in air from SO_2); (iii) NO — **P**; (iv) O_3 — **S**; (v) PANs — **S**. Secondary pollutants form by atmospheric reaction of the primary ones.

Bài tập luyện tập

27. Using the three-cell model, explain why most of the world's major hot deserts lie near $30°$N/S rather than at the equator itself.

Lời giải chi tiết

The equator lies within the **rising** limb of the Hadley cell, where intense heating drives strong convective uplift, condensation and heavy rainfall. Air that rose at the equator loses most of its moisture, then travels poleward aloft and **sinks** back to the surface at about $30°$N/S. This descending air warms adiabatically as it is compressed, producing a persistent belt of high pressure with very low rainfall — which is why deserts (Sahara, Arabian, Australian) cluster near $30°$N/S rather than at the equator, which receives the heaviest rainfall of any latitude band.

Bài tập luyện tập

28. State which pressure belt (equator, $30°$, or $60°$) is associated with each description: (i) descending, warm, dry air; (ii) rising air at the polar front producing changeable frontal rainfall; (iii) strong convective uplift and heavy convectional rainfall.

Lời giải chi tiết

(i) **30**° (subtropical high, the sinking limb of the Hadley cell). (ii) **60**° (sub-polar low, where the Ferrel and Polar cells meet at the polar front). (iii) **Equator** (equatorial low, the rising limb of the Hadley cell).

Bài tập luyện tập

29. On a diurnal air-quality graph for a smog-prone city, NO_x concentration peaks sharply at 08:00 and ozone concentration peaks broadly at 14:00. Explain this time lag.

Lời giải chi tiết

NO_x is a **primary** pollutant emitted directly by morning traffic, so it rises and peaks almost immediately with rush-hour volume. Ozone is a **secondary** pollutant that must first be generated by sunlight-driven photochemical reactions acting on the NO_x and VOCs already present; this takes time and requires strong sunlight, which itself builds through the morning and peaks around midday to early afternoon. The ozone peak therefore lags several hours behind the primary NO_x peak.

Bài tập luyện tập

30. Explain why a valley city surrounded by hills is especially prone to severe, prolonged photochemical smog episodes.

Lời giải chi tiết

Surrounding hills block horizontal winds that would otherwise disperse pollutants, and cool, dense air draining down the slopes at night can pool in the valley floor, favouring the formation of a **temperature inversion** (a layer of warmer air trapping cooler, pollutant-laden air beneath it). With both horizontal dispersal (blocked by hills) and vertical dispersal (blocked by the inversion) suppressed, pollutants emitted by traffic and industry accumulate over successive days rather than dispersing, and this stagnant air is then acted on by sunlight, allowing photochemical smog to intensify over the course of the episode.

Climate Change and Energy Production

> **Mục tiêu Unit:** Hiệu ứng nhà kính tự nhiên so với hiệu ứng nhà kính tăng cường, cách các khí nhà kính (CO2, CH4, N2O, hơi nước, O3, CFC) hấp thụ bức xạ hồng ngoại đi ra và khái niệm tiềm năng nóng lên toàn cầu (GWP); cân bằng năng lượng của Trái Đất (bức xạ sóng ngắn tới, suất phản chiếu albedo, bức xạ sóng dài đi ra); bằng chứng biến đổi khí hậu (đường Keeling, lõi băng, số liệu nhiệt độ, mực nước biển dâng, sông băng lùi, dịch chuyển vật hậu); vòng phản hồi dương và âm, điểm tới hạn (tipping point); tác động của biến đổi khí hậu; giảm thiểu so với thích ứng, các thoả thuận quốc tế (Kyoto, Paris); tài nguyên năng lượng, an ninh năng lượng, mật độ năng lượng và khái niệm cơ cấu năng lượng (energy mix).

7.1 The greenhouse effect

7.1.1 The natural greenhouse effect

The Earth is warmed by the Sun, but the atmosphere plays a decisive role in setting the surface temperature. Roughly **one-third** of the incoming solar radiation is reflected straight back to space; the remainder is absorbed by the surface and atmosphere and warms the planet. A warm surface radiates energy back towards space, but it does so at much longer wavelengths than the incoming sunlight. This wavelength difference is the key to the greenhouse effect.

Incoming solar radiation is dominated by **shortwave radiation** (visible light and near-infrared, peaking near $0.5\ \mu m$), because the Sun is very hot (≈ 5800 K). The much cooler Earth (≈ 288 K) re-radiates energy as **longwave (thermal) infrared radiation**, peaking near $10\ \mu m$. The atmosphere is largely transparent to the incoming shortwave radiation but strongly absorbs part of the outgoing longwave radiation. **Greenhouse gases** are the atmospheric constituents responsible for this selective absorption.

> The **natural greenhouse effect** is the warming that results when greenhouse gases absorb outgoing longwave (infrared) radiation and re-radiate part of it back towards the surface. Without it the mean surface temperature would be about $-18\,^{\circ}$C instead of the observed $\approx 15\,^{\circ}$C — a difference of roughly $33\,^{\circ}$C that makes the planet habitable.

The principal natural greenhouse gases are **water vapour** (H2O), **carbon dioxide** (CO2), **methane** (CH4), **nitrous oxide** (N2O), and **ozone** (O3). Each of these molecules has vibrational and rotational modes whose energies match the wavelengths of thermal infrared radiation, so they absorb outgoing longwave photons. Symmetrical diatomic molecules such as N2 and O2 — which make up about 99% of the atmosphere — do not absorb infrared and are *not* greenhouse gases.

> GIẢI THÍCH TIẾNG VIỆT
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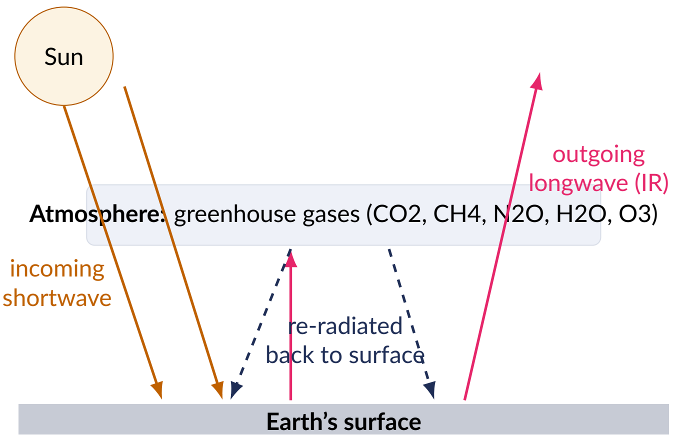
> **Hiệu ứng nhà kính tự nhiên (natural greenhouse effect):** một phần bức xạ sóng dài (hồng ngoại) mà bề mặt Trái Đất phát ra bị các **khí nhà kính** hấp thụ và bức xạ ngược một phần trở lại bề mặt, làm hành tinh ấm hơn. Nếu không có hiệu ứng này, nhiệt độ trung bình bề mặt sẽ khoảng $-18\,^{\circ}$C thay vì $\approx 15\,^{\circ}$C — chênh lệch khoảng $33\,^{\circ}$C giúp sự sống tồn tại. Bức xạ Mặt Trời tới chủ yếu là **sóng ngắn**; Trái Đất (lạnh hơn) phát lại **sóng dài**. Khí quyển gần như trong suốt với sóng ngắn nhưng hấp thụ mạnh sóng dài. Các khí N2 và O2 (chiếm $\approx 99\%$ khí quyển) *không* phải khí nhà kính vì phân tử đối xứng, không hấp thụ hồng ngoại.



The greenhouse effect. Incoming **shortwave** solar radiation passes through the atmosphere and warms the surface. The surface emits **longwave infrared**; greenhouse gases absorb much of it and re-radiate part back to the surface, raising surface temperature.

7.1.2 The enhanced greenhouse effect

Human activity has increased the atmospheric concentration of several greenhouse gases well above their pre-industrial values. Burning fossil fuels and clearing forests raise CO2; agriculture, livestock, landfills and fossil-fuel extraction raise CH4; fertiliser use raises N2O; and industry has released synthetic **chlorofluorocarbons (CFCs)**, which are both potent greenhouse gases and ozone-depleting substances. The result is a stronger trapping of longwave radiation than would occur naturally.

> The **enhanced (anthropogenic) greenhouse effect** is the additional warming caused by human-driven increases in greenhouse-gas concentrations. It intensifies the natural effect, producing a positive **radiative forcing** — a net gain of energy in the Earth system that raises global mean temperature.

7.1.3 Global warming potential (GWP)

Different gases differ in how strongly they absorb infrared radiation and how long they persist in the atmosphere. To compare them on a common scale we use **global warming potential**.

> The **global warming potential (GWP)** of a gas is the total warming (radiative forcing integrated over a chosen time horizon, usually 100 years) caused by emitting 1 kg of that gas, expressed *relative* to 1 kg of CO2. By definition GWP$(\text{CO2}) = 1$. The mass of CO2 that would cause the same warming as a given emission is its CO2-**equivalent** (CO2e):
>
> $$\text{CO2e} = m_{\text{gas}} \times \text{GWP}_{\text{gas}}.$$

Representative 100-year GWP values (rounded) are: CO2 $= 1$, CH4 ≈ 28, N2O ≈ 265, and many CFCs in the range $\approx 5{,}000$–$14{,}000$. Methane is short-lived (about a decade) but absorbs infrared far more efficiently per molecule than CO2; nitrous oxide is both efficient and very long-lived.

> **GIẢI THÍCH TIẾNG VIỆT**
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> **Tiềm năng nóng lên toàn cầu (GWP):** thước đo lượng nhiệt do phát thải 1 kg một khí gây ra trong một khoảng thời gian (thường 100 năm), *so với* 1 kg CO2. Theo định nghĩa GWP của CO2 bằng 1. Để quy đổi ra CO2 **tương đương** (CO2e): nhân khối lượng khí với GWP của nó. Ví dụ GWP của CH4 ≈ 28, N2O ≈ 265. Metan tồn tại ngắn (khoảng một thập kỷ) nhưng hấp thụ hồng ngoại mạnh hơn nhiều so với CO2 trên mỗi phân tử.

Ví dụ mẫu · Converting methane emissions to CO2-equivalent

A dairy farm releases 500 kg of methane (CH4) per year from its livestock. Using a 100-year GWP of 28 for methane, calculate the CO2-equivalent emission.
Solution. Apply CO2e $= m_{\text{gas}} \times$ GWP:

$$\text{CO2e} = 500\,\text{kg} \times 28 = 14000\,\text{kg CO2e} = 14\,\text{tonnes CO2e}.$$

So 500 kg of methane warms the climate as much as 14 tonnes of CO2 over a century — a striking illustration of why livestock methane matters despite the modest mass involved.

Ví dụ mẫu · A mixed-gas CO2e inventory

In one year a factory emits 2000 tonnes of CO2, 30 tonnes of CH4, and 4 tonnes of N2O. Using GWP values of 1, 28 and 265 respectively, find the total emission in CO2e and identify the largest single contributor.
Solution. Convert each gas:

$$\begin{aligned}
\text{CO2} &: 2000 \times 1 = 2000\,\text{t CO2e},\\
\text{CH4} &: 30 \times 28 = 840\,\text{t CO2e},\\
\text{N2O} &: 4 \times 265 = 1060\,\text{t CO2e}.
\end{aligned}$$

Total $= 2000 + 840 + 1060 = 3900$ tonnes CO2e. Although CO2 dominates by mass, note that only 4 tonnes of N2O contributes more (1060 t) than 30 tonnes of CH4 (840 t), because N2O has a far higher GWP.

7.2 Earth's energy budget

7.2.1 Incoming shortwave, albedo, and outgoing longwave

Over the long term the Earth is in approximate **radiative balance**: the energy absorbed from the Sun equals the energy radiated back to space. If absorption exceeds emission, the system gains energy and warms; if emission exceeds absorption, it cools.

The average solar power arriving at the top of the atmosphere, spread over the whole planet, is about 340 W.m^{-2} (one quarter of the **solar constant** ≈ 1360 W.m^{-2}, because the disc that intercepts sunlight has area πr^2 while the sphere that radiates has area $4\pi r^2$). Of the incoming shortwave radiation:

- a fraction is **reflected** back to space by clouds, aerosols, and bright surfaces such as ice and snow;
- the remainder is **absorbed** by the atmosphere and surface, warming the planet.

> The **albedo** of a surface is the fraction of incoming shortwave radiation that it reflects, a dimensionless number between 0 and 1. Fresh snow has a high albedo (≈ 0.8–0.9); open ocean and dark forest have a low albedo (≈ 0.06–0.15). Earth's average **planetary albedo** is about 0.30. The fraction *absorbed* is $(1-\alpha)$, where α is the albedo.

A simple energy-balance statement is therefore:

$$\underbrace{(1-\alpha)\,S/4}_{\text{absorbed shortwave}} = \underbrace{\sigma T_e^4}_{\text{outgoing longwave}},$$

where S is the solar constant, α the planetary albedo, σ the Stefan–Boltzmann constant, and T_e the effective radiating temperature. Solving this balance for Earth's numbers gives $T_e \approx 255$ K ($\approx -18\,^\circ$C)

— the temperature the planet would have with no greenhouse effect, confirming the $\approx 33\,^\circ$C warming quoted earlier.

VN **GIẢI THÍCH TIẾNG VIỆT**

Cân bằng bức xạ: về lâu dài, năng lượng Trái Đất hấp thụ từ Mặt Trời bằng năng lượng bức xạ ra không gian. Công suất Mặt Trời trung bình tới đỉnh khí quyển ≈ 340 W.m^{-2}. **Suất phản chiếu (albedo, α)** là tỉ lệ bức xạ sóng ngắn bị phản xạ; phần hấp thụ là $(1-\alpha)$. Tuyết mới có albedo cao (0.8–0.9), đại dương và rừng tối có albedo thấp; albedo trung bình của hành tinh ≈ 0.30. Nếu absorbed = outgoing longwave thì nhiệt độ bức xạ hiệu dụng ≈ 255 K ($\approx -18\,^\circ$C).

Ví dụ mẫu · Reflected and absorbed shortwave radiation

At a certain location the incoming shortwave radiation is 340 W.m^{-2} and the local albedo is 0.30. Calculate (a) the power per square metre reflected and (b) the power per square metre absorbed.

Solution.

(a) Reflected $= \alpha \times S_{\text{in}} = 0.30 \times 340$ W.m^{-2} $= 102$ W.m^{-2}.

(b) Absorbed $= (1-\alpha) \times S_{\text{in}} = 0.70 \times 340$ W.m^{-2} $= 238$ W.m^{-2}.

Check: $102 + 238 = 340$ W.m^{-2}, accounting for all incoming radiation.

Ví dụ mẫu · How melting ice changes local absorption

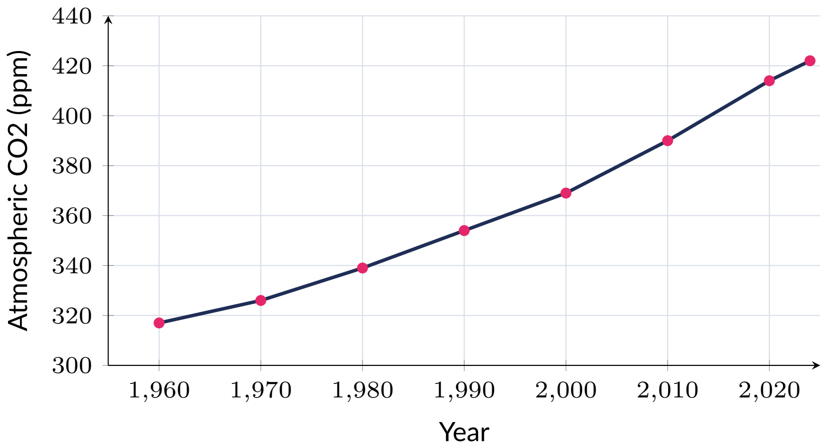
A patch of Arctic sea ice (albedo 0.60) melts and is replaced by open ocean (albedo 0.06). The incoming shortwave radiation is 200 W.m^{-2}. By how much does the absorbed power per square metre increase?

Solution. Absorbed by ice $= (1-0.60) \times 200 = 80$ W.m^{-2}. Absorbed by ocean $= (1-0.06) \times 200 = 188$ W.m^{-2}. Increase $= 188 - 80 = 108$ W.m^{-2}. The newly exposed ocean absorbs more than twice as much energy, which warms the water and encourages further melting — the basis of the ice–albedo feedback discussed below.

7.3 Evidence for climate change

7.3.1 The Keeling curve and rising atmospheric CO2

Since 1958, continuous measurements of atmospheric CO2 at the Mauna Loa Observatory in Hawaii have produced the **Keeling curve**. It shows two features: a small annual sawtooth (Northern-Hemisphere plants draw down CO2 each growing season) superimposed on a strong, accelerating long-term rise. Concentrations climbed from about 315 ppm in 1958 to over 420 ppm today, well above the pre-industrial value of ≈ 280 ppm.



A Keeling-style curve of the long-term rise in atmospheric CO2 at Mauna Loa. Values are approximate annual means; the concentration has risen from ≈ 317 ppm in 1960 to > 420 ppm today, and the rate of rise has itself increased.

Ví dụ mẫu · Reading a rate of CO2 rise from the Keeling curve

Using the figure, the atmospheric CO2 concentration was 369 ppm in 2000 and 414 ppm in 2020. Calculate the mean rate of increase in ppm per year over this period.

Solution. Rate $= \dfrac{\Delta C}{\Delta t} = \dfrac{414 - 369}{2020 - 2000} = \dfrac{45}{20} = 2.25$ ppm.yr^{-1}.

For comparison, between 1960 and 1980 the rise was $\dfrac{339 - 317}{20} = 1.1$ ppm.yr^{-1}. The rate has roughly doubled, showing that the increase is accelerating, not merely continuing.

7.3.2 Other lines of evidence

Multiple independent records corroborate the warming:

- **Ice cores.** Air bubbles trapped in Antarctic and Greenland ice preserve samples of the ancient atmosphere. Cores spanning $> 800{,}000$ years show CO2 and CH4 oscillating with the ice ages, and confirm that today's concentrations are unprecedented over that interval. Oxygen-isotope ratios in the ice act as a palaeo-thermometer.
- **Instrumental temperature records.** Thermometer data since the mid-19th century show a global mean surface warming of roughly $1.1\,^\circ$C above pre-industrial levels, with the most rapid rise since about 1970.
- **Sea-level rise.** Tide gauges and satellite altimetry show global mean sea level rising by around 3.3 mm.yr^{-1} in recent decades, driven by thermal expansion of seawater and melting land ice.
- **Retreating glaciers and shrinking sea ice.** Mountain glaciers worldwide are losing mass, and Arctic summer sea-ice extent has declined markedly.
- **Phenological shifts. Phenology** is the timing of seasonal biological events. Earlier spring leaf-out and flowering, earlier bird migration and breeding, and poleward or upslope range shifts are all documented biological responses to warming.

VN **GIẢI THÍCH TIẾNG VIỆT**

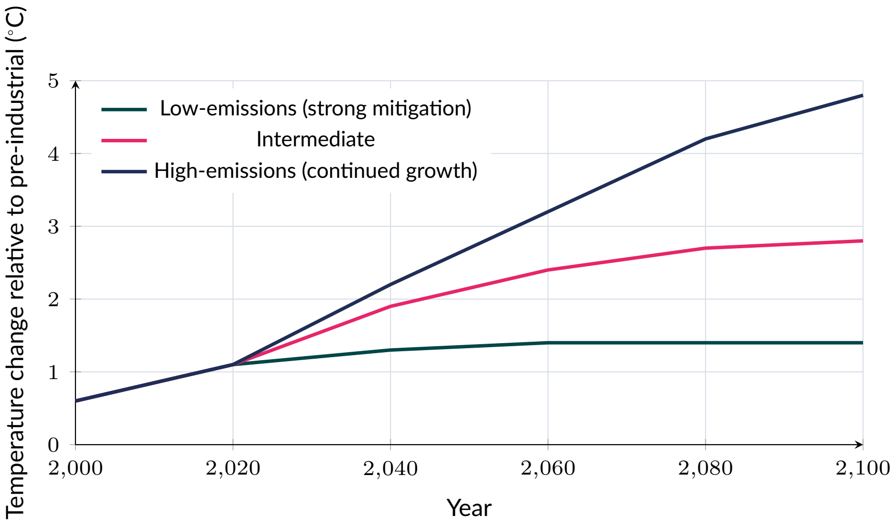
Bằng chứng biến đổi khí hậu: (1) **Đường Keeling** — CO2 khí quyển tăng liên tục từ 1958; (2) **lõi băng** — bọt khí lưu giữ khí quyển cổ, cho thấy CO2 hiện nay cao chưa từng có trong $> 800{,}000$ năm; (3) **số liệu nhiệt kế** — Trái Đất ấm lên $\approx 1.1\,^\circ$C so với thời tiền công nghiệp; (4) **mực nước biển dâng** ≈ 3.3 mm.yr^{-1} (giãn nở nhiệt + băng tan); (5) **sông băng lùi** và băng biển Bắc Cực thu hẹp; (6) **dịch chuyển vật hậu (phenology)** — thời điểm ra lá, ra hoa, di cư sớm hơn và vùng phân bố loài dịch về phía cực/lên cao.

7.4 Climate models and future scenarios

7.4.1 Why scenarios, not single predictions

Because future greenhouse-gas emissions depend on unpredictable human choices — economic growth, technology, and policy — climate scientists do not attempt a single deterministic prediction of the future climate. Instead, **global climate models (GCMs)**, large computer simulations built from the physical laws governing radiation, fluid motion in the atmosphere and ocean, and feedback processes (Section 7.4), are run under a range of **emissions scenarios**: internally consistent storylines about how greenhouse-gas emissions might plausibly evolve, from aggressive mitigation to continued high emissions.

Running the same physical model under several different emissions scenarios separates two distinct sources of uncertainty in a temperature projection: (1) **scenario uncertainty** — how much humanity actually emits in the future, which is a matter of policy and economic choice, not physics; and (2) **model uncertainty** — how precisely the climate system's physical response (particularly cloud behaviour, ocean heat uptake, and feedback strength) is captured by a necessarily simplified model (Chapter 1). Presenting a *range* of projected outcomes, rather than one number, communicates both sources of uncertainty honestly rather than implying false precision.



Illustrative (schematic, not official) projected global mean temperature change under three emissions scenarios. All scenarios track observed warming closely to the present, then diverge sharply — the divergence itself is driven by *policy choices*, not physical uncertainty.

VN **GIẢI THÍCH TIẾNG VIỆT**

Vì phát thải khí nhà kính trong tương lai phụ thuộc vào lựa chọn chính sách và kinh tế của con người — không thể dự đoán chắc chắn — các nhà khoa học khí hậu chạy **mô hình khí hậu toàn cầu (GCM)** theo nhiều **kịch bản phát thải** khác nhau thay vì đưa ra một con số dự đoán duy nhất. Có hai nguồn bất định tách biệt: (1) **bất định kịch bản** — con người thực sự sẽ phát thải bao nhiêu (thuộc về chính sách, không phải vật lý); (2) **bất định mô hình** — mô hình vật lý (đặc biệt về mây, hấp thụ nhiệt đại dương, độ mạnh phản hồi) mô phỏng chính xác đến đâu. Trình bày một **khoảng** kết quả thay vì một con số duy nhất giúp truyền đạt trung thực cả hai loại bất định này.

Ví dụ mẫu · Interpreting scenario divergence

Using the figure, the low-emissions and high-emissions scenarios both show almost identical warming ($\approx 1.1\,^\circ$C) by 2020, but project very different outcomes by 2100 ($1.4\,^\circ$C versus $4.8\,^\circ$C). Explain why the scenarios agree closely in the near term but diverge so sharply by the century's end, and state what this implies about the value of near-term mitigation choices.

Near-term warming (to about 2020–2030) is dominated by greenhouse gases *already* emitted in the past, which take decades to fully manifest as warming because of the ocean's large heat capacity and thermal inertia; this warming is now largely locked in regardless of which future scenario is chosen. The scenarios diverge sharply later in the century because that is when *cumulative future emissions* — which differ enormously between a strongly mitigated pathway and a high-emissions pathway — dominate the total radiative forcing. This has a direct policy implication: choices made today about emissions have comparatively little effect on warming over the next decade (already largely committed) but a very large effect on how much warming occurs by the century's end, meaning the benefit of mitigation accrues mainly to future decades rather than the present one — a key reason climate policy requires long-term commitment rather than short-term reversal.

VN GIẢI THÍCH TIẾNG VIỆT

Sự ấm lên trong ngắn hạn chủ yếu do khí nhà kính *đã phát thải trong quá khứ* gây ra (do quán tính nhiệt của đại dương, phải mất hàng thập kỷ mới biểu hiện đầy đủ) nên gần như đã "định sẵn" bất kể chọn kịch bản nào. Các kịch bản chỉ phân kỳ rõ rệt về cuối thế kỷ vì lúc đó **tổng phát thải tích luỹ trong tương lai** mới thực sự chi phối. Điều này có ý nghĩa chính sách quan trọng: quyết định giảm phát thải hôm nay ảnh hưởng rất ít đến thập kỷ tới nhưng ảnh hưởng rất lớn đến mức ấm lên vào cuối thế kỷ — vì vậy chính sách khí hậu cần cam kết dài hạn chứ không phải thay đổi ngắn hạn.

(!) Lỗi thường gặp: Do not treat a climate model's inability to predict the *exact* future emissions pathway as equivalent to uncertainty about whether added greenhouse gases warm the climate. The physical mechanism of the enhanced greenhouse effect (Section 7.1) is well established and is not the source of the spread seen between scenario lines in a projection graph; the spread reflects genuine uncertainty about *future human choices* (scenario uncertainty) and, to a smaller degree, about precise climate sensitivity (model uncertainty) — not doubt about the basic physics of warming itself.

7.5 Feedback loops and tipping points

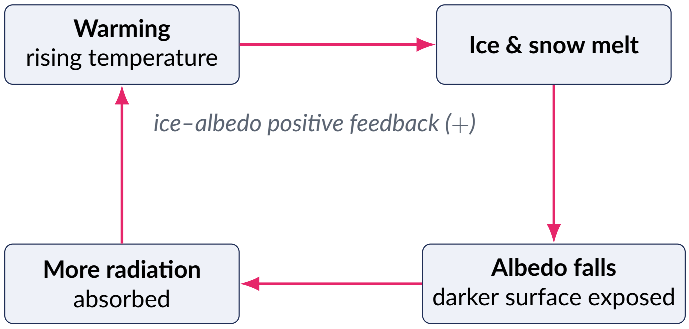
7.5.1 Positive and negative feedback

A **feedback** occurs when the output of a process loops back to alter that same process. In a **positive feedback**, the response amplifies the original change (destabilising, self-reinforcing); in a **negative feedback**, the response counteracts the original change (stabilising).

Key **positive feedbacks** that amplify warming:

- **Ice–albedo feedback.** Warming melts bright ice and snow, exposing darker ocean or land with lower albedo, which absorbs more radiation, which causes more warming and more melting.
- **Permafrost methane feedback.** Warming thaws permafrost, releasing stored CH_4 and CO_2, which enhances the greenhouse effect and causes further thawing.
- **Water-vapour feedback.** Warmer air holds more water vapour, itself a greenhouse gas, which traps more longwave radiation and amplifies warming.

An example of **negative feedback** is increased low-cloud cover or enhanced longwave emission from a warmer surface (the Stefan–Boltzmann term σT^4 rises steeply with temperature), both of which act to shed energy and resist further warming.



The ice–albedo **positive feedback** loop. Each step reinforces the next, so an initial warming is amplified rather than damped.

7.5.2 Tipping points

A **tipping point** is a threshold beyond which a small additional change pushes a system into a qualitatively different state, often abruptly and irreversibly on human timescales. Positive feedbacks can carry a system past such thresholds. Frequently cited examples include the collapse of the Greenland or West Antarctic ice sheets, dieback of the Amazon rainforest, and disruption of the Atlantic thermohaline circulation. Because tipping points may be crossed before their effects are obvious, they are a central reason for the precautionary principle in climate policy.

GIẢI THÍCH TIẾNG VIỆT

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Vòng phản hồi (feedback): phản hồi dương khuếch đại thay đổi ban đầu (mất ổn định), **phản hồi âm** triệt tiêu thay đổi (ổn định). Phản hồi dương làm ấm lên: ice–albedo (băng tan → albedo giảm → hấp thụ nhiều hơn), metan từ tầng đất đóng băng vĩnh cửu (permafrost), và hơi nước. Phản hồi âm ví dụ: bề mặt nóng phát bức xạ sóng dài mạnh hơn (σT^4). **Điểm tới hạn (tipping point):** ngưỡng mà vượt qua sẽ đẩy hệ sang trạng thái khác, thường đột ngột và khó đảo ngược.

Ví dụ mẫu · Reasoning through a positive-feedback loop

Explain, step by step, why the thawing of Arctic permafrost is a positive feedback, and state one consequence for climate policy.

Solution. Trace the loop: (1) global temperatures rise; (2) frozen permafrost soils thaw; (3) micro-organisms decompose the newly available organic matter, releasing CH4 and CO2; (4) these greenhouse gases enhance the greenhouse effect and trap more outgoing longwave radiation; (5) this causes further warming, which returns to step (2) and thaws still more permafrost. Because each pass around the loop *amplifies* the original warming, it is a **positive feedback**.

Policy consequence: emission budgets calculated only from human sources may underestimate future warming, because the permafrost can add its own emissions once triggered. This strengthens the case for early, precautionary emission cuts before such feedbacks are activated.

7.6 Impacts of climate change

Warming does not act uniformly; its consequences ripple through physical, ecological and human systems.

- **Sea-level rise** threatens low-lying coasts and small-island states through inundation, coastal erosion, and saltwater intrusion into freshwater aquifers and farmland.
- **Ocean acidification.** The ocean absorbs about a quarter of emitted CO2; dissolved CO2 forms carbonic acid, lowering ocean pH. This impairs the ability of corals, molluscs and plankton to build

calcium-carbonate shells and skeletons. (Note that acidification is a direct chemical effect of CO2, not of warming itself.)

- **Changing precipitation.** Some regions become wetter and others drier; the intensity of extreme rainfall, droughts and heatwaves increases.
- **Ecosystem and species shifts.** Ranges move poleward and upslope; the timing of interacting species (for example pollinators and flowers) can fall out of step; warm-water coral reefs bleach.
- **Agriculture.** Shifting growing seasons, water stress, new pest and disease ranges, and extreme events alter crop yields — beneficial in a few high-latitude areas but harmful in many tropical and subtropical regions.
- **Human health.** Heat stress, expanded ranges of vector-borne diseases (such as malaria and dengue), poorer air quality, and disruption of food and water supplies all raise health burdens.
- **Climate refugees.** People displaced by sea-level rise, drought, or extreme events may be forced to migrate, creating humanitarian and geopolitical pressures.

VN GIẢI THÍCH TIẾNG VIỆT

Tác động của biến đổi khí hậu: mực nước biển dâng (ngập, xâm nhập mặn); **axit hoá đại dương** (CO2 hoà tan tạo axit cacbonic, hạ pH, cản trở sinh vật tạo vỏ CaCO3) — đây là tác động hoá học trực tiếp của CO2, không phải của sự nóng lên; thay đổi lượng mưa và cực đoan khí hậu; dịch chuyển hệ sinh thái và loài; ảnh hưởng nông nghiệp; sức khoẻ con người (nắng nóng, bệnh truyền qua vector); và **người tị nạn khí hậu (climate refugees)**.

Sector	Typical harmful impact	Typical adaptation response
Coastal settlements	Inundation, erosion, saltwater intrusion into aquifers/farmland	Sea walls, managed retreat, mangrove restoration
Agriculture	Shifting growing seasons, water stress, new pest/disease ranges	Drought-resistant varieties, changed planting calendars, irrigation efficiency
Marine ecosystems	Coral bleaching, ocean acidification impairing shell/skeleton formation	Marine protected areas, reef restoration, reduced local stressors (pollution, overfishing)
Human health	Heat stress, expanded vector-borne disease ranges	Early-warning systems, cooling centres, vector control
Water resources	Altered precipitation, more frequent drought or flood extremes	Reservoir management, water-conservation schemes, flood defences

Selected climate-change impacts by sector, paired with a typical adaptation response — illustrating that adaptation measures are usually sector-specific rather than one general fix.

Ví dụ mẫu · Quantifying ocean acidification

Ocean surface pH has fallen from a pre-industrial value of approximately 8.2 to approximately 8.1 today. Recall that pH is a $\log_{10}$ scale, so each fall of 1.0 pH unit corresponds to a tenfold increase in hydrogen ion concentration $[\text{H+}]$. Estimate the percentage increase in $[\text{H+}]$ (acidity) corresponding to this 0.1 unit pH fall, given $10^{0.1} \approx 1.26$.

A fall of $\Delta\text{pH} = 0.1$ corresponds to a factor increase in $[\text{H+}]$ of $10^{0.1} \approx 1.26$, i.e. a 26% increase in hydrogen ion concentration.

Although a shift from pH 8.2 to 8.1 sounds small on the pH scale, because pH is logarithmic this actually represents roughly a 26% increase in ocean acidity — a useful reminder that small-looking changes on a logarithmic scale can correspond to large proportional changes in the underlying quantity, and why scientists describe this shift as ecologically significant despite the modest-looking pH numbers.

GIẢI THÍCH TIẾNG VIỆT
VN
Vì thang pH là thang **logarit**, một thay đổi pH nhỏ (từ $8{,}2$ xuống $8{,}1$) tương ứng với mức tăng nồng độ ion H$+$ (độ axit) lớn hơn nhiều so với cảm giác ban đầu — cụ thể khoảng 26%. Đây là lý do các nhà khoa học coi sự thay đổi pH tưởng chừng nhỏ này là có ý nghĩa sinh thái đáng kể.

7.7 Mitigation and adaptation

7.7.1 Mitigation: reducing the cause

Mitigation means reducing the causes of climate change — chiefly cutting greenhouse-gas emissions or removing gases already emitted. Strategies include:

- switching from fossil fuels to **renewable energy** (solar, wind, hydro, geothermal);
- improving **energy efficiency** so less energy is needed per unit of output;
- **carbon capture and storage (CCS)**, trapping CO2 from power stations or the air and storing it underground;
- **reforestation and afforestation**, using photosynthesis to remove CO2 into biomass and soils;
- economic instruments — **carbon taxes** (a price per tonne of CO2) and **carbon trading** (cap-and-trade markets in emission permits) — to make emitters pay;
- **geo-engineering**, large-scale intervention such as injecting reflective aerosols into the stratosphere or fertilising the ocean; these are controversial and carry uncertain side effects, so most experts treat them as a last resort rather than a substitute for emission cuts.

7.7.2 Adaptation: living with the consequences

Adaptation means adjusting to the impacts that occur regardless of mitigation. Measures include **sea walls** and coastal defences against rising seas, **drought-resistant crop** varieties and changed planting calendars, improved **flood management** (levees, wetland restoration, better drainage), water-conservation schemes, and early-warning systems for extreme weather. Mitigation and adaptation are complementary: mitigation limits how bad the problem becomes, while adaptation manages the impacts that are already unavoidable.

7.7.3 International agreements

Because greenhouse gases mix globally, no single country can solve the problem alone, so international cooperation is essential. The **Kyoto Protocol** (1997) set binding emission-reduction targets for developed countries. The **Paris Agreement** (2015) committed almost all nations to hold warming to *well below* $2\,^{\circ}$C above pre-industrial levels, pursuing efforts to limit it to $1.5\,^{\circ}$C, through voluntary Nationally Determined Contributions that are periodically strengthened.

GIẢI THÍCH TIẾNG VIỆT
VN
Giảm thiểu (mitigation) nhắm vào *nguyên nhân*: chuyển sang năng lượng tái tạo, nâng hiệu suất năng lượng, thu giữ và lưu trữ cacbon (CCS), trồng rừng, thuế cacbon và mua bán phát thải, và địa kỹ thuật (geo-engineering, gây tranh cãi). **Thích ứng (adaptation)** nhắm vào *hậu quả*: đê biển, giống cây chịu hạn, quản lý lũ, cảnh báo sớm. Hai chiến lược bổ sung cho nhau. **Thoả thuận quốc tế:** Nghị định thư **Kyoto** (1997) đặt mục tiêu ràng buộc cho nước phát triển; Thoả thuận **Paris** (2015) hướng tới giữ mức nóng lên dưới $2\,^{\circ}$C, cố gắng đạt $1.5\,^{\circ}$C.

Ví dụ mẫu · Classifying strategies as mitigation or adaptation

Classify each of the following as mitigation (M) or adaptation (A): (i) building a sea wall around a coastal city; (ii) installing rooftop solar panels; (iii) planting mangrove forests along an eroding coast; (iv) introducing a national carbon tax.
Solution. (i) **A** — a sea wall manages an impact (rising seas) without reducing emissions. (ii) **M** — solar panels displace fossil-fuel electricity, cutting emissions. (iii) This is a useful trick question: mangroves both defend the coast (**A**) *and* sequester carbon (**M**), so it counts as **both**. (iv) **M** — a carbon tax raises the cost of emitting and so reduces the cause.
The key test: does the measure reduce greenhouse-gas concentrations (mitigation) or reduce vulnerability to impacts that will occur anyway (adaptation)?

Ví dụ mẫu · The effect of a carbon tax on emissions cost

A power company emits 3.9 million tonnes of CO2e per year (the factory total from the earlier example, scaled up). A government introduces a carbon tax of 40 USD per tonne of CO2e. Calculate the annual tax bill, and comment on the incentive it creates.
Solution. Tax bill $= 3{,}900{,}000$ t $\times\ 40$ USD/t $= 156$ million USD per year.
This large recurring cost gives the company a direct financial incentive to cut emissions: every tonne of CO2e avoided saves $40. If, say, efficiency measures and renewables could remove 20% of emissions, the firm would save 0.20×156 million $= 31.2$ million USD each year, which can justify substantial investment in mitigation.

7.8 Energy resources and security

7.8.1 Renewable and non-renewable resources

Energy resources are classed as **renewable** — replenished by natural processes on a human timescale (solar, wind, hydro, geothermal, biomass, tidal and wave) — or **non-renewable**, existing in finite stocks that are effectively depleted once used (the fossil fuels coal, oil and natural gas, together with nuclear fuels such as uranium). Fossil fuels dominate the current global supply and are the principal source of anthropogenic CO2.

> **Energy density** is the amount of energy stored per unit mass (or per unit volume) of a fuel, for example in MJ.kg^{-1}. Fossil fuels and especially nuclear fuel have very high energy densities, which is why they are convenient and portable; most renewables capture a diffuse, low-density flux and so require large areas or installations to gather comparable energy.

A useful measure for electricity generators is the **capacity factor**: the actual energy produced over a period divided by the energy that would have been produced running at full rated power the whole time. Baseload plants (nuclear, coal) have high capacity factors; intermittent renewables (solar, wind) have lower ones because the resource is variable.

Source	Advantages	Limitations
Coal / oil / gas	High energy density; reliable baseload; established infrastructure	Finite; high CO2 and pollutant emissions; price volatility
Nuclear	Very high energy density; low operating CO2; reliable baseload	Radioactive waste; high capital cost; accident risk; long build times
Solar (PV)	Renewable; no operating emissions; modular	Intermittent (day/weather); low density needs large area; needs storage
Wind	Renewable; no operating emissions; low running cost	Intermittent; visual/noise concerns; site-dependent
Hydro	Renewable; storable; high capacity factor	Ecosystem & displacement impacts; geographically limited
Geothermal	Renewable; reliable baseload; small footprint	Location-specific; high drilling cost
Biomass	Renewable; uses waste; can be carbon-neutral	Emissions if unsustainable; competes with land/food
Tidal / wave	Renewable; predictable (tides)	Few suitable sites; high cost; marine impacts

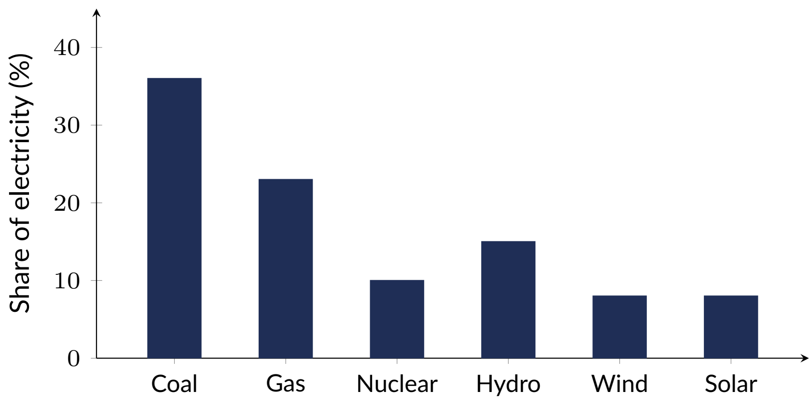
Comparison of the main energy sources, with representative advantages and limitations. No single source is ideal on every criterion, which is why countries rely on a mix.

7.8.2 Energy security and the energy mix

> **Energy security** is the reliable, affordable, and uninterrupted availability of energy for a country. It depends on having sufficient supply, diverse sources, and stable access.

A country's choice of energy sources is shaped by many factors: its **natural resource endowment** (domestic coal, oil, gas, hydro potential, sunshine, wind), **cost and technology**, **political and cultural attitudes** (for example public acceptance of nuclear power), **environmental policy** and climate commitments, and its degree of dependence on **imports** from other states.

> An **energy mix** is the combination of different energy sources a country uses to meet its total demand. Diversifying the mix improves energy security (reducing reliance on any single source or supplier) and can lower emissions as renewables replace fossil fuels.



An illustrative national **energy mix** for electricity. The exact figures are hypothetical and sum to 100%; the point is that supply is spread across several sources to balance cost, reliability, and emissions.

> VN **GIẢI THÍCH TIẾNG VIỆT**
> **Tài nguyên năng lượng: tái tạo** (mặt trời, gió, thuỷ điện, địa nhiệt, sinh khối, thuỷ triều/sóng) so với **không tái tạo** (than, dầu, khí, và nhiên liệu hạt nhân). **Mật độ năng lượng (energy density):** năng lượng trên một đơn vị khối lượng — nhiên liệu hoá thạch và hạt nhân rất cao, năng lượng tái tạo loãng nên cần diện tích lớn. **An ninh năng lượng:** nguồn cung tin cậy, giá phải chăng,

không gián đoạn. **Cơ cấu năng lượng (energy mix):** tổ hợp các nguồn một quốc gia sử dụng; đa dạng hoá giúp tăng an ninh năng lượng và có thể giảm phát thải. Lựa chọn phụ thuộc tài nguyên sẵn có, chi phí/công nghệ, chính trị–văn hoá, chính sách môi trường và mức phụ thuộc nhập khẩu.

Ví dụ mẫu · Comparing land use of solar and wind

A solar farm produces 5 GWh per year on 10 hectares. A wind farm produces 18 GWh per year on 60 hectares (measuring the land actually occupied by turbine bases and access roads). Which uses land more efficiently for energy output?

Solution. Compute output per hectare.

Solar: $\dfrac{5\text{ GWh}}{10\text{ ha}} = 0.5\,\text{GWh/ha}$ per year.

Wind: $\dfrac{18\text{ GWh}}{60\text{ ha}} = 0.3\,\text{GWh/ha}$ per year.

The solar farm generates more energy per hectare (0.5 vs 0.3 GWh/ha). Note, however, that wind turbines leave most of their footprint usable for farming, so "land occupied" can be defined differently — a reminder to state assumptions clearly when comparing sources.

Ví dụ mẫu · Capacity factor of two power plants

A nuclear plant rated at 1000 MW generates 7884 GWh in a year (8760 hours). A wind farm rated at 200 MW generates 525.6 GWh in the same year. Compare their capacity factors.

Solution. Maximum possible energy = rated power × hours.

Nuclear: max $= 1000\text{ MW} \times 8760\text{ h} = 8760000\,\text{MWh} = 8760\,\text{GWh}$; capacity factor $= \dfrac{7884}{8760} = 0.90 = 90\%$.

Wind: max $= 200\text{ MW} \times 8760\text{ h} = 1752000\,\text{MWh} = 1752\,\text{GWh}$; capacity factor $= \dfrac{525.6}{1752} = 0.30 = 30\%$.

The nuclear plant runs near full power almost continuously (90%), typical of baseload; the wind farm (30%) reflects the intermittent resource. This is why intermittent renewables are usually paired with storage or flexible back-up.

Ví dụ mẫu · Energy density and fuel mass

Coal has an energy density of about 30 MJ.kg^{-1}; natural gas about 55 MJ.kg^{-1}. To deliver 3.3 GJ of chemical energy, what mass of each fuel is needed, and which is lighter?

Solution. Mass = energy ÷ energy density. Convert 3.3 GJ $= 3300$ MJ.

Coal: $\dfrac{3300\text{ MJ}}{30\text{ MJ kg}^{-1}} = 110\,\text{kg}$.

Natural gas: $\dfrac{3300\text{ MJ}}{55\text{ MJ kg}^{-1}} = 60\,\text{kg}$.

Natural gas is lighter (60 vs 110 kg) for the same energy, because of its higher energy density; it also emits less CO2 per unit energy than coal, which is why gas is often used as a "bridge" fuel.

Ví dụ mẫu · Payback time of a solar investment

A household installs a solar array costing 6000 USD. It saves 750 USD per year on electricity bills. Ignoring interest and maintenance, calculate the simple payback time, and state one factor that would lengthen it.

Solution. Simple payback $= \dfrac{\text{initial cost}}{\text{annual saving}} = \dfrac{6000}{750} = 8$ years.

After eight years the system has paid for itself; thereafter the electricity is effectively free (until the panels degrade). A factor that would *lengthen* the payback: a lower capacity factor (for example a cloudier location) reduces annual output and thus annual savings, pushing the payback time beyond eight years. Maintenance costs or a fall in grid electricity prices would also lengthen it.

7.9 Practice problems

Bài tập luyện tập

1. Which of the following is *not* a greenhouse gas?

(A) Methane (CH4)

(B) Nitrous oxide (N2O)

(C) Nitrogen (N2)

(D) Water vapour (H2O)

Lời giải chi tiết

(C). Molecular nitrogen N2 is a symmetrical diatomic molecule with no infrared-active vibrational mode, so it does not absorb outgoing longwave radiation. It makes up about 78% of the atmosphere but plays no role in the greenhouse effect. Methane, nitrous oxide and water vapour are all greenhouse gases.

Bài tập luyện tập

2. State the difference between the natural and the enhanced greenhouse effect.

Lời giải chi tiết

The **natural** greenhouse effect is the warming produced by greenhouse gases present in the atmosphere without human input; it raises the mean surface temperature from about $-18\,^\circ$C to $\approx 15\,^\circ$C and makes Earth habitable. The **enhanced** greenhouse effect is the *additional* warming caused by human activities that raise greenhouse-gas concentrations above natural levels, producing a positive radiative forcing and driving global warming.

Bài tập luyện tập

3. A landfill emits 120 tonnes of methane per year. Using a GWP of 28, express this as CO2-equivalent.

Lời giải chi tiết

CO2e $= m \times$ GWP $= 120 \times 28 = 3360$ tonnes CO2e per year. The methane traps as much heat over a century as $3{,}360$ tonnes of CO2.

Bài tập luyện tập

4. The 100-year GWP of CO_2 is, by definition:

(A) 0 **(C)** 28

(B) 1 **(D)** 265

Lời giải chi tiết

(B). GWP is measured *relative* to CO_2, so CO_2 has a GWP of exactly 1 by definition. Values of 28 and 265 are approximate GWPs for CH_4 and N_2O.

Bài tập luyện tập

5. Explain why methane has a much higher GWP than CO_2 even though it stays in the atmosphere for a far shorter time.

Lời giải chi tiết

GWP combines two factors: how strongly a molecule absorbs infrared radiation and how long it persists. Methane absorbs outgoing longwave radiation far more efficiently *per molecule* than CO_2, so during the decade or so it remains airborne it exerts a strong warming effect. Its short lifetime limits the 100-year integral, but the high per-molecule potency still gives it a GWP of about 28 — well above CO_2's value of 1.

Bài tập luyện tập

6. Incoming shortwave radiation at a site is 300 W.m^{-2} and the surface albedo is 0.25. Calculate the power per square metre (a) reflected and (b) absorbed.

Lời giải chi tiết

(a) Reflected $= \alpha S = 0.25 \times 300 = 75$ W.m^{-2}.
(b) Absorbed $= (1-\alpha)S = 0.75 \times 300 = 225$ W.m^{-2}. Check: $75 + 225 = 300$ W.m^{-2}.

Bài tập luyện tập

7. A surface of fresh snow (albedo 0.85) receives 400 W.m^{-2} of shortwave radiation. What fraction, and what power, is absorbed?

Lời giải chi tiết

Fraction absorbed $= 1 - 0.85 = 0.15$. Power absorbed $= 0.15 \times 400 = 60$ W.m^{-2}. Fresh snow reflects most incoming radiation, so it absorbs very little and stays cold — one reason ice sheets are self-preserving until warming triggers the ice–albedo feedback.

Bài tập luyện tập

8. The value ≈ 340 W.m^{-2} for globally averaged incoming solar radiation is roughly one quarter of the solar constant. Explain why the factor is one quarter.

Lời giải chi tiết

The Earth intercepts sunlight over its cross-sectional **disc** of area πr^2, but it distributes and re-radiates that energy over its whole **spherical** surface of area $4\pi r^2$. The ratio $\pi r^2/4\pi r^2 = 1/4$, so the average flux over the planet is one quarter of the solar constant: $1360/4 = 340$ W.m^{-2}.

Bài tập luyện tập

9. The Keeling curve is a record of:

(A) Global sea-level rise

(B) Atmospheric CO2 concentration

(C) Ocean pH

(D) Arctic sea-ice extent

Lời giải chi tiết

(B). The Keeling curve is the continuous record of atmospheric CO2 concentration measured at Mauna Loa since 1958, showing a seasonal sawtooth on a rising long-term trend.

Bài tập luyện tập

10. From data, atmospheric CO2 was 354 ppm in 1990 and 414 ppm in 2020. Calculate the mean rate of rise in ppm per year.

Lời giải chi tiết

$$\text{Rate} = \frac{414 - 354}{2020 - 1990} = \frac{60}{30} = 2.0\,\text{ppm.yr}^{-1}.$$

Bài tập luyện tập

11. Explain how ice cores provide evidence of past atmospheric composition and temperature.

Lời giải chi tiết

As snow accumulates and compresses into glacial ice, it traps tiny bubbles of the contemporary atmosphere. Drilling deep cores and analysing these bubbles reveals past concentrations of CO2 and CH4 layer by layer, giving a record spanning more than $800{,}000$ years. Oxygen-isotope ratios in the ice itself act as a proxy thermometer for the temperature at the time the snow fell. Together these show that today's greenhouse-gas levels are unprecedented over that interval and that CO2 and temperature have varied together.

Bài tập luyện tập

12. Define *phenology* and give one example of a phenological shift attributed to climate change.

Lời giải chi tiết

Phenology is the study of the timing of recurring seasonal biological events, such as flowering, leaf-out, migration, or breeding. An example of a climate-driven shift is earlier spring flowering or earlier bird migration in warming regions; poleward or upslope range shifts of species are also accepted.

Bài tập luyện tập

13. Classify each feedback as positive or negative: (a) warming increases atmospheric water vapour, a greenhouse gas; (b) a warmer surface radiates more longwave energy to space.

Lời giải chi tiết

(a) **Positive** — more water vapour traps more longwave radiation, amplifying the initial warming. (b) **Negative** — enhanced longwave emission (σT^4 rises with temperature) sheds energy and counteracts the warming, stabilising the system.

Bài tập luyện tập

14. Describe the ice–albedo feedback as a loop and state whether it stabilises or destabilises the climate.

Lời giải chi tiết

Loop: warming melts reflective ice and snow → darker ocean or land is exposed → albedo falls, so more shortwave radiation is absorbed → further warming → more melting. Each pass amplifies the change, so it is a **positive feedback** that **destabilises** the climate (drives it further from its starting state).

Bài tập luyện tập

15. Define a *tipping point* and give one example relevant to climate change.

Lời giải chi tiết

A **tipping point** is a critical threshold beyond which a small additional change pushes a system into a qualitatively different, often irreversible state. Examples: collapse of the Greenland or West Antarctic ice sheet, Amazon rainforest dieback, or shutdown of the Atlantic thermohaline circulation.

Bài tập luyện tập

16. Ocean acidification is caused directly by:

(A) Rising air temperature
(B) Dissolved CO2 forming carbonic acid
(C) Sea-level rise
(D) Increased albedo

Lời giải chi tiết

(B). CO2 dissolving in seawater forms carbonic acid, which lowers ocean pH. This is a direct chemical consequence of higher CO2, distinct from the warming caused by the greenhouse effect.

Bài tập luyện tập

17. Explain why sea-level rise threatens small-island states in more than one way.

Lời giải chi tiết

Rising seas cause **inundation** of low-lying land and **coastal erosion**, directly reducing habitable and farmable area. In addition, higher sea level drives **saltwater intrusion** into freshwater aquifers and soils, contaminating drinking-water supplies and reducing agricultural productivity. Storm surges on top of a higher baseline sea level also become more damaging. Together these can make islands uninhabitable, potentially creating climate refugees.

Bài tập luyện tập

18. Distinguish between mitigation and adaptation, giving one example of each.

Lời giải chi tiết

Mitigation reduces the *causes* of climate change (greenhouse-gas emissions), for example switching to renewable energy or imposing a carbon tax. **Adaptation** adjusts to the *impacts* that occur anyway, for example building sea walls or planting drought-resistant crops. Mitigation limits how severe the problem becomes; adaptation manages the unavoidable consequences.

Bài tập luyện tập

19. A firm emits 50000 tonnes of CO2e per year. Under a carbon tax of 30 USD per tonne, calculate the annual tax bill and the saving from cutting emissions by 10000 tonnes.

Lời giải chi tiết

Tax bill $= 50{,}000 \times 30 = 1500000$ USD per year. Cutting 10000 tonnes saves $10{,}000 \times 30 = 300000$ USD per year, giving the firm a strong incentive to invest in mitigation up to that value.

Bài tập luyện tập

20. Which international agreement, adopted in 2015, committed nearly all nations to hold warming well below $2\,^{\circ}$C?

(A) The Kyoto Protocol

(B) The Montreal Protocol

(C) The Paris Agreement

(D) The Rio Declaration

Lời giải chi tiết

(C). The Paris Agreement (2015) set the "well below $2\,^{\circ}$C, pursuing $1.5\,^{\circ}$C" goal through Nationally Determined Contributions. Kyoto (1997) preceded it; the Montreal Protocol addresses ozone-depleting substances, not the broad climate target.

Bài tập luyện tập

21. State two advantages and two limitations of nuclear power as an energy source.

Lời giải chi tiết

Advantages (any two): very high energy density; low operating CO2 emissions; reliable baseload output with a high capacity factor; small land footprint per unit energy. Limitations (any two): long-lived radioactive waste; high capital cost and long build times; risk of accidents; dependence on finite uranium and public/political opposition.

Bài tập luyện tập

22. A wind farm rated at 150 MW generates 394.2 GWh in a year (8760 hours). Calculate its capacity factor.

Lời giải chi tiết

Maximum energy $= 150$ MW $\times$ 8760 h $= 1314000$ MWh $= 1314$ GWh. Capacity factor $= \dfrac{394.2}{1314} = 0.30 = 30\%$, typical of onshore wind.

Bài tập luyện tập

23. Define *energy security* and list three factors that influence a country's choice of energy sources.

Lời giải chi tiết

Energy security is the reliable, affordable, and uninterrupted supply of energy for a country. Factors influencing the choice (any three): natural resource endowment (domestic fossil fuels, hydro potential, sunshine, wind); cost and available technology; political and cultural attitudes (for example acceptance of nuclear power); environmental policy and climate commitments; and dependence on imports from other states.

Bài tập luyện tập

24. Explain what is meant by an *energy mix* and why diversifying it improves energy security.

Lời giải chi tiết

An **energy mix** is the combination of different energy sources a country uses to meet total demand. Diversifying spreads supply across several sources and suppliers, so a shortage, price spike, or supply cut in any one source (for example imported gas) has a smaller effect on the whole system. A diverse mix also lets reliable baseload sources cover the intermittency of renewables, improving overall reliability and, when renewables replace fossil fuels, lowering emissions.

Bài tập luyện tập

25. A biomass power station burns fuel with an energy density of 15 MJ.kg^{-1}. What mass is needed to supply 3000 MJ? Compare with coal at 30 MJ.kg^{-1}.

Lời giải chi tiết

Biomass: mass $= \dfrac{3000}{15} = 200$ kg. Coal: mass $= \dfrac{3000}{30} = 100$ kg. Biomass needs twice the mass of coal for the same energy because its energy density is half as large; low-density fuels require more material handling.

Bài tập luyện tập

26. A community considers two projects for 4.4 GJ of delivered energy: a solar system saving 550 USD per year costing 4400 USD, and a diesel generator costing 1000 USD but 800 USD per year to run. Discuss which is preferable over a 10-year horizon.

Lời giải chi tiết

Solar payback $= 4400/550 = 8$ years; over 10 years it costs 4400 USD up front, then effectively free energy, and it produces no operating emissions. The diesel generator costs $1000 + 10 \times 800 = 9000$ USD over 10 years and emits CO2 continuously. Although diesel is cheaper to install, its high running cost makes it far more expensive over the horizon (9000 USD vs 4400 USD), and it worsens climate impact. The solar option is preferable on both cost and emissions, provided the site has adequate sunshine (a low capacity factor would lengthen the payback).

Bài tập luyện tập

27. Explain why climate scientists present projected future warming as a *range* across several emissions scenarios rather than as a single predicted temperature.

Lời giải chi tiết

A single prediction would falsely imply that future warming is already physically determined. In reality, future warming depends on **scenario uncertainty** (how much greenhouse gas humanity actually chooses to emit — a matter of policy and economic choice, not physics) and, to a lesser extent, **model uncertainty** (precisely how sensitive the physical climate system is, e.g. cloud feedbacks and ocean heat uptake). Presenting a range of outcomes under different emissions scenarios communicates both sources of uncertainty honestly, and shows decision-makers how much of the projected outcome is still within humanity's control through policy choices.

Bài tập luyện tập

28. Two emissions scenarios project almost identical warming by 2030 but diverge sharply by 2100. Explain why near-term warming is largely the same across scenarios while long-term warming differs so much.

Lời giải chi tiết

Near-term warming is dominated by greenhouse gases already emitted in the past, whose full warming effect is delayed for decades by the ocean's large thermal inertia — this warming is now largely "locked in" regardless of the scenario chosen. The scenarios diverge later in the century because, by then, **cumulative future emissions** (which differ enormously between a strongly mitigated and a high-emissions pathway) dominate the total radiative forcing. This implies mitigation choices made today have their largest effect on warming decades from now, not immediately — a key reason climate policy requires sustained, long-term commitment.

Bài tập luyện tập

29. Ocean surface pH is projected to fall from about 8.1 today to about 7.8 by 2100 under a high-emissions scenario. Using $10^{0.3} \approx 2.0$, estimate the factor by which hydrogen ion concentration $[\mathrm{H+}]$ (acidity) would increase over this period.

Lời giải chi tiết

ΔpH $= 8.1 - 7.8 = 0.3$ units. Because pH is a $\log_{10}$ scale, this fall corresponds to a factor increase in $[\text{H}+]$ of $10^{0.3} \approx 2.0$ — i.e. ocean water would become approximately **twice** as acidic (in terms of hydrogen ion concentration) by 2100 under this scenario, illustrating again how a seemingly modest change on the pH scale corresponds to a large proportional change in acidity.

Bài tập luyện tập

30. State one impact of climate change that is a direct chemical consequence of rising atmospheric CO_2 *itself*, as opposed to a consequence of the associated warming, and explain the distinction.

Lời giải chi tiết

Ocean acidification is the clearest example: dissolved CO_2 reacts with seawater to form carbonic acid, directly lowering ocean pH, *regardless of any accompanying temperature rise*. This is distinct from impacts such as sea-level rise, coral bleaching from heat stress, or shifting precipitation patterns, all of which are consequences of the *warming* that enhanced CO_2 concentrations cause via the greenhouse effect. The distinction matters because even a hypothetical technology that captured heat without reducing atmospheric CO_2 concentration would not prevent ocean acidification, since it is driven by the CO_2 molecule dissolving in seawater, not by temperature.

Human Systems and Resource Use

Mục tiêu Unit: Động lực dân số: tỉ suất sinh thô (CBR), tỉ suất tử thô (CDR), tỉ lệ gia tăng tự nhiên NIR $= (\text{CBR} - \text{CDR})/10$ (%), thời gian tăng gấp đôi theo quy tắc 70, tổng tỉ suất sinh (TFR), tháp dân số (mở rộng/ổn định/thu hẹp); mô hình chuyển đổi dân số (DTM) 5 giai đoạn và các hạn chế; các yếu tố ảnh hưởng đến biến động dân số và quan hệ giữa phát triển với nhân khẩu học; vốn tự nhiên và thu nhập tự nhiên; tài nguyên tái tạo, có thể bổ sung và không tái tạo; **dấu chân sinh thái (ecological footprint)**, sức tải sinh học (biocapacity), thâm hụt/dự trữ sinh thái; chất thải rắn sinh hoạt (SDW) và thứ bậc xử lí chất thải; hệ đô thị, đảo nhiệt đô thị, dòng tài nguyên qua thành phố và chiến lược đô thị bền vững.

8.1 Human population dynamics

The size of a human population changes through only four processes: **births** and **immigration** add people, while **deaths** and **emigration** remove them. Over a whole country immigration and emigration often roughly balance, so demographers concentrate first on the balance between births and deaths, which is called **natural change**.

8.1.1 Crude birth rate and crude death rate

The **crude birth rate (CBR)** is the number of live births per thousand people in a population per year:

$$\text{CBR} = \frac{\text{number of live births in a year}}{\text{total mid-year population}} \times 1000.$$

The **crude death rate (CDR)** is defined the same way for deaths:

$$\text{CDR} = \frac{\text{number of deaths in a year}}{\text{total mid-year population}} \times 1000.$$

Both are called *crude* because they take no account of the age structure of the population. A country full of young adults will have a low CDR simply because few people are old, even if health care is poor; a country with many elderly people (for example Japan) can have a relatively high CDR despite excellent health care.

8.1.2 Natural increase rate and doubling time

The **natural increase rate (NIR)** is the percentage rate at which a population grows through births minus deaths, ignoring migration. Because CBR and CDR are expressed per 1000 and a percentage is per 100, we divide their difference by 10:

$$\boxed{\text{NIR (\%)} = \frac{\text{CBR} - \text{CDR}}{10}}$$

A positive NIR means the population is growing; a negative NIR means it is shrinking. If migration is significant, the overall growth rate adds the net migration rate.

Once we know the percentage growth rate we can estimate the **doubling time** — the number of years for the population to double in size — using the **rule of 70**:

$$\boxed{t_{\text{double}} = \frac{70}{\text{growth rate (\% per year)}}}$$

The rule of 70 is a convenient approximation of the exact expression $\ln 2/\ln(1+r)$, because $\ln 2 \approx 0.693 \approx 70\%$. It works well for the small growth rates seen in real populations.

VN GIẢI THÍCH TIẾNG VIỆT

CBR (tỉ suất sinh thô) là số ca sinh sống trên 1000 dân mỗi năm; **CDR** (tỉ suất tử thô) là số ca tử vong trên 1000 dân mỗi năm. Cả hai gọi là "thô" vì bỏ qua cấu trúc tuổi. **Tỉ lệ gia tăng tự nhiên** NIR $=$ (CBR $-$ CDR)$/10$ tính theo phần trăm/năm; chia cho 10 vì CBR, CDR tính trên 1000 còn phần trăm tính trên 100. **Thời gian tăng gấp đôi** $t = 70/$tốc độ tăng $(\%)$ — quy tắc 70, xuất phát từ $\ln 2 \approx 0{,}70$.

Ví dụ mẫu · Natural increase rate from CBR and CDR

A country records a CBR of 32 and a CDR of 8 (both per 1000 per year). Find the natural increase rate.

Solution. NIR $= \dfrac{\text{CBR} - \text{CDR}}{10} = \dfrac{32-8}{10} = \dfrac{24}{10} = 2.4\%$ per year.

The population grows by 2.4% each year through natural change alone — a rapidly growing population typical of a less economically developed country in the early stages of demographic transition.

Ví dụ mẫu · Doubling time via the rule of 70

Using the country above with NIR $= 2.4\%$, estimate the doubling time. Then compare with a second country whose NIR is 0.5%.

Solution. For the first country: $t = \dfrac{70}{2.4} \approx 29.2$ years — the population doubles in roughly 29 years.

For the second: $t = \dfrac{70}{0.5} = 140$ years. A fivefold difference in growth rate produces a nearly fivefold difference in doubling time; small changes in the percentage rate translate into very large changes in how fast a population expands.

8.1.3 Migration and the overall growth rate

Natural increase (births minus deaths) is only part of the story of population change: **migration** — the movement of people into (**immigration**) or out of (**emigration**) a population — can add to or subtract from it independently.

The **overall population growth rate** combines both components:

$$\text{overall growth rate} = \text{NIR} + \text{net migration rate}$$

where the **net migration rate** is (immigrants $-$ emigrants) per 1000 population per year, expressed as a percentage in the same way as NIR. Migration is driven by **push factors** (conditions that drive people to leave an area — conflict, poverty, unemployment, environmental degradation or disaster, persecution) and **pull factors** (conditions that attract people to a destination — employment opportunities, higher wages, safety, family reunification, better services). For some countries and time periods, net migration can be a larger driver of total population change than natural increase itself — one of the limitations of the DTM noted in Section 8.2.

VN GIẢI THÍCH TIẾNG VIỆT

Tỉ lệ tăng trưởng tổng thể $=$ NIR $+$ tỉ lệ di cư ròng (net migration rate), trong đó tỉ lệ di cư ròng $=$ (người nhập cư $-$ người xuất cư)/1000 dân/năm, tính theo % giống NIR. Di cư chịu tác động của **yếu tố đẩy (push factors)** — xung đột, nghèo đói, thất nghiệp, suy thoái môi trường — và **yếu tố kéo (pull factors)** — cơ hội việc làm, lương cao hơn, an toàn, đoàn tụ gia đình, dịch vụ tốt hơn. Ở một số quốc gia/giai đoạn, di cư ròng có thể là động lực thay đổi dân số lớn hơn cả gia tăng tự nhiên.

Ví dụ mẫu · Combining natural increase and net migration

A country has CBR $= 14$ and CDR $= 8$ (per 1000 per year). In the same year, $45{,}000$ people immigrate and $15{,}000$ emigrate, out of a total mid-year population of $6{,}000{,}000$. Calculate the NIR, the net migration rate, and the overall population growth rate.

NIR $= \dfrac{14-8}{10} = 0.6\%$ per year.

Net migration rate $= \dfrac{45{,}000 - 15{,}000}{6{,}000{,}000} \times 100 = \dfrac{30{,}000}{6{,}000{,}000} \times 100 = 0.5\%$ per year.

Overall growth rate $= 0.6\% + 0.5\% = 1.1\%$ per year.

Here, migration contributes nearly as much to total population growth (0.5%) as natural increase does (0.6%) — a reminder that a country's total growth rate cannot be estimated from CBR and CDR alone whenever migration is significant.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ví dụ trên cho thấy di cư (đóng góp $0{,}5\%$) gần bằng gia tăng tự nhiên (đóng góp $0{,}6\%$) vào tăng trưởng dân số tổng thể — vì vậy không thể chỉ dùng CBR và CDR để ước tính tỉ lệ tăng trưởng tổng thể của một quốc gia khi di cư có vai trò đáng kể.

8.1.4 Total fertility rate

The **total fertility rate (TFR)** is the average number of children a woman would have over her lifetime if she experienced the age-specific fertility rates observed in a given year. Unlike CBR, the TFR is not distorted by age structure, so it is a better measure of underlying reproductive behaviour. The **replacement fertility rate** — the TFR at which a population exactly replaces itself in the long run — is about **2.1** children per woman in countries with low child mortality (slightly above 2 to allow for children who do not survive to reproductive age; higher where child mortality is high). A TFR persistently below replacement leads, after a lag, to a declining and ageing population.

VN **GIẢI THÍCH TIẾNG VIỆT**

TFR (tổng tỉ suất sinh) là số con trung bình một phụ nữ sinh trong đời theo mức sinh của một năm nhất định. TFR không bị ảnh hưởng bởi cấu trúc tuổi nên phản ánh hành vi sinh sản tốt hơn CBR. **Mức sinh thay thế** $\approx 2{,}1$ con/phụ nữ; dưới mức này dân số sẽ giảm và già hoá sau một độ trễ.

8.1.5 Age–sex population pyramids

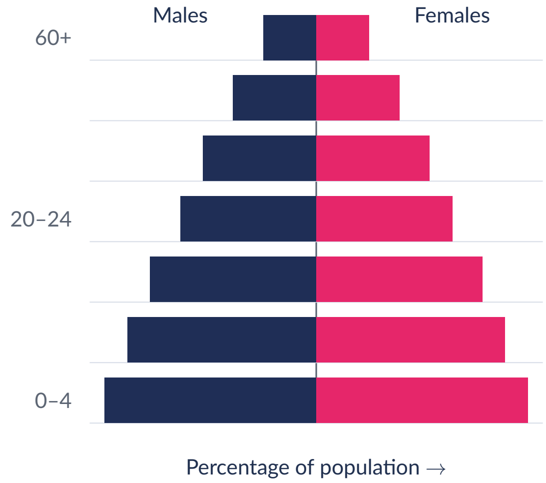
An **age–sex pyramid** (population pyramid) is a pair of back-to-back horizontal bar charts showing the percentage (or number) of the population in each five-year age band, males on the left and females on the right. Its *shape* summarises the demographic condition of a country:

- **Expansive** — a wide base tapering rapidly to a narrow top. High CBR and high NIR; many children, few elderly. Typical of a rapidly growing LIC/lower-MIC (for example Niger).
- **Stationary** — near-vertical sides with a roughly rectangular body that only narrows at the oldest ages. CBR $\approx$ CDR, NIR near zero, population size stable. Typical of a mature HIC (for example Sweden).

- **Constrictive** — a base narrower than the middle, so the pyramid appears to be "pinched in" at the bottom. Low CBR, below-replacement TFR, an ageing population and eventual decline (for example Japan).

A pyramid also reveals **dependency**. The **dependency ratio** compares the economically dependent population (typically those aged under 15 and 65-plus) with the working-age population (15–64):

$$\text{Dependency ratio} = \frac{\text{population } (<15) + \text{population } (65+)}{\text{population } (15\text{–}64)} \times 100.$$



An **expansive** age–sex pyramid: a broad base of young children tapering rapidly, indicating a high CBR, high NIR and a young, growing population.

> **GIẢI THÍCH TIẾNG VIỆT** VN
>
> **Tháp dân số** vẽ tỉ lệ mỗi nhóm tuổi (nam trái, nữ phải). Hình dạng cho biết tình trạng nhân khẩu: **mở rộng (expansive)** — đáy rộng, CBR và NIR cao, dân số trẻ và tăng nhanh; **ổn định (stationary)** — gần chữ nhật, CBR ≈ CDR, dân số ổn định; **thu hẹp (constrictive)** — đáy hẹp hơn thân, dân số già hoá và sẽ giảm. **Tỉ số phụ thuộc** $=$ (dưới $15 +$ trên $65)/(15\text{–}64) \times 100$.

Ví dụ mẫu · Classifying a pyramid and computing dependency

A country's population is split as: under-15s $= 34\%$, ages 15–64 $= 61\%$, and 65-plus $= 5\%$. Classify the likely pyramid shape and compute the dependency ratio.

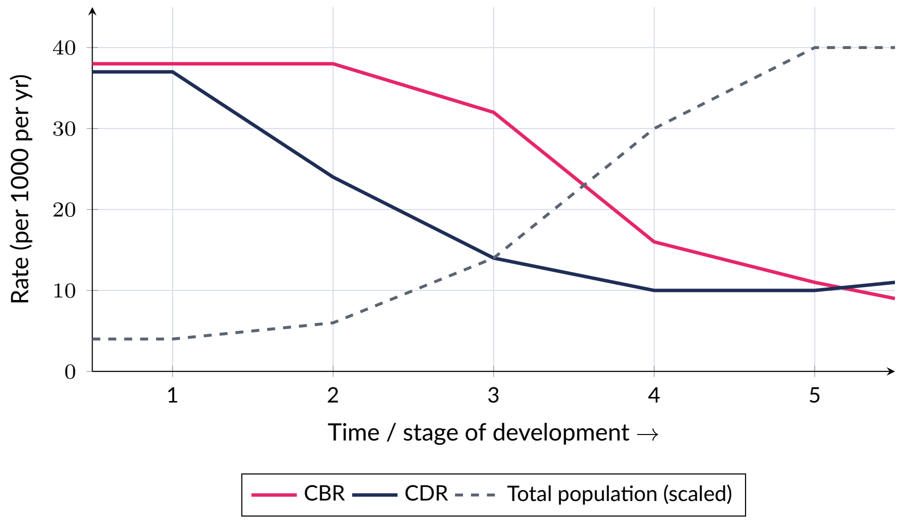
Solution. A large young base (34% under 15) with a small elderly group (5%) gives a broad-based, sharply tapering **expansive** pyramid.

$$\text{Dependency ratio} = \frac{34+5}{61} \times 100 = \frac{39}{61} \times 100 \approx 63.9.$$

About 64 dependants for every 100 workers, dominated by *child* dependency rather than elderly dependency.

8.2 The Demographic Transition Model

The **Demographic Transition Model (DTM)** describes how CBR, CDR, total population and NIR change as a country develops from a pre-industrial, agrarian society into a post-industrial, urbanised one. In its five-stage form it is read as a graph of CBR and CDR (falling curves) over time, with total population plotted as a third line.



The five-stage DTM: CDR falls first (stage 2), then CBR falls (stage 3), so total population rises steeply while the two rates converge; in stage 5 CBR can drop below CDR and population declines.

8.2.1 The five stages

- **Stage 1 — high stationary.** Both CBR and CDR are high (≈ 35–40) and fluctuate; NIR is near zero, so population is low and stable. Pre-industrial societies with poor sanitation, unreliable food supply, and no modern medicine. Essentially no country is in stage 1 today.
- **Stage 2 — early expanding.** CDR falls sharply (better sanitation, clean water, food security, vaccination) while CBR stays high. The gap between them opens, NIR rises to its maximum, and total population begins to grow rapidly. Many LICs.
- **Stage 3 — late expanding.** CBR now falls (contraception, urbanisation, female education, lower infant mortality reducing the "need" for many children, children becoming an economic cost rather than a labour asset). CDR continues to fall or levels off. NIR is still positive but declining; population growth slows. Many emerging MICs.
- **Stage 4 — low stationary.** Both CBR and CDR are low (≈ 10); NIR is near zero and population is high and roughly stable. Mature HICs.
- **Stage 5 — decline (proposed).** CBR falls *below* CDR (very low TFR combined with an ageing population raising CDR), so NIR becomes negative and total population declines and ages. Examples proposed include Japan, Germany and Italy.

Behaviour of the key variables through the DTM

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
CBR	high	high	falling	low	low
CDR	high	falling fast	falling / low	low	low, slowly rising
NIR	≈ 0	rising (max)	positive, falling	≈ 0	negative
Total population	low, stable	rising fast	rising, slowing	high, stable	high, declining

8.2.2 Limitations of the model

The DTM is a useful generalisation but it has real limitations. It was built on the historical experience of industrialising *European* countries and may not fit others. It does not include **migration**, which can be a larger driver of change than natural increase (for example in Gulf states or small island nations). It assumes development *drives* falling fertility, whereas cultural, religious and policy factors (China's former one-child policy; pronatalist policies elsewhere) can move fertility independently of income. It gives no timescale — some countries pass through the stages in decades, others over more than a century — and the original four-stage version did not predict the stage-5 decline now observed. Finally, it treats a country as a single unit, hiding large internal differences between rich cities and poor rural regions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mô hình chuyển đổi dân số (DTM) mô tả CBR, CDR và tổng dân số thay đổi qua 5 giai đoạn khi một nước phát triển. Giai đoạn 2: CDR giảm mạnh trước (vệ sinh, y tế, thực phẩm) trong khi CBR còn cao ⇒ NIR đạt đỉnh, dân số bùng nổ. Giai đoạn 3: CBR bắt đầu giảm (tránh thai, đô thị hoá, giáo dục nữ giới). Giai đoạn 4: cả hai đều thấp, dân số ổn định. Giai đoạn 5: CBR $<$ CDR ⇒ dân số giảm và già hoá (Nhật, Đức, Ý). **Hạn chế**: dựa trên châu Âu, bỏ qua di cư, giả định phát triển quyết định mức sinh, không có mốc thời gian, và che giấu khác biệt vùng miền trong một nước.

Ví dụ mẫu · Identifying the DTM stage from data

Three countries report the following (per 1000 per year):

	CBR	CDR	NIR
Country X	40	14	?
Country Y	12	9	?
Country Z	9	11	?

Complete the NIR column and assign each country a DTM stage.

Solution.

- **X**: NIR $= (40 - 14)/10 = +2.6\%$. High CBR, still-high but falling CDR, large positive NIR ⇒ **stage 2** (early expanding).
- **Y**: NIR $= (12 - 9)/10 = +0.3\%$. Both rates low, NIR near zero ⇒ **stage 4** (low stationary).
- **Z**: NIR $= (9 - 11)/10 = -0.2\%$. CBR below CDR, negative NIR ⇒ **stage 5** (decline).

8.3 Factors affecting population change and development

Fertility and mortality respond to a web of interacting factors. **Factors that tend to lower CBR / TFR** include: improved education, especially of girls and women; wider access to contraception and family planning; rising female participation in the paid workforce; urbanisation (where children are a cost, not farm labour); falling infant and child mortality (so parents no longer have many children to insure against loss); later marriage; and rising incomes. **Factors that tend to raise CBR** include: a tradition of large families or high status attached to children; religious or cultural opposition to contraception; the economic value of child labour in agriculture; high infant mortality; and pronatalist government policies. **Factors that lower CDR** include clean water and sanitation, secure food supply, vaccination and antibiotics, and improved maternal and child health care.

The broad empirical pattern is that **as development rises, fertility falls**. Measures of development such as GDP per capita, the Human Development Index (HDI), female literacy and life expectancy correlate strongly and negatively with TFR. This is why the DTM couples demographic change to economic development. But the relationship is not mechanical: government policy, culture and religion can decouple fertility from income in either direction.

VN **GIẢI THÍCH TIẾNG VIỆT**

Các yếu tố **giảm CBR/TFR**: giáo dục (đặc biệt cho nữ), tránh thai, phụ nữ đi làm, đô thị hoá, tử vong trẻ em giảm, kết hôn muộn, thu nhập tăng. Các yếu tố **giảm CDR**: nước sạch, vệ sinh, an ninh lương thực, tiêm chủng, kháng sinh, chăm sóc y tế. Quy luật chung: **phát triển tăng**

> **thì mức sinh giảm** (TFR tương quan âm với GDP/người, HDI, tỉ lệ biết chữ của nữ, tuổi thọ) — nhưng chính sách, văn hoá, tôn giáo có thể tách rời mức sinh khỏi thu nhập.

8.4 Resource use and natural capital

8.4.1 Natural capital and natural income

Recall from Topic 1 that **natural capital** is the stock of natural resources and ecological systems that yield useful goods and services to humanity — forests, fish stocks, fertile soil, aquifers, the atmosphere. **Natural income** is the yield (the goods and services) that this capital produces: timber, a fish harvest, clean water, climate regulation, pollination. Managing resources **sustainably** means using only the natural income — living off the interest without depleting the capital stock, so the same yield remains available indefinitely.

8.4.2 Renewable, replenishable and non-renewable resources

Natural resources are usually classified by how, and how fast, they are regenerated:

- **Renewable natural capital** — living resources that reproduce and regenerate on a human timescale, such as fish, forests and crops. They can be harvested sustainably *if* the harvest does not exceed the rate of natural replacement; over-harvesting turns a renewable resource into a depleting one.
- **Replenishable natural capital** — non-living resources that are continually restored by natural processes but are not themselves alive, such as groundwater and the ozone layer. They can be degraded or polluted faster than they recover.
- **Non-renewable natural capital** — resources that exist in fixed stocks and either do not renew or renew only over geological time, such as fossil fuels and mineral ores. Any use permanently reduces the stock.

The **value of a resource changes over time and place**. A substance becomes a "resource" only when a society has the technology, need and economic means to exploit it: uranium was worthless before nuclear fission; lithium was a minor commodity before rechargeable batteries. Value also varies with location and culture — fresh water is priceless in a desert and taken for granted beside a river; a forest may be valued for timber in one economy and for carbon storage or ecotourism in another. Scarcity, technological change, substitution and shifting cultural priorities all continually rewrite what counts as a valuable resource.

> VN GIẢI THÍCH TIẾNG VIỆT
> **Vốn tự nhiên** là kho tài nguyên và hệ sinh thái tạo ra hàng hoá, dịch vụ; **thu nhập tự nhiên** là phần "lãi" chúng sinh ra. Dùng bền vững nghĩa là chỉ tiêu thụ thu nhập tự nhiên, không làm cạn vốn. Phân loại: **tái tạo (renewable)** — sinh vật tự tái sinh (cá, rừng) nếu khai thác không vượt tốc độ phục hồi; **có thể bổ sung (replenishable)** — phi sinh vật được khôi phục tự nhiên (nước ngầm, tầng ozon); **không tái tạo (non-renewable)** — kho cố định (nhiên liệu hoá thạch, quặng). Giá trị tài nguyên thay đổi theo thời gian và không gian tuỳ công nghệ, nhu cầu và văn hoá.

8.5 The ecological footprint

The **ecological footprint (EF)** is the area of productive land and water required to supply all the resources a population consumes and to absorb all the wastes it produces — in particular the land needed to sequester its carbon-dioxide emissions — using prevailing technology, expressed per capita in **global hectares (gha)**. It is a model that converts diverse forms of consumption into a single, comparable measure of the demand a population places on the biosphere.

8.5.1 How it is calculated conceptually

Conceptually the footprint sums several component areas: cropland to grow food and fibre; grazing land for animal products; fishing grounds; forest for timber and paper; built-up land for infrastructure; and — usually the largest single component for a HIC — the **carbon (energy) land**: the forest area that would be needed to absorb the population's fossil-fuel CO2 emissions. A simple estimate of the carbon land is

$$\text{carbon land area} = \frac{\text{annual CO2 emissions}}{\text{carbon absorbed per hectare per year}}.$$

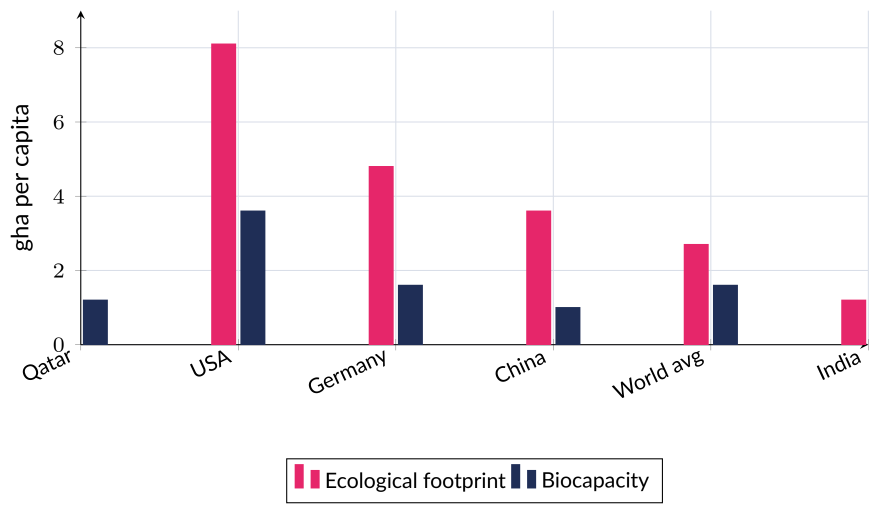
8.5.2 Biocapacity, deficit and reserve

The **biocapacity** of an area is the productive capacity actually available — the amount of biologically productive land and water it contains, expressed in gha per capita. Comparing the two gives the balance of an economy with nature:

$$\text{ecological balance} = \text{biocapacity} - \text{ecological footprint}.$$

If the footprint exceeds biocapacity the region runs an **ecological deficit** (it is in "overshoot", drawing down natural capital or importing biocapacity from elsewhere); if biocapacity exceeds the footprint it holds an **ecological reserve**. Globally, humanity's footprint now exceeds Earth's biocapacity, so we are in overshoot.

HICs have much larger footprints than LICs because of high per-capita energy use (large carbon land), meat-rich diets (large grazing and cropland demand), high consumption of manufactured goods, extensive built land, and long-distance transport and imports. Two people can consume identical calories yet have very different footprints depending on how their energy is generated and how their food is produced.



Illustrative per-capita ecological footprint versus biocapacity. Where the pink bar exceeds the navy bar the country runs an ecological deficit; the gap is far larger for HICs than for LICs.

VN **GIẢI THÍCH TIẾNG VIỆT**

Dấu chân sinh thái là diện tích đất và nước sản xuất cần để cung cấp tài nguyên một dân số tiêu thụ và hấp thụ chất thải (đặc biệt là CO2), tính theo hecta toàn cầu (gha)/người. Thành phần lớn nhất ở nước giàu thường là **đất carbon** = CO2 phát thải / lượng hấp thụ mỗi ha. **Sức tải sinh học (biocapacity)** là năng lực sản xuất thực có. Nếu dấu chân > sức tải ⇒ **thâm hụt sinh thái** (overshoot); ngược lại là **dự trữ sinh thái**. Nước HIC có dấu chân lớn hơn nhiều do dùng nhiều năng lượng, ăn nhiều thịt, tiêu thụ hàng hoá và nhập khẩu.

Ví dụ mẫu · Carbon land from emissions and sequestration

A person emits $10{,}000$ kg (10 tonnes) of CO2 per year. Productive forest sequesters about $5{,}000$ kg of CO2 per hectare per year. Estimate the carbon-land component of this person's ecological footprint.
Solution.

$$\text{carbon land} = \frac{\text{emissions}}{\text{sequestration per ha}} = \frac{10{,}000\ \text{kg}}{5{,}000\ \text{kg ha}^{-1}} = 2.0\ \text{ha}.$$

Two hectares of forest are needed just to absorb this one person's carbon emissions, before adding cropland, grazing, fishing and built land. This carbon component alone already exceeds the global average biocapacity of about 1.6 gha per person.

Ví dụ mẫu · Full footprint and ecological deficit

A citizen's footprint components are: carbon land 2.0 gha, cropland 1.1 gha, grazing 0.5 gha, forest products 0.4 gha, fishing 0.2 gha and built land 0.1 gha. Their country's biocapacity is 1.7 gha per capita. Find the total footprint and the ecological balance.
Solution. Total footprint:

$$2.0 + 1.1 + 0.5 + 0.4 + 0.2 + 0.1 = 4.3 \text{ gha per capita.}$$

Ecological balance $=$ biocapacity $-$ footprint $= 1.7 - 4.3 = -2.6$ gha per capita.
The negative value is an **ecological deficit** of 2.6 gha per person: the country consumes about $4.3/1.7 \approx 2.5$ times its own biocapacity, meeting the shortfall by importing biocapacity and drawing down global natural capital.

Ví dụ mẫu · How many Earths?

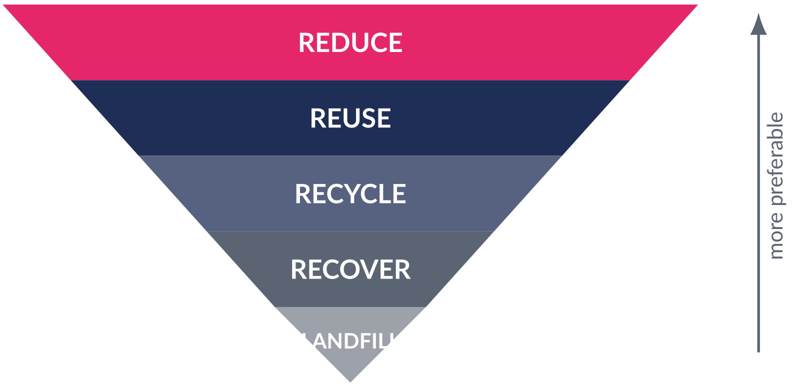
If the average world citizen has a footprint of 2.7 gha but the biosphere provides only 1.6 gha per person, how many "Earths" would be needed if everyone lived at the world-average level?
Solution. $\frac{2.7}{1.6} \approx 1.7$ Earths. Humanity would need about 1.7 planets to sustain current average consumption indefinitely — a direct statement of global overshoot.

8.6 Solid domestic waste

Solid domestic waste (SDW) — household "rubbish" or municipal solid waste — is the mixed solid material discarded from homes. Both its **volume** and its **composition** have changed with development. As incomes rise the *quantity* of waste per person rises, and the *mix* shifts from mostly organic (food, ash) toward packaging, plastics, paper, glass, metals and increasingly electronic waste (e-waste). Rising affluence, single-use packaging and short product lifespans all drive the volume upward, straining disposal systems.

8.6.1 The waste hierarchy

Waste-management strategies are ranked in the **waste hierarchy**, from most to least environmentally preferable: **reduce** (avoid creating waste in the first place — the most effective option), then **reuse**, then **recycle**, then **recover** (extract energy, for example by incineration with energy recovery, or capture methane from decomposition), and finally **dispose** to **landfill** as the least preferable option. Higher tiers conserve resources and energy and produce less pollution.



The waste hierarchy: reduce > reuse > recycle > recover > landfill. The widest, top tier (reduce) prevents waste at source and is the most environmentally preferable.

8.6.2 Managing SDW and the pollution-management model

Concrete strategies fall into two families. **Landfill** buries waste; it is cheap but consumes land, can leak leachate into groundwater and emits methane (a potent greenhouse gas) unless captured. **Incineration** burns waste, cutting volume by up to about 90% and allowing energy recovery, but it produces air pollution and toxic ash and requires costly emission controls. **Recycling and composting** return materials and nutrients to use, reducing both raw-material extraction and landfill demand.

These map onto the general **pollution-management model**, which offers three levels of intervention, most to least effective:

1. **Altering the human activity** that produces the pollutant — reducing consumption, redesigning products, replacing materials. Most effective because it prevents the pollutant.
2. **Regulating and controlling the release** of the pollutant — recycling schemes, landfill leachate liners and methane capture, incinerator scrubbers.
3. **Clean-up and restoration** after the pollutant has entered the environment — reclaiming landfill sites, remediating contaminated land. Least effective and often most costly.

VN GIẢI THÍCH TIẾNG VIỆT

Chất thải rắn sinh hoạt (SDW) tăng cả về khối lượng lẫn thay đổi thành phần khi thu nhập tăng (từ hữu cơ sang bao bì, nhựa, giấy, kim loại, rác điện tử). **Thứ bậc xử lí chất thải**: giảm thiểu > tái sử dụng > tái chế > thu hồi (năng lượng) > chôn lấp. **Mô hình quản lí ô nhiễm** có ba mức: (1) thay đổi hoạt động của con người (hiệu quả nhất), (2) kiểm soát phát thải, (3) dọn dẹp và phục hồi (kém hiệu quả nhất). Chôn lấp: rẻ nhưng tốn đất, rò rỉ nước rỉ rác và phát thải mêtan. Đốt: giảm $\sim 90\%$ thể tích, thu hồi năng lượng nhưng gây ô nhiễm không khí và tro độc.

Ví dụ mẫu · Recycling rate and waste diversion

A town generates $8{,}000$ tonnes of SDW per year. It recycles $1{,}800$ tonnes and composts a further $1{,}000$ tonnes; the rest goes to landfill. Find the recycling rate, the total diversion rate, and the mass landfilled.

Solution. Recycling rate $= \dfrac{1{,}800}{8{,}000} \times 100 = 22.5\%$.

Total diverted from landfill $= 1{,}800 + 1{,}000 = 2{,}800$ tonnes, so diversion rate $= \dfrac{2{,}800}{8{,}000} \times 100 = 35\%$.

Mass landfilled $= 8{,}000 - 2{,}800 = 5{,}200$ tonnes, i.e. 65% of the waste stream.

Ví dụ mẫu · Effect of a reduction programme

The same town launches a "reduce" campaign that cuts total waste generation by 15%, while keeping the same tonnages recycled and composted. What is the new landfill mass and the new diversion rate?

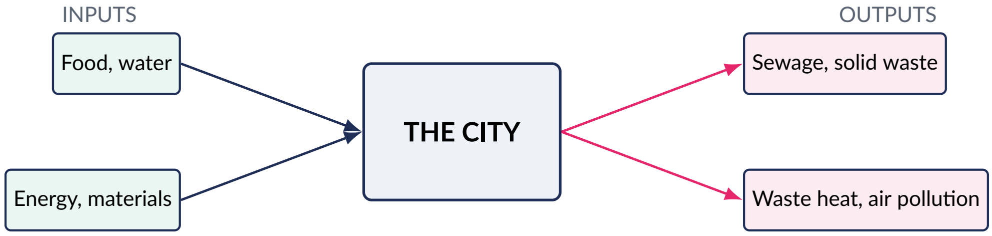
Solution. New generation $= 8{,}000 \times (1 - 0.15) = 6{,}800$ tonnes. Diverted mass unchanged at $2{,}800$ tonnes, so landfilled $= 6{,}800 - 2{,}800 = 4{,}000$ tonnes. New diversion rate $= \dfrac{2{,}800}{6{,}800} \times 100 \approx 41.2\%$.

Reducing at source (the top of the hierarchy) cut landfill from $5{,}200$ to $4{,}000$ tonnes — a larger absolute saving than the recycling already achieved, illustrating why "reduce" outranks "recycle".

8.7 Urban systems and sustainability

8.7.1 Urbanisation and the urban ecosystem

Urbanisation is the increasing proportion of a population living in towns and cities. More than half the world's people are now urban, and the share is rising fastest in LICs and MICs. A city can be analysed as an **urban ecosystem** — but an unusual one: it is a largely *heterotrophic* system that cannot supply its own energy or materials and depends on large **inputs** of food, water, fuel and manufactured goods drawn from a much larger surrounding area, converting them into **outputs** of sewage, solid waste, waste heat and air pollution. Because these flows are mostly linear (resources in, wastes out) rather than cyclical, cities concentrate both consumption and pollution.



Resource flows through a city: large inputs of food, water, energy and materials are transformed into outputs of sewage, solid waste, waste heat and air pollution — a largely linear metabolism.

8.7.2 The urban heat island and urban footprints

The **urban heat island (UHI)** effect is the tendency for a city to be warmer than its rural surroundings — often by several degrees Celsius, especially at night. Dark surfaces (asphalt, roofs) absorb solar radiation; concrete and brick store heat and release it slowly; vegetation and open water that would cool the air through evapotranspiration are scarce; and waste heat from vehicles, buildings and industry adds directly to the load. The UHI raises energy demand for cooling, worsens air quality, and increases heat-stress mortality during heatwaves.

Because cities import resources and export wastes across vast areas, their **ecological footprint** is many times their own physical area — a city occupies a small land area but depends on a "ghost acreage" of cropland, forest, fishing grounds and carbon-sink land spread around the world.

8.7.3 Strategies for sustainable cities

Making cities more sustainable means shrinking their per-capita footprint and closing their resource loops:

- **Compact cities** — higher-density, mixed-use development that shortens journeys, reduces car dependence and preserves surrounding land.
- **Public and active transport** — efficient mass transit, cycling and walking infrastructure to cut per-capita transport energy and emissions.

- **Green space and green infrastructure** — parks, street trees, green roofs and urban wetlands that cool the city (reducing the UHI), manage stormwater, support biodiversity and improve wellbeing.
- **Energy and buildings** — renewable generation, district heating, and well-insulated, efficient buildings.
- **Circular-economy ideas** — designing out waste by reusing, recycling and recovering materials and energy locally (composting organic waste, capturing waste heat, treating and reusing water) so the city's metabolism becomes more cyclical and less linear.

VN GIẢI THÍCH TIẾNG VIỆT

Đô thị hoá là tỉ lệ dân sống ở thành phố tăng lên. Thành phố là **hệ sinh thái đô thị** dị dưỡng: cần **đầu vào** lớn (thực phẩm, nước, năng lượng, vật liệu) và thải ra **đầu ra** (nước thải, rác, nhiệt thải, ô nhiễm không khí) — dòng chảy chủ yếu tuyến tính. **Đảo nhiệt đô thị (UHI)**: thành phố ấm hơn vùng nông thôn do bề mặt tối hấp thụ nhiệt, bê tông giữ nhiệt, thiếu cây xanh và nhiệt thải. Dấu chân sinh thái của thành phố lớn hơn nhiều lần diện tích thực. **Chiến lược bền vững**: thành phố nén (compact city), giao thông công cộng, không gian xanh, năng lượng tái tạo và ý tưởng **kinh tế tuần hoàn** (tái sử dụng, tái chế, thu hồi để khép kín dòng tài nguyên).

Ví dụ mẫu · A city's footprint versus its area

A city covers 600 km^2 and has 3 million residents, each with an ecological footprint of 4.0 gha. Compare the total footprint area with the city's own area. (1 gha $= 0.01$ km^2.)
Solution. Total footprint $= 3{,}000{,}000 \times 4.0 = 12{,}000{,}000$ gha $= 12{,}000{,}000 \times 0.01 = 120{,}000$ km^2.
Ratio $= \dfrac{120{,}000}{600} = 200$. The city depends on a productive area about **200 times** its own area — vivid evidence of the "ghost acreage" on which every large city relies.

Ví dụ mẫu · Emissions saved by a transit shift

A city of 2 million people averages 1.8 tonnes of transport CO2 per person per year. A new metro persuades 30% of residents to cut their personal transport emissions by half. Find the annual CO2 saving.
Solution. Residents affected $= 0.30 \times 2{,}000{,}000 = 600{,}000$. Each saves $\frac{1}{2} \times 1.8 = 0.9$ t/yr.

$$\text{Saving} = 600{,}000 \times 0.9 = 540{,}000 \text{ tonnes CO2 per year.}$$

More than half a million tonnes of CO2 avoided annually — a measurable reduction in the city's carbon footprint from a single compact-city strategy.

8.8 Practice problems

Bài tập luyện tập

A population has a CBR of 28 and a CDR of 9 (per 1000 per year). Its natural increase rate is:

(A) 1.9%

(B) 3.7%

(C) 19%

(D) 0.19%

Lời giải chi tiết

(A). NIR $= (28-9)/10 = 19/10 = 1.9\%$ per year. Dividing by 10 converts a per-1000 difference into a per-100 (percentage) rate.

Bài tập luyện tập

Using the rule of 70, a population growing at 1.9% per year will double in approximately:

(A) 37 years
(B) 70 years
(C) 133 years
(D) 19 years

Lời giải chi tiết

(A). $t = 70/1.9 \approx 36.8 \approx 37$ years.

Bài tập luyện tập

Which measure is *not* distorted by a population's age structure?

(A) Crude birth rate
(B) Crude death rate
(C) Total fertility rate
(D) Natural increase rate

Lời giải chi tiết

(C). The TFR is based on age-specific fertility rates, so it reflects reproductive behaviour independent of how many people happen to be young or old. CBR, CDR and NIR are all "crude" and therefore age-sensitive.

Bài tập luyện tập

Explain why two countries with identical crude death rates might have very different levels of health care.

Lời giải chi tiết

CDR ignores age structure. A country with a very young population can have a low CDR simply because few people are old enough to be at high risk of dying, even if health care is poor. A country with many elderly people can have an equal or higher CDR despite excellent health care, because a larger fraction of its population is in the high-mortality age bands. Thus equal CDRs can hide opposite health-care situations.

Bài tập luyện tập

A country's TFR has fallen to 1.4 children per woman. State the replacement fertility rate and explain the long-term consequence.

Lời giải chi tiết

Replacement fertility is about 2.1 children per woman (just above 2 to allow for children who do not survive to reproductive age). At a TFR of 1.4, well below replacement, each generation is smaller than the last. After a lag (while large older cohorts remain), the population will **decline**

and age, raising the elderly dependency ratio and shifting the pyramid toward a constrictive shape.

Bài tập luyện tập

An expansive population pyramid is characterised by:

(A) A narrow base and wide top
(B) A broad base tapering rapidly upward
(C) Vertical, near-rectangular sides
(D) A base narrower than the middle

Lời giải chi tiết

(B). A broad base of young children tapering rapidly indicates high CBR and high NIR — a young, rapidly growing population. (A) and (D) describe constrictive/ageing pyramids; (C) describes a stationary pyramid.

Bài tập luyện tập

A population is 30% under 15, 64% aged 15–64 and 6% aged 65+. Calculate the dependency ratio and state which type of dependency dominates.

Lời giải chi tiết

Dependency ratio $= \dfrac{30+6}{64} \times 100 = \dfrac{36}{64} \times 100 = 56.25 \approx 56$. There are about 56 dependants per 100 workers, dominated by **child** dependency (30% young versus 6% elderly).

Bài tập luyện tập

In which stage of the DTM does the death rate fall sharply while the birth rate remains high, giving the fastest population growth?

(A) Stage 1
(B) Stage 2
(C) Stage 4
(D) Stage 5

Lời giải chi tiết

(B). Stage 2 (early expanding): CDR drops (sanitation, medicine, food security) while CBR stays high, opening the widest gap between the curves and producing the maximum NIR.

Bài tập luyện tập

A country reports CBR $= 10$, CDR $= 12$ (per 1000). Calculate the NIR, state its sign, and assign a DTM stage.

Lời giải chi tiết

NIR $= (10-12)/10 = -0.2\%$ per year — **negative**, so the population is shrinking. Low CBR below a slightly higher CDR (raised by an ageing population) indicates **stage 5** (decline).

Bài tập luyện tập

Outline two limitations of the Demographic Transition Model.

Lời giải chi tiết

Any two of: (1) it is based on European industrial history and may not fit other countries; (2) it ignores migration, which can dominate population change; (3) it assumes development drives falling fertility, but policy, religion and culture can decouple the two; (4) it gives no timescale for the stages; (5) the original four-stage version did not predict stage-5 decline; (6) it treats a country as a single unit, hiding internal regional differences.

Bài tập luyện tập

Explain how the education of girls and women tends to reduce total fertility rate.

Lời giải chi tiết

Education raises the age of marriage and first birth, improves knowledge and use of contraception, increases female participation in paid work (raising the opportunity cost of childbearing), and gives women greater autonomy over reproductive decisions. It also lowers infant mortality, so parents no longer have many children to insure against loss. Together these lower the TFR — one of the strongest empirical predictors of falling fertility.

Bài tập luyện tập

Which correctly describes sustainable use of a renewable natural resource?

(A) Harvesting faster than the resource regenerates

(B) Harvesting at or below the rate of natural replacement

(C) Using only non-renewable substitutes

(D) Leaving the resource entirely unused

Lời giải chi tiết

(B). Living off the natural income means harvesting at or below the replacement rate, so the capital stock — and hence the future yield — is preserved. Harvesting faster (A) depletes the stock.

Bài tập luyện tập

Classify each resource as renewable, replenishable or non-renewable: (i) a commercial fishery; (ii) groundwater in an aquifer; (iii) crude oil.

Lời giải chi tiết

(i) A fishery is **renewable** (living, self-regenerating if not over-harvested). (ii) Groundwater is **replenishable** (non-living but naturally restored, though it can be drawn down faster than it recharges). (iii) Crude oil is **non-renewable** (a fixed stock renewed only over geological time).

Bài tập luyện tập

The largest single component of a typical high-income citizen's ecological footprint is usually:

(A) Cropland
(B) Built-up land
(C) Carbon (energy) land
(D) Fishing grounds

Lời giải chi tiết

(C). High per-capita fossil-fuel use makes carbon (energy) land — the forest area needed to absorb CO2 emissions — the dominant component of most HIC footprints.

Bài tập luyện tập

A person emits $8{,}000$ kg of CO2 per year and forest sequesters $4{,}000$ kg per hectare per year. Calculate the carbon-land component of their footprint.

Lời giải chi tiết

carbon land $= \dfrac{8{,}000}{4{,}000} = 2.0$ ha. Two hectares of forest are needed solely to absorb this person's annual CO2.

Bài tập luyện tập

A country's ecological footprint is 5.6 gha per capita and its biocapacity is 2.1 gha per capita. Calculate the ecological balance and state whether the country is in deficit or reserve.

Lời giải chi tiết

Balance $= 2.1 - 5.6 = -3.5$ gha per capita. The negative value is an **ecological deficit** of 3.5 gha per person; the country consumes about $5.6/2.1 \approx 2.7$ times its own biocapacity.

Bài tập luyện tập

Explain two reasons why a high-income country generally has a larger ecological footprint than a low-income country.

Lời giải chi tiết

Any two of: high per-capita fossil-fuel energy use gives a large carbon land component; meat-rich diets demand more cropland and grazing land per calorie; high consumption of manufactured and imported goods embeds resource use from elsewhere; extensive built infrastructure and car-based transport; and long supply chains. Each raises consumption and waste-absorption demand per person.

Bài tập luyện tập

Place the tiers of the waste hierarchy in order from most to least environmentally preferable.

Lời giải chi tiết

Reduce $>$ **reuse** $>$ **recycle** $>$ **recover (energy)** $>$ **dispose (landfill).** Reducing prevents waste at source and conserves the most resources and energy; landfill is the least preferable because it discards materials and can leak leachate and methane.

Bài tập luyện tập

A city produces $50{,}000$ tonnes of SDW per year. It recycles $9{,}000$ tonnes and composts $6{,}000$ tonnes. Calculate the recycling rate, the total diversion rate, and the tonnage landfilled.

Lời giải chi tiết

Recycling rate $= 9{,}000/50{,}000 \times 100 = 18\%$. Diverted $= 9{,}000 + 6{,}000 = 15{,}000$ t, diversion rate $= 15{,}000/50{,}000 \times 100 = 30\%$. Landfilled $= 50{,}000 - 15{,}000 = 35{,}000$ t (70%).

Bài tập luyện tập

According to the pollution-management model, which level of intervention is the most effective, and why?

Lời giải chi tiết

Altering the human activity that produces the pollutant (level 1) is most effective because it *prevents* the pollutant from being generated at all — for example reducing consumption or redesigning products. Regulating release (level 2) and clean-up/restoration (level 3) act only after the pollutant exists and are progressively more costly and less effective.

Bài tập luyện tập

State two advantages and two disadvantages of incinerating solid domestic waste.

Lời giải chi tiết

Advantages: reduces waste *volume* by up to about 90%, so less landfill is needed; allows **energy recovery** (heat/electricity). Disadvantages: produces **air pollution** (including toxic gases and particulates) requiring costly scrubbers; leaves **toxic ash** that still needs disposal; high capital cost.

Bài tập luyện tập

The tendency for a city to be several degrees warmer than its rural surroundings is called the:

(A) Ecological deficit
(B) Urban heat island
(C) Demographic transition
(D) Ghost acreage

Lời giải chi tiết

(B). The urban heat island (UHI) arises from heat-absorbing dark surfaces, heat-storing concrete, scarce vegetation and waste heat from human activity.

Bài tập luyện tập

Explain why a city is described as a largely "linear" system, and name two strategies that make its metabolism more cyclical.

Lời giải chi tiết

A city imports large **inputs** (food, water, energy, materials) and exports **outputs** (sewage, solid waste, waste heat, air pollution) without returning most materials to use — resources flow straight through rather than cycling, so the metabolism is linear. Two strategies to make it more cyclical (circular economy): compost/recover organic waste and capture energy; recycle and reuse materials; treat and reuse water; capture waste heat for district heating. (Any two.)

Bài tập luyện tập

A metro system lets 25% of a 4-million city's residents halve their personal transport emissions of 2.0 t CO2 per person per year. Calculate the annual CO2 saving.

Lời giải chi tiết

Residents affected $= 0.25 \times 4{,}000{,}000 = 1{,}000{,}000$. Each saves $\frac{1}{2} \times 2.0 = 1.0$ t/yr. Saving $= 1{,}000{,}000 \times 1.0 = 1{,}000{,}000$ tonnes CO2 per year.

Bài tập luyện tập

Identify two strategies for a more sustainable city and, for each, explain briefly how it reduces the city's ecological footprint.

Lời giải chi tiết

Examples: **Compact, mixed-use development** shortens journeys and cuts car dependence, lowering transport energy and carbon land. **Public/active transport** reduces per-capita fossil-fuel use and emissions. **Green space/green roofs** cool the city (reducing UHI and cooling energy), manage stormwater and support biodiversity. **Circular-economy measures** (recycling, composting, water reuse, waste-heat capture) cut raw-material extraction and waste output. Each lowers per-capita consumption or waste-absorption demand, shrinking the footprint. (Any two.)

Ôn tập nhanh — tóm tắt toàn bộ khoá ESS trước kì thi:

- **Hệ thống (Topic 1)**: kho – dòng – chuyển giao – biến đổi; đầu vào/đầu ra; phản hồi âm (ổn định) và dương (khuếch đại); cân bằng động, resilience, tipping point. Ba nhánh EVS: sinh thái – nhân loại – công nghệ trung tâm. Vốn tự nhiên vs thu nhập tự nhiên; định luật nhiệt động (entropy tăng, hệ sinh thái là hệ mở).
- **Sinh thái (Topic 2)**: chuỗi/lưới thức ăn, bậc dinh dưỡng, tháp năng lượng/sinh khối/số lượng; hiệu suất chuyển hoá $\sim 10\%$; GPP, NPP, GSP, NSP; chu trình carbon và nitơ; đường cong tăng trưởng S và J, sức tải K, giới hạn r/K.
- **Đa dạng sinh học (Topic 3)**: đa dạng loài – di truyền – hệ sinh thái; chỉ số Simpson; nguyên nhân tuyệt chủng; Sách Đỏ IUCN, CITES, khu bảo tồn tại chỗ (in situ) và chuyển vị (ex situ), thiết kế khu bảo tồn.
- **Nước (Topic 4)**: chu trình nước, thời gian lưu, khan hiếm nước vật lí và kinh tế, nước ảo, đập lớn; ô nhiễm biển, phú dưỡng, BOD, chỉ thị sinh học, đánh bắt quá mức và sản lượng bền vững tối đa (MSY).
- **Đất và lương thực (Topic 5)**: tầng đất, kết cấu (tam giác đất), độ phì; suy thoái và xói mòn đất, sa mạc hoá; hệ thống lương thực, hiệu suất năng lượng của thịt vs cây trồng, an ninh lương thực bền vững.
- **Khí quyển & khí hậu (Topic 6–7)**: thành phần khí quyển, tầng ozon và chất phá huỷ (CFC), Nghị định thư Montreal; ô nhiễm không khí đô thị, sương mù quang hoá, mưa acid; hiệu ứng nhà kính, khí nhà kính, phản hồi khí hậu, giảm thiểu (mitigation) vs thích ứng (adaptation).
- **Con người & tài nguyên (Topic 8)**: CBR, CDR, NIR $=$ (CBR $-$ CDR)$/10$, quy tắc 70, TFR, tháp dân số, DTM 5 giai đoạn; dấu chân sinh thái vs sức tải sinh học, thâm hụt/dự trữ; thứ bậc chất thải, mô hình quản lí ô nhiễm; đảo nhiệt đô thị, dòng tài nguyên đô thị, thành phố bền vững.
- **Mẹo thi**: luôn nêu định nghĩa chính xác, dùng số liệu/công thức khi có thể; với câu "evaluate/discuss" hãy trình bày cả hai mặt rồi kết luận có căn cứ; gắn mỗi lập luận với một hệ giá trị môi trường (EVS) khi thích hợp.

Đồng hành cùng 8020 English

Cảm ơn bạn đã học cùng bộ giáo trình quốc tế 8020. **Điểm thật · Thầy thật · Kết quả thật** — nhiều học viên chỉ cần 1–2 khoá để đạt kết quả mong muốn.

> **Chương trình đào tạo tại 8020 English**
> **IELTS** Academic/General · **SAT** · PTE · Duolingo · TOEFL | **AP** (College Board) · **IB** Diploma · **Cambridge** IGCSE / A-Level | săn học bổng du học.

Vì sao chọn 8020 English?

- **100% giáo viên** đạt tối thiểu 8.0 IELTS hoặc 1500 SAT — đội ngũ Giáo sư · Tiến sĩ · Thạc sĩ tốt nghiệp trường top đầu thế giới (Carnegie Mellon — #1 Hoa Kỳ về Khoa học Máy tính).
- **Kèm 1–1** mọi độ tuổi; lớp sĩ số nhỏ 2–5 bạn (đa số dưới 10 bạn/lớp).
- Lộ trình cá nhân hoá, theo sát tiến độ từng học viên; lớp OFFLINE tại TP.HCM & ONLINE toàn quốc.

Bảng vàng học viên

AP 5/5 — Calculus AB/BC	**AP** 4–5 — Biology, Chemistry	**IB** 90/100 — Economics
SAT 1590 / 1570 / 1550	**IELTS** 8.0–9.0	**Duolingo** 110 · **PTE** 90

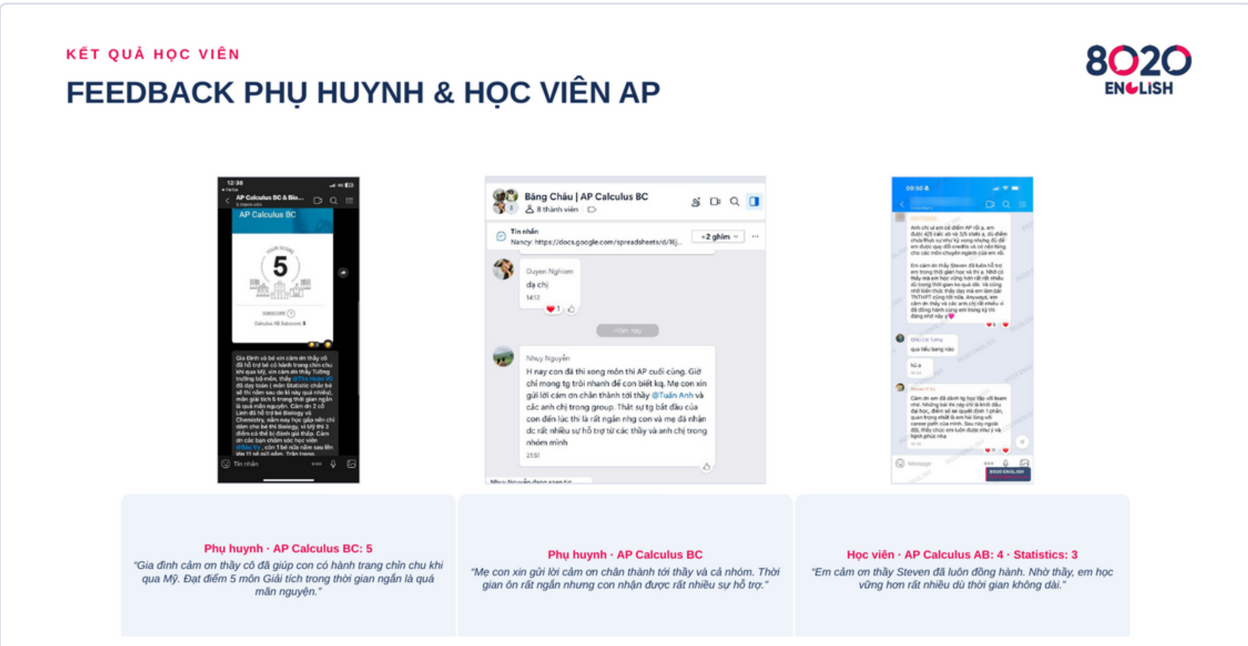
Cảm nhận học viên & phụ huynh

> *"Bạn đã cải thiện được tư duy Writing — kỹ năng từng là nỗi sợ lớn nhất — và cuối cùng đã đậu vào trường top như mong muốn. Thái độ học tập cực kỳ nghiêm túc; ngay cả khi nằm viện vẫn cố gắng học đều đặn."*
>
> — Phan Thị Thanh Hằng · IELTS Overall 8.5

> *"Cần tất cả kỹ năng trên 7.5 để xét vào trường top 1 Anh Quốc về Y học (chương trình UKFPO của NHS) — và đã đạt mục tiêu sau khi học Writing 1–1."*
>
> — Trần Hoàng Bảo Ngọc · IELTS Overall 8.0 (Writing 6.0 → 7.5)

> *"Gia đình và bé xin cảm ơn thầy cô đã giúp con có hành trang chỉn chu khi qua Mỹ. Đạt điểm 5 môn Giải tích trong thời gian ngắn là quá mãn nguyện."*
>
> — Phụ huynh · AP Calculus BC 5/5

> *"Em cảm ơn thầy đã luôn đồng hành. Nhờ thầy, em học vững hơn rất nhiều dù thời gian ôn không dài."*
>
> — Học viên · AP Calculus AB 4

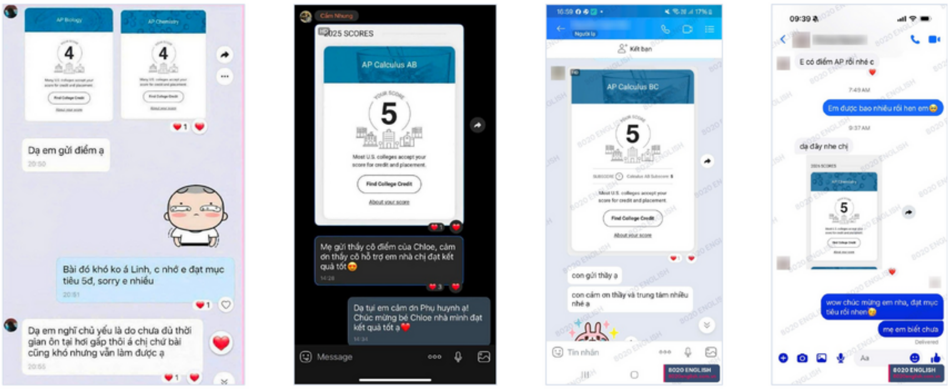


Feedback phụ huynh & học viên AP — nhiều môn đạt điểm 4 & 5

Điểm thi thật của học viên

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ AP



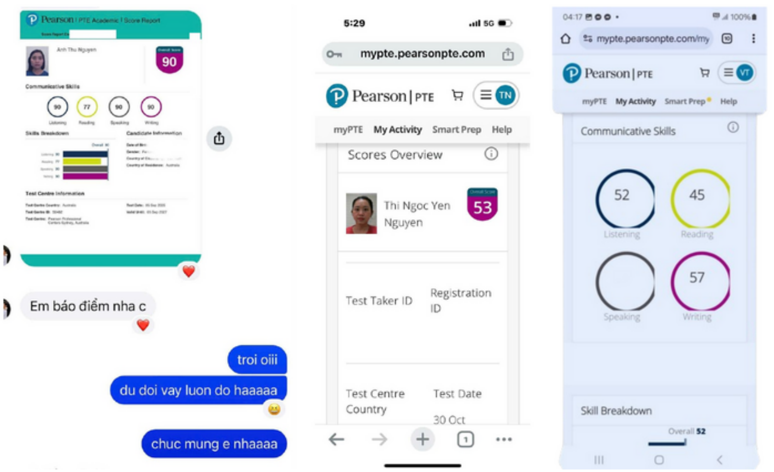
AP Biology: 4 · AP Chemistry: 4 — AP Calculus AB: 5 — AP Calculus BC: 5 — AP Chemistry: 5

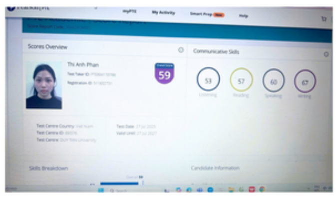
Bảng điểm AP thật của học viên – nhiều môn đạt điểm 4 & 5

Bảng điểm AP thật — Calculus AB/BC 5/5 · Biology & Chemistry 4–5 (College Board)

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ PTE



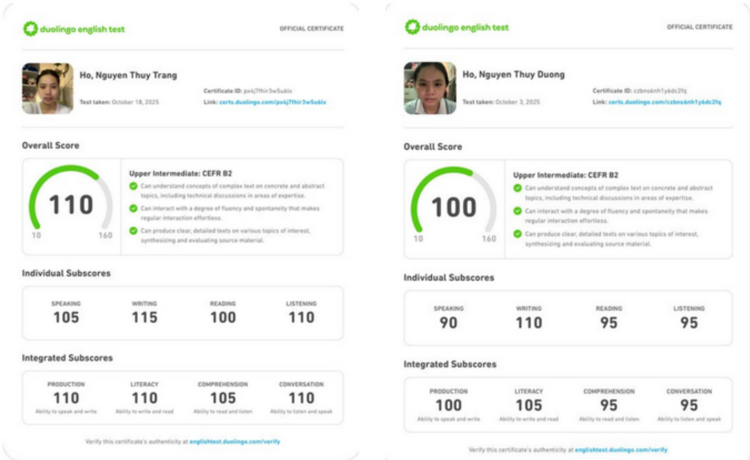


Bảng điểm PTE thật của học viên

Học viên 8020 — PTE Academic 90

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ DUOLINGO



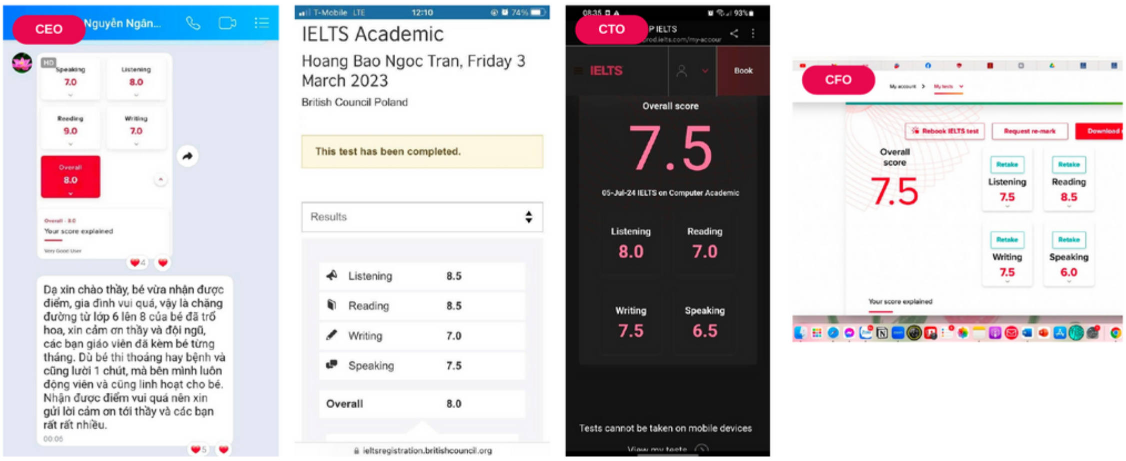
Duolingo English Test – 110 & 100

Học viên 8020 — Duolingo English Test 110 & 100

KẾT QUẢ HỌC VIÊN

THÀNH TÍCH HỌC VIÊN

Bảng điểm thi thật – chất lượng được giám sát nghiêm ngặt. Một số học viên chỉ cần 1–2 khóa để đạt kết quả mong muốn.



Học viên 8020 — IELTS 8.0 / 7.5 / 8.5 (báo điểm thật)