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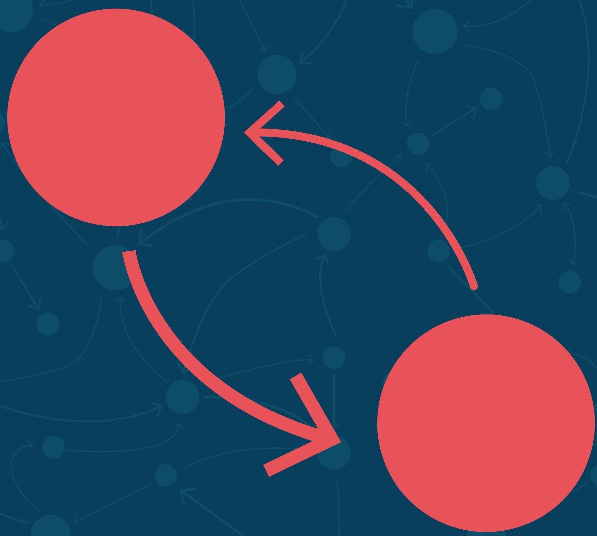

STUDY GUIDE

ENVIRONMENTAL SYSTEMS AND SOCIETIES SL

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Environmental systems and societies
Study Guide

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Welcome to the IB Academy guide book for IB Environmental Systems and Society Standard Level.

This guide contains all the theory you should know for your final exam. To achieve top marks this theory should be complimented with case studies. Although not covered in this booklet, we provide some in our online podcast series.

The guide starts with an explanation of systems and models which are the foundations for the whole course. We will then look at systems in the natural world before turning our attention to humans and their impact. Throughout the guide there are helpful hints from the former IB students who now teach with IB Academy.

Our IB Environmental Systems and Society Standard Level revision course builds on this guide with interactive lectures, exam-style exercise and effective feedback; helping to put the theory into practice and helping you achieve your best possible result.

For more information and details on our revision courses, be sure to visit our website at ib.academy.

We hope that you find this guide helpful.

IB.Academy Team

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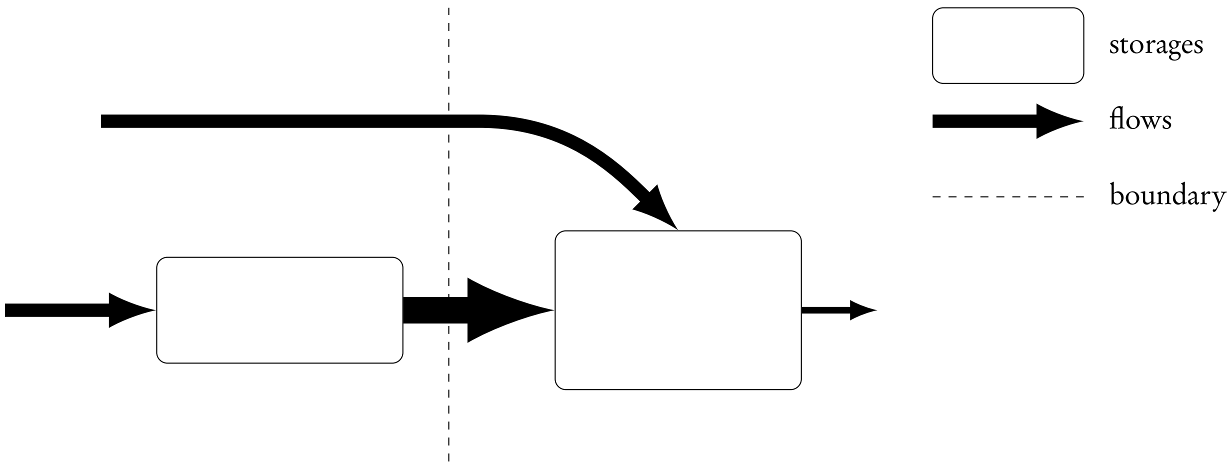
ACADEMY

SYSTEMS AND MODELS

1

In this course we are examining the resources and flows of the world; large and small; natural and man-made. Often these interactions can be very complicated. By using a systems approach we simplify everything into a model. Although we may lose details with this simplification, often we achieve a better and more holistic overview.

1.1 Components of systems



Storages stores of matter or energy. Often shown as a box but can be other shapes. The size can be representative of the size of the storage.

Flows transfers or transformations between storages or outside of the model. Often shown as arrows with the direction indicating the direction of the flow. The size can be representative of the size of the flow.

Inputs flows coming into a system or storage

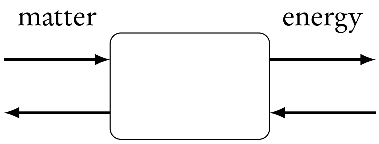
Outputs flows going out of a system or storage

Boundaries the dividing line between two systems (for example the atmosphere and ground). Shown by a line through flows. These are not necessary but help with representing the model.

1.2 Types of systems

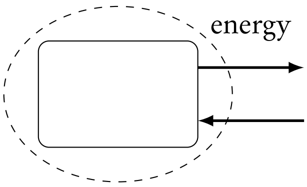
There are three types of systems:

Open system



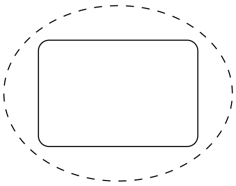
Energy and matter can flow in and out of the systems.
Applies for most systems.

Closed system



Only energy can flow in and out of the system. Most are artificially constructed, often for experimental process, however the entire planet can be thought of as a closed system.

Isolated system



Nothing can flow in or out of the system. These systems are hypothetical but it is possible to describe the entire universe as an isolated system.

1.3 Energy within systems

All flows of energy are governed by the laws of thermodynamics.

1. Conservation of energy: Energy in an isolated system, can be transformed but cannot be created or destroyed.
2. Entropy, the amount of disorder in a system, increases over time. In other words, energy in a system will try dissipate itself to a lower energy level. This is why there is a decrease in the available energy as we move along a food chain.

Due to these laws, systems will normally exist in a stable equilibrium (there is a tendency for it to return to the previous equilibrium following disturbance). Note this does not mean that the systems is static, just that it is balanced. A steady-state equilibrium is the condition of an open system in which there are no changes over the longer term, but in which there may be oscillations in the very short term.

When a change in energy or matter occurs in the systems, the system will respond in one of two ways: either

1. a negative feedback loop will stabilise the system, by increasing a flow that counteracts the change (or)
2. a positive feedback loop which amplifies the change and so destabilises the system; the system will continue to destabilise until it reaches a *tipping point* where a new equilibrium is created.

A **tipping point** is the minimum amount of change within a system that will destabilize it, causing it to reach a new equilibrium or stable state.

A resilient system is one that tends to maintain its stability. Often larger and more diverse storages improve stability, absorbing the changes. Humans can affect this by reducing these two factors. However it is sometimes hard to identify changes in systems and predict tipping points as there is often a time delay with feedback loops.

SYSTEMS IN THE NATURAL WORLD

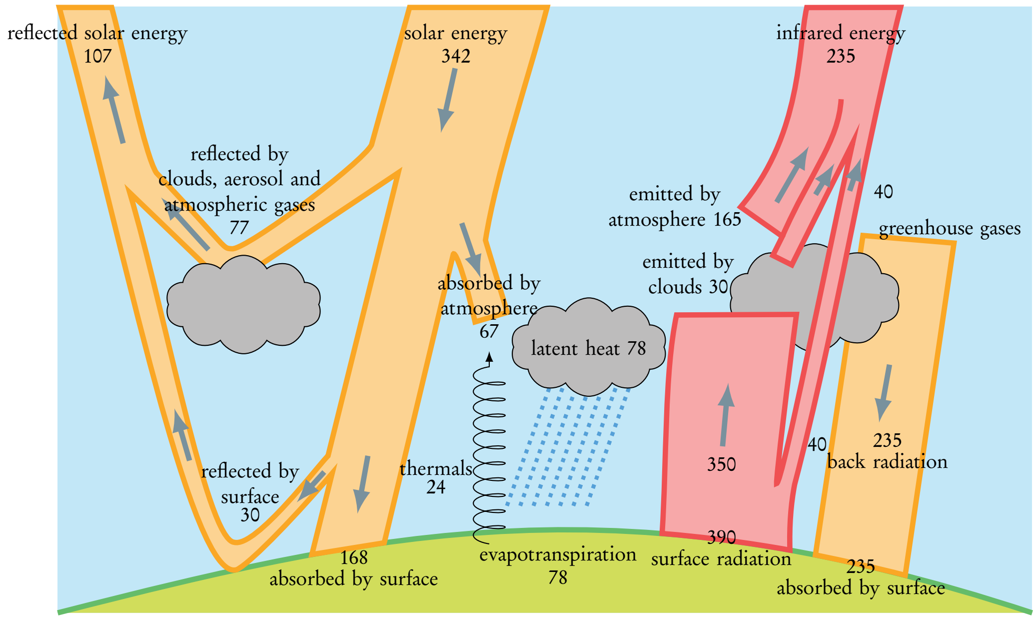
2

We can model the earth as a single system but, as mentioned in the first chapter, this can be an over-simplification. As we want to investigate more complex interactions we find that earth is a system of systems. We can divide planet earth into Biomes, which are themselves collections of ecosystems; and within each ecosystems are smaller communities of interactions between the environment and the species that inhabit it. In the following chapter we will examine systems at all of these scales. But first we will look at the flows of energy and matter that are the building blocks for life as we know it.

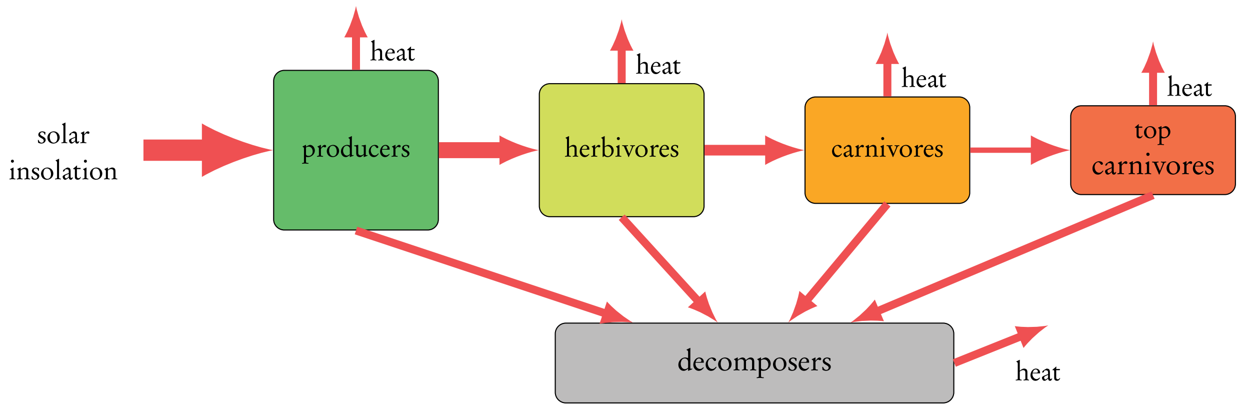
2.1 Flows of energy and matter

2.1.1 Solar (energy)

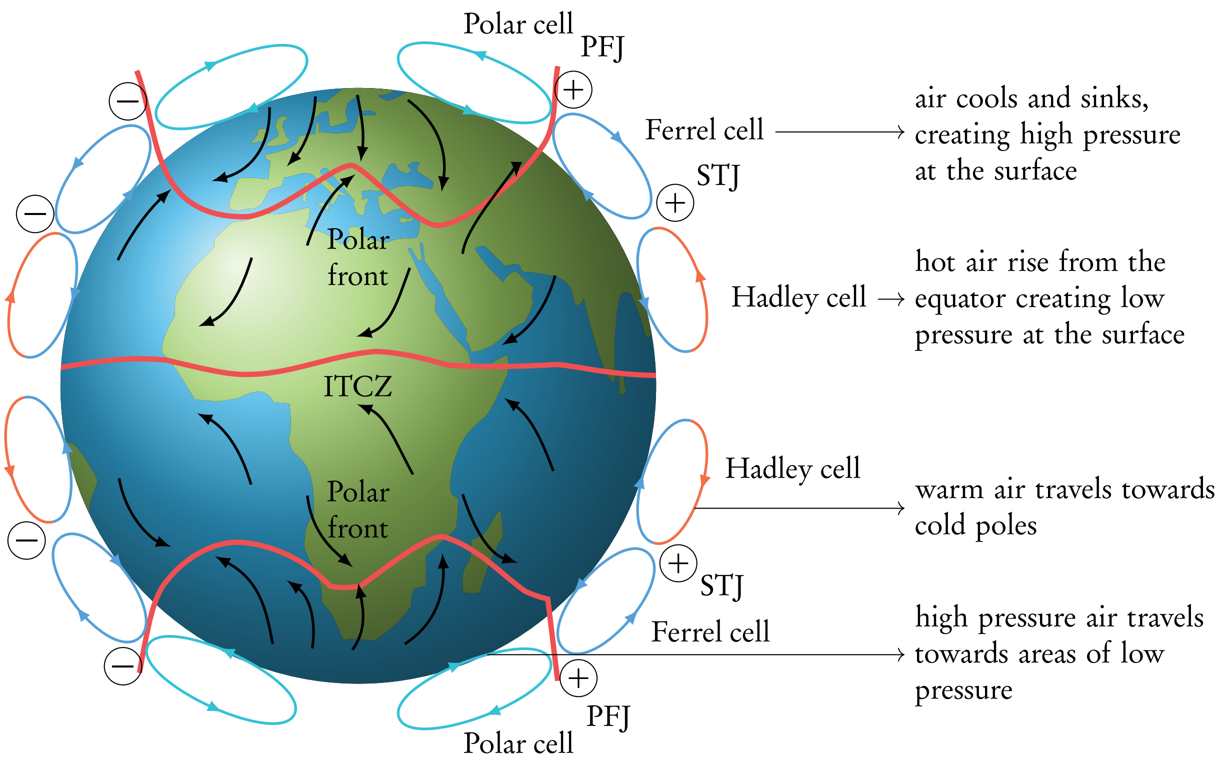
The sun provides the earth with an average 1400 watts per square meter. This energy comes into the earth as short wave radiation and is reradiated out as long wave radiation that can be trapped in the atmosphere. Known as the **greenhouse effect**, this natural phenomenon is necessary in maintaining suitable temperatures for living systems. A lot of the sun's energy is unavailable for ecosystems as this energy is absorbed by inorganic matter or reflected back into the atmosphere. Pathways of radiation through the atmosphere involve a loss of radiation through reflection and absorption.



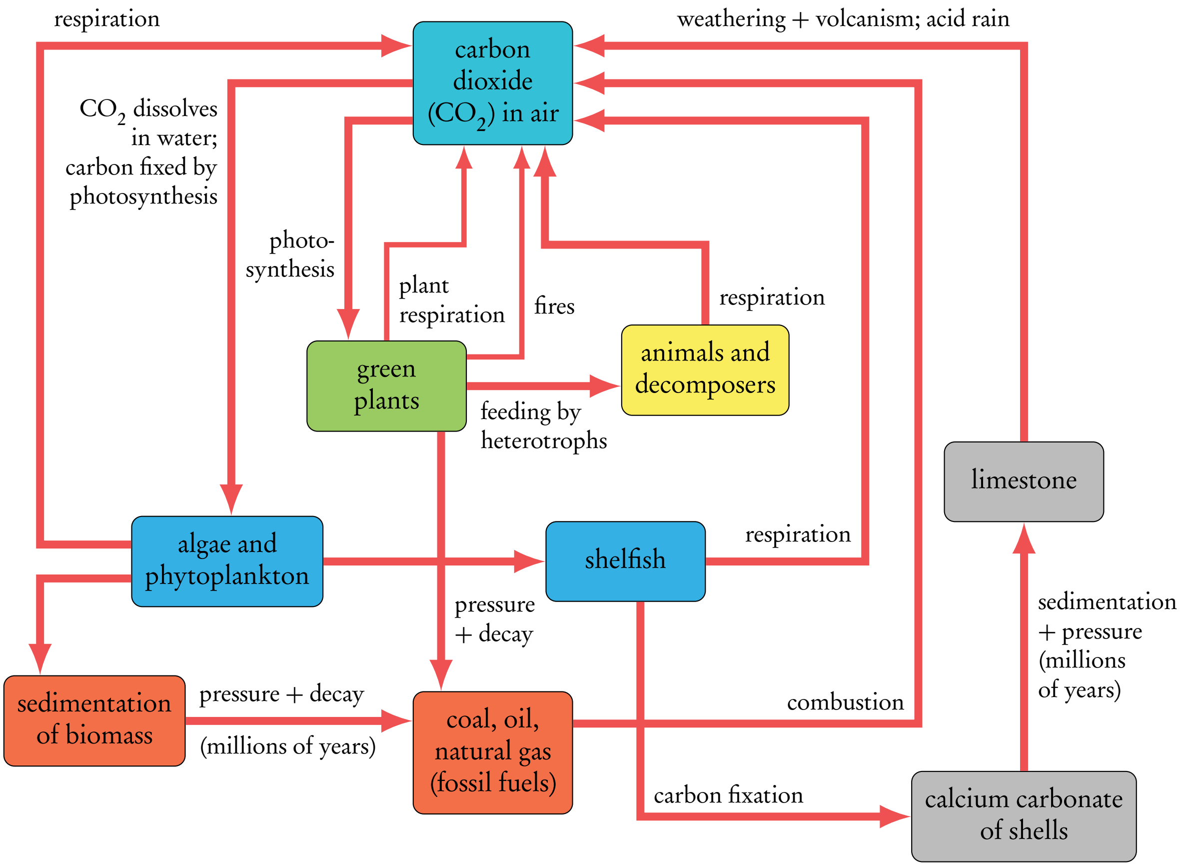
In fact plants convert (through photosynthesis) only 0.06% of that energy in to useable chemical energy. As this useable energy is passed up the food chain, energy is lost as heat re-radiated to the atmosphere from every tropic level. The amount of energy available to the next trophic level is found by the ecological efficiency (energy used for new biomass / energy supplied). This averages 10%. Eventually all the energy will become heat.



Furthermore solar energy is not evenly distributed across the earth's surface. Higher latitudes receive less due to their shallow angle towards the sun. This also varies seasonally. Due to the laws of thermodynamics, the excess energy at the equator wants to move to areas of lower energy north and south. This energy is transported in the air (and water vapour) and causes the global winds and weather. The main movement can be represented by the tricellular model shown below; however in reality the air movement is much more complex due to jet streams and the Coriolis effect.



2.1.2 Carbon cycle (matter)



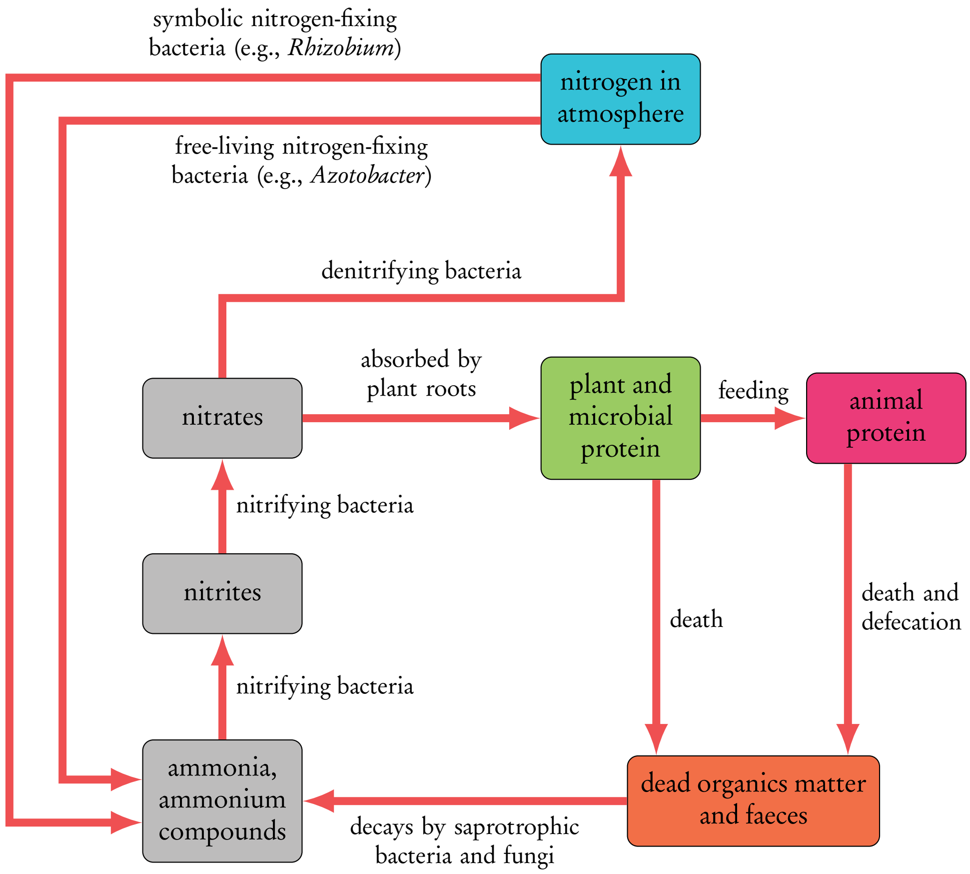
Flows

Transfers: consumption (feeding), death and decomposition, carbon dioxide from the atmosphere dissolving in rainwater and the ocean.
Transformations: photosynthesis (carbon fixation), respiration, combustion and fossilization.

Storages

Organic: organisms and forests.
Inorganic: the atmosphere, soil, fossil fuels and oceans.

2.1.3 Nitrogen cycle (matter)



Flows

Transfers: absorption, consumption (feeding), death and decomposition.
Transformations: nitrogen fixation by bacteria and lightning, and denitrification by bacteria in water-logged soils; assimilation.

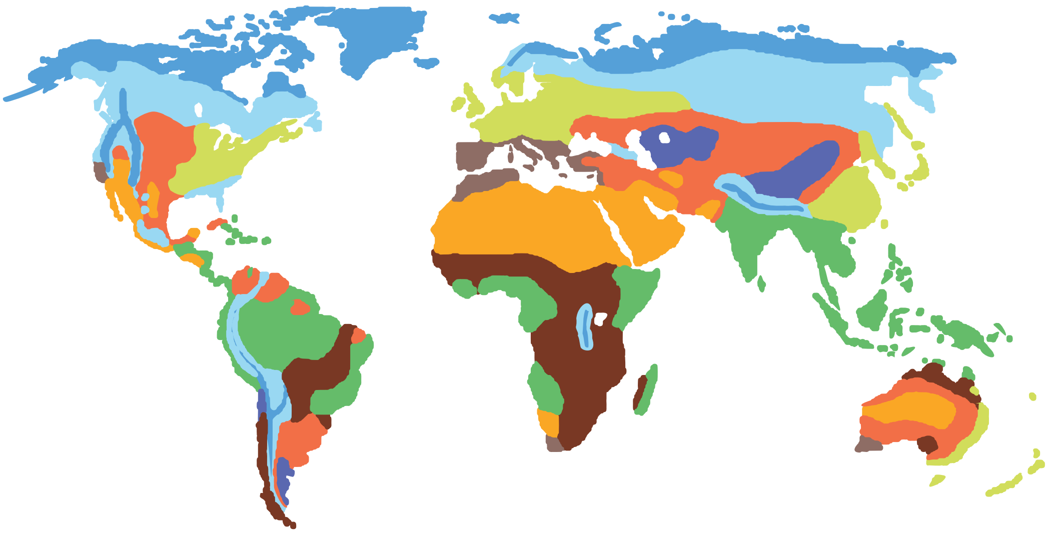
Storages

Organic: organisms.
Inorganic: the atmosphere, soil, fossil fuels and water bodies.

All these systems have been affected by human activities, such as burning fossil fuels, deforestation, urbanization and agriculture. We will examine these more closely in chapter 5.

2.2 Biomes

Biomes are defined by their climatic condition resulting from the **insolation** (amount of solar radiation that reaches the earth's surface), precipitation and temperature they receive. There are five major classes, in which there are subclasses. You can see how they are arranged in rough bands across the earth. This can be explained by the variation of solar energy received and the tricellular model of atmospheric circulation. The pattern is complicated by local differences due to altitude, ocean currents and winds.



Forest
- Tropical forest
- Temperate deciduous forest
- Coniferous forest (boreal)

Grassland
- Savanna (tropical grassland)
- Temperate grassland
- Chaparral (Mediterranean)

Tundra
- Tundra
  - arctic
  - alpine

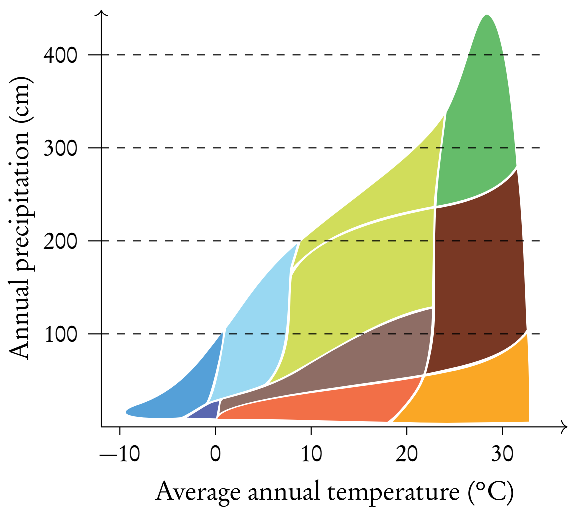
Desert
- Hot desert
- Cold desert

(similar to tundra but with less water availability)

Aquatic

Freshwater
- swamps
- lakes
- ponds
- streams
- rivers
- bogs

Marine
- rock shore
- mud flats
- coral reef
- mangrove swamp
- continental shelf
- deep ocean (Any water beyond the continental shelf; includes hydrothermal vents)



The table compares some of these biomes.

Biome

Area (10^6 km^2)	Solar radiation (W/m^2 year)	Annual precipitation (mm)	Net Primary Productivity (g/m^2 year)	Total plant biomass (million tonnes)	Total animal biomass (million tonnes)	Mean biomass (kg/m^2)

Tropical rainforests

Area (10^6 km^2)	Solar radiation (W/m^2 year)	Annual precipitation (mm)	Net Primary Productivity (g/m^2 year)	Total plant biomass (million tonnes)	Total animal biomass (million tonnes)	Mean biomass (kg/m^2)
17	175	2000–5000	2200 (40% of terrestrial ecosystems)	765000	330	45

Location and climate: Within 25° north and south of the equator. Warm and wet with little seasonal variation.
Structure: Large species diversity in many niches. Tall emergent trees, canopy, understory of smaller trees, shrub layer. Nutrients are predominantly in the top-soil. Without the support of tree roots, these nutrients are quickly washed away.

Temperate forests

Area (10^6 km^2)	Solar radiation (W/m^2 year)	Annual precipitation (mm)	Net Primary Productivity (g/m^2 year)	Total plant biomass (million tonnes)	Total animal biomass (million tonnes)	Mean biomass (kg/m^2)
12	125 (greater seasonal variation)	600–2500	1200	385000	160	32.5

Location and climate: Between 40°–60° north and south of the equator. Mild climate.
Structure: Deciduous forests, often dominated by one species of tree. Below the trees is either a shrub layer or forest floor. Rich soils fed by the rapid breaking down of leaf litter.

Boreal forests (Taiga)

Area (10^6 km^2)	Solar radiation (W/m^2 year)	Annual precipitation (mm)	Net Primary Productivity (g/m^2 year)	Total plant biomass (million tonnes)	Total animal biomass (million tonnes)	Mean biomass (kg/m^2)
17	200-750	300–500	800	240000	57	20

Tropical grasslands (savanna)

Area (10^6 km^2)	Solar radiation (W/m^2 year)	Annual precipitation (mm)	Net Primary Productivity (g/m^2 year)	Total plant biomass (million tonnes)	Total animal biomass (million tonnes)	Mean biomass (kg/m^2)
15	225	500–1300	900	60000	220	4

Location and climate: Mostly located in Africa (below Sahara), Brazil and northern Australia. Warm with seasonal rainfall and fires.
Structure: Ample vegetation supports the largest terrestrial mammals (elephants, giraffes) and large herds of migrating herbivores (wildebeest, zebra). These intern support large predators (lions, cheetahs).

Temperate grasslands

9	150	250–1000 (too low for forest to form)	600	14000	60	1.6

Location and climate: In centres of continents, between 40°–60°
Structure: Large range of grasses supporting large numbers of herbivore and so carnivores. Food webs and ecosystems are simple.

Arctic tundra and alpine

8	90 (high variation)	<250	140	5000	3.5	0.6

Location and climate: Tundra is found just south of the arctic ice cap. Alpine on high mountain tops. Cold with high winds.
Structure: Permafrost prevents the growth of vegetation in the winter. In summer Low growing grasses, shrubs and mosses support a variety of small hibernating mammals. Simply ecosystems with slow rates of growth and decomposition. Possibly the most fragile biome and so the first to be effected by climate change.

Desert

24	up to 300	<250	90	500	0.02	0.02

Location and climate: 30° north and south of the equator.
Structure: Supports a small number of well adapted plant and animal (mainly reptile) species Water storage and collection are prime features.

Deep oceans

352	Varies – None below 1000 m	n/a	20–300	1000000+	800–2000	Very low

Location and climate: 65% of Earth's surface. Averaging 3.5 miles deep
Structure: 0 m–200 m: phytoplankton, cyanobacteria and algae photosynthesis the available sunlight, supporting a range of zooplankton, fish and invertebrates.
200 m–1000 m: Larger generally carