

1.2 Systems

System: An assemblage of parts and their relationships forming a functioning entirety or whole.

1.2.1 Systems are sets of interacting or interdependent components

- **Elements:** measurable things. For example trees, shrubs, herbs, birds and insects (items we can count, measure, weight).
- **Processes:** change elements from one form to another. For example, growth, mortality, decomposition, and disturbance (what happens to the elements, or what the elements do).

1.2.2 A systems approach is a holistic way of visualizing a complex set of interactions, and it can be applied to ecological or societal situations

Benefits of the systems approach include holistic understanding and informed decision-making: Supports decisions that consider long-term impacts and interdependencies.

Applications include **ecological systems**, often modelling nutrient cycles like carbon and nitrogen, showing how changes in one part can impact the entire ecosystem. **Societal systems** analyze human systems (e.g. cities) to identify environmental impacts, guiding sustainable practices.

1.2.3 In system diagrams, storages are usually represented as rectangular boxes and flows as arrows, with the direction of each arrow indicating the direction of each flow.

The components of system diagrams include:

Storages: Reservoirs where energy or matter is held. Typically represented as rectangular boxes. Examples: a lake (water), forest (carbon), or a city (population).

Flows: Movement of energy or matter between storages. Flows are depicted as arrows, with each arrow indicating the direction of the flow between storages.

- **Input:** import of energy/matter across system boundary
- **Output:** export of energy/matter across system boundary

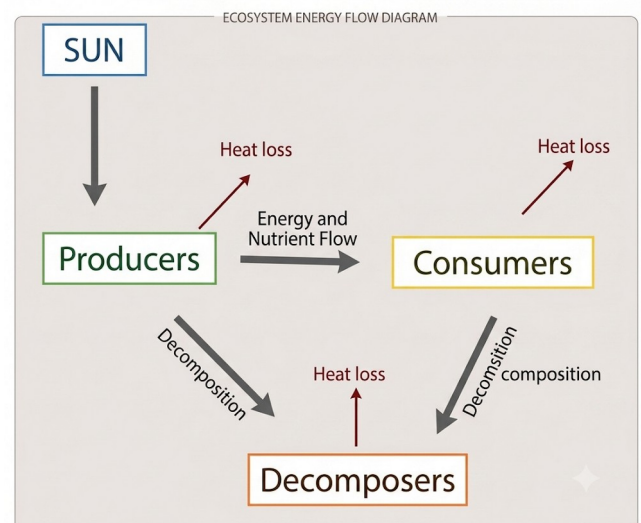
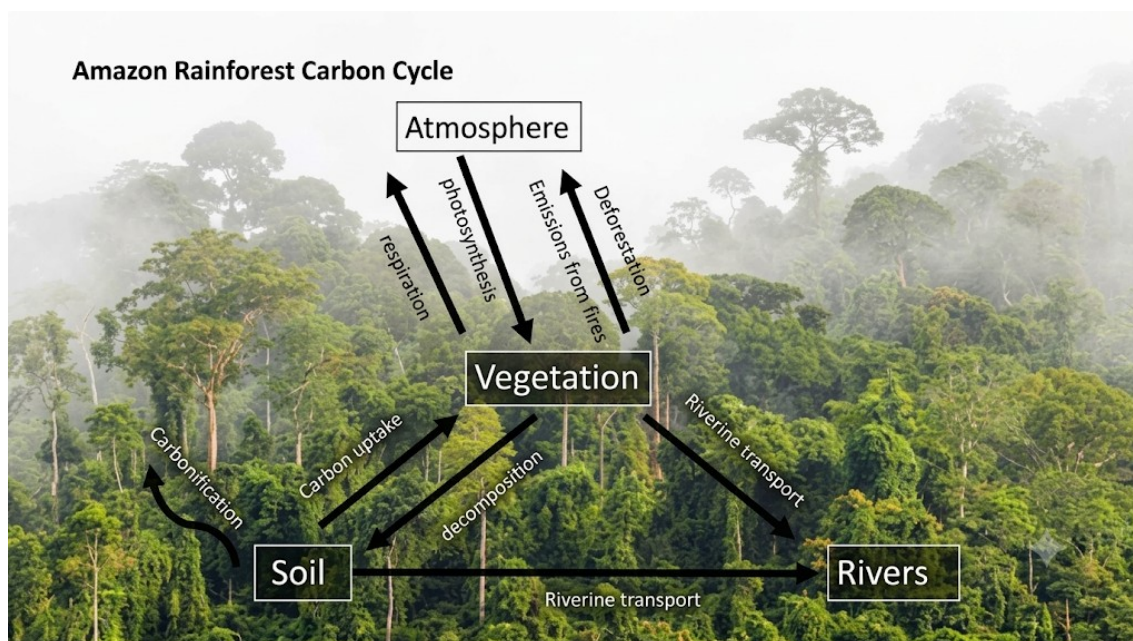
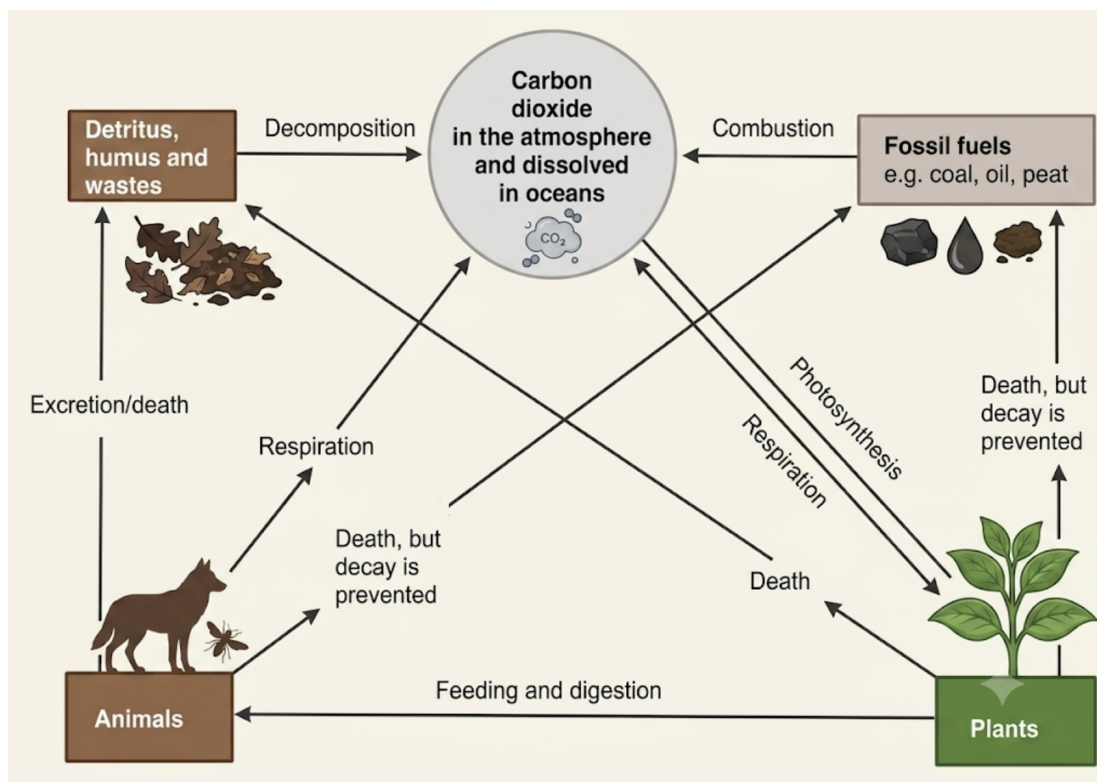


Diagram of the Carbon Cycle



1.2.4 Flows are processes that may be either transfers or transformations

Transfer involves only a change in the **location** of energy or matter

- The movement of material through living organisms or in non-living processes
- The movement of energy
- Examples: harvesting of forest products, the fall of forest debris on the ground

Transformation involves a change in the **chemical nature**, a change in **state** or a change in **energy**

- Light energy to chemical energy (e.g. photosynthesis)
- Matter to matter
- Matter to energy (e.g. respiration)
- Energy to matter

1.2.5 Systems can be open or closed

- An **open** system exchanges **matter and energy** with its surroundings (e.g. a forest, a lake). Most systems are open systems. All ecosystems are open systems exchanging matter and energy with their surrounding environment.
- A **closed** system exchanges **energy but not matter**. No natural closed systems exist on Earth but the planet itself can be thought of as an “almost” closed system.
 - The “[Biosphere II](#)” experiment (a prototype city) was an attempt to model this (Arizona, 1980). The experiment failed, showing how difficult it is to make a sustainable closed system. So, strictly, closed systems do not occur naturally on Earth, but the global cycles, for example, water and nitrogen cycles, approximate (that is, resemble) closed systems.

System	Energy exchanged	Matter exchanged
Open	Yes	Yes
Closed	Yes	No

1.2.6 The Earth is a single integrated system encompassing the biosphere, the hydrosphere, the cryosphere, the geosphere, the atmosphere and the anthroposphere.

James Lovelock's [Gaia hypothesis](#) is a model of the Earth as a single integrated system. The theory was introduced to explain how atmospheric composition and temperatures are interrelated through feedback control mechanisms. The hypothesis views Earth as a single, self-regulating system, like a living organism.

1.2.7 The concept of a system can be applied at a range of scales.



Small-Scale Systems: Example: A Bromeliad plant in a Rainforest

- On a small scale, a bromeliad hosting its own mini-ecosystem provides a clear example of a system. The plant collects water in its leaves, creating a habitat for organisms such as insects, frogs, and microorganisms. The bromeliad acts as a storage for nutrients and water, while the organisms represent different components interacting within this system. Processes include nutrient cycling and energy flows between the organisms and the plant.

Large-Scale Systems: Example: A whole Rainforest

At a larger scale, a rainforest encompasses a vast array of life forms and abiotic components interacting in a complex system. It includes various sub-systems like forest patches, rivers, and wildlife populations. The rainforest system regulates climate, recycles carbon and water, and supports immense biodiversity, demonstrating interconnected processes.

Global-Scale Systems: Example: Atmospheric Circulation

- On a global scale, global atmospheric circulation includes wind patterns that distribute heat and moisture around the planet (processes), exemplifying a system that operates on a planetary level.

1.2.8 Negative feedback loops occur when the output of a process inhibits or reverses the operation of the same process in such a way as to reduce change

Feedback mechanisms change a system to a new state or return it to its original state. Feedback loops can respectively be positive or negative (without an associated connotation such as 'good' or 'bad'). They are

called **loops** because the output of a process circles back to become an input for the next step, in other words they 'feed back' an effect on the initial parameter, visualised in the shape of a circle or loop.

For example, if we feel hungry we have the option of eating and returning to our original state (negative feedback) or not eating and feeling more hungry changing to a new state (positive feedback).

When we feel cold, we can wear warmer clothes to return to our initial calm state (negative feedback) or stay with less clothing and feel even colder (positive feedback). Natural systems act exactly the same way.

→ **Negative feedback** pushes a system or component back to its initial state (enhances stability)

→ **Positive feedback** pushes a system or component to a new state (promotes change)

1.2.9 As an open system, an ecosystem will normally exist in a stable equilibrium, either in a steady-state equilibrium or in one developing over time (e.g. succession), maintained by stabilizing negative feedback loops.

→ **Negative feedback** loops are used to bring stability as they counteract deviation (variability).

Predator-prey interactions are often controlled by negative feedback which controls population densities.

Ecosystems (open system) normally exist in a **stable equilibrium**, maintained by stabilizing negative feedback loops. These can manifest in one of two ways:

1. **Steady-state equilibrium:** where there are no long-term changes, although there may be small fluctuations. Through negative feedback, the system will return to its original equilibrium condition after the temporary disturbance passes.

Example: A mature, climax rainforest. Trees die, new ones grow, but the overall biomass and structure stay **the same** over decades.

2. **Succession:** when ecosystems evolve from one equilibrium state to another, different to the original! Here, species composition and community structure change.

Example: After a volcanic eruption, bare rock (initial state) slowly turns into a forest (new equilibrium).

The system is changing every year, but it is developing steadily toward a final climax community.

During succession, **negative feedback** loops don't keep the ecosystem exactly the same; instead, they **stabilize each** succession **stage** so that the ecosystem does not collapse while it transitions.

Equilibrium Type	What the Negative Feedback Loop Does
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Steady-State (Stable Forest)	Resists change to keep the ecosystem at the exact same constant baseline.
Succession (Successive Forest)	Protects and stabilizes the ecosystem while it moves to a new and different baseline.

1.2.10 Positive feedback loops occur when a disturbance leads to an amplification of that disturbance, destabilizing the system and driving it away from its equilibrium.

- **Positive feedback** loops amplify changes, pushing systems out of equilibrium and into a new state. They drive rapid, compounding changes, creating instability.

Examples:

Population Growth: An increase in population leads to more births, which further increases the population.

Melting Ice Caps: Reduced albedo (i.e. light reflection) from melting ice increases global warming, which leads to more ice melt, further destabilizing the climate.

1.2.11 & 1.2.12 Positive feedback loops will tend to drive the system towards a tipping point.

- A **tipping point** is a critical threshold where even a small change triggers significant, often irreversible shifts in an ecosystem, leading to a new equilibrium.

Examples:

Arctic Ice Melt: Warming leads to ice melt, reducing albedo and further accelerating warming, potentially leading to ice-free Arctic summers [tipping point].

Deforestation and CO₂: Reduced forests mean less CO₂ absorption, raising atmospheric carbon, increasing temperatures, further harming forests, promoting further deforestation.

Forest to Savanna Transition: In tropical regions, slight changes in climate or human activity (deforestation) can reduce rainfall, disrupting the water cycle enough to shift the ecosystem from dense forest to savanna [tipping point]. This has impacts on species composition, biodiversity, and carbon storage.

Collapse of Fisheries: Overfishing can lead fisheries to a tipping point where the fish population cannot sustain itself due to insufficient reproduction rates [tipping point]. This shift from a thriving fish population to one that is economically and ecologically unsustainable impacts species survival and community livelihood.

1.2.13 Models

→ A **model** is a simplified version of reality used to understand how our system works and to predict how it will respond to a change. It inevitably involves some approximation.

Advantages:

- Easier to work with than complex reality, summarizing systems
- Used to understand how a system works and to predict how it will respond to change
- Helps visualize patterns and scales that are challenging (i.e. really big or really small things)
- Applied to other similar situations

Disadvantages:

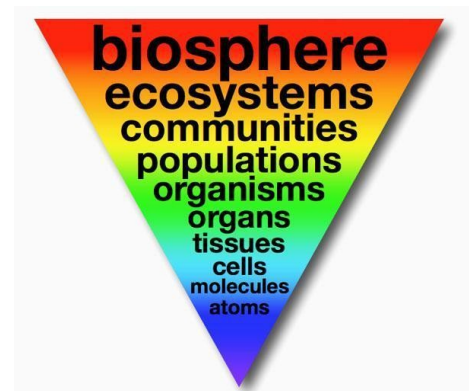
- Accuracy is lost because the model is simplified, possible loss of information and oversimplification.
- If assumptions are wrong, the model will be wrong.
- Predictions can be inaccurate (e.g. predictive models of climate change may give varying results)

Examples of models

food chains; food webs; pyramids of numbers, biomass & productivity, S & J growth curves; r & K-selected species; predator-prey curves; negative & positive feedback mechanisms; aquariums!

1.2.15 Interactions between components in systems can generate emergent properties

- An **emergent property** is a property which a collection or complex **system has**, but which the individual **members do not**. A failure to realize that a property is emergent leads to the **error of division** (assuming that if a system has a property, the parts possess it too, which may not be true!).
- An example of this is the emergent properties of a **coral reef**. The interactions between the various organisms that live on the reef create high **primary productivity** and **biodiversity** in an otherwise nutrient-poor marine "desert". But not any single organism contains these properties as standalone. Predator-prey oscillations and



trophic cascades are other examples of emergent properties where patterns of change occur that would not occur in isolated components.

1.2.16 The resilience of a system, ecological or social, refers to its tendency to avoid tipping points and maintain stability

→ Resilience is the ability of a system to return to its original state after disturbance. It is a measure of how this system responds to things such as food, fire, pollution, new climate, disease, extinction etc.

A system is more resilient:

- The more **complex** it is (e.g. higher biodiversity)
- The **larger** it is or when species have wide geographical ranges
- The more **negative feedback loops** in place

Components of Resilience

- **Resistance:** This is the ability of a system to withstand external pressures without significant alteration to its structure or functionality. In ecological terms, this could be a forest resisting pest infestations; socially, a community maintaining cultural integrity despite economic pressures.
- **Recovery:** It involves the speed and extent to which a system returns to its original state after being disturbed. For example, a coral reef might recover from bleaching if water temperature stabilizes, or an economy might rebound after a financial crash when conditions become favorable again.
- **Adaptation:** It refers to the ability of a system to adjust to changes and new conditions in order to maintain its function. This could be a species evolving new reproductive strategies in response to climate change or a company adopting new technologies to survive market changes.

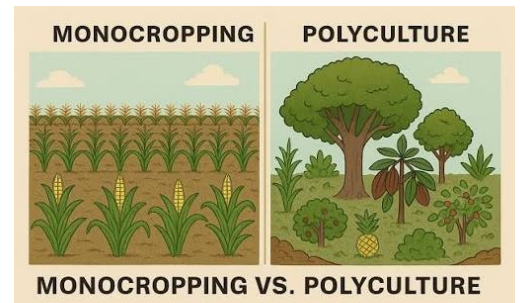
1.2.17 Diversity and the size of storages within systems can contribute to their resilience and affect their speed of response to change (time lags).

Diversity: Diverse systems have multiple species or elements performing similar functions, creating redundancy. This allows the system to stay stable even if one component is affected.

Storage Size: Larger storages provide greater buffering capacity, enabling systems to absorb changes and recover more effectively.

Example: North American Prairie Systems vs. Monoculture Crops:

Natural Prairie Systems: Historically, the North American prairies were ecosystems with high biodiversity, including a variety of grasses, herbs, and shrubs, supported by a complex soil ecosystem. This diversity allowed the prairie to be highly resilient to weather variations and disturbances like fire, maintaining ecosystem function and soil fertility.



Monoculture Systems: In contrast, large areas of these prairies have been converted to monocultures, where only one type of crop (e.g. corn, soybeans) is planted extensively. Monocultures lack biodiversity and are much less resilient. They are more susceptible to pests, diseases, and climate fluctuations, often requiring significant inputs of fertilizers, pesticides, and water to maintain production. Increased vulnerability to ecological and economic setbacks.

1.2.18 Humans can affect the resilience of systems through reducing these storages and diversity.

Human activity, like deforestation and pollution, reduces the diversity and storage sizes in ecosystems. This reduction limits an ecosystem's ability to recover from disturbances, weakening overall resilience.

Examples of Resilience Loss:

- a) Deforestation:** Reduces carbon storage in forests and lowers biodiversity, making ecosystems more vulnerable to disruptions.
- b) Pollution:** Contaminants can lower water quality and soil health, decreasing the resilience of aquatic and terrestrial systems by reducing species diversity and disrupting ecological processes.

Consequences for Sustainability:

Reduced resilience in ecosystems means a diminished capacity to maintain ecosystem services essential for long-term environmental stability.

- a) Increased Vulnerability to Invasive Species:** With the original habitat disturbed and native species populations reduced, invasive species find it easier to establish and dominate, further shifting the ecological balance. Examples of invasive (also known as alien) species include the lionfish (Mediterranean), the zebra mussel (Europe, America), the asian tiger mosquito (global) and more.
- b) Reduced Recovery Capability:** Ecosystems with diminished biodiversity and storage sizes are less capable of self-repair and regeneration. This can lead to long-lasting degradation and desertification, conditions that are often irreversible.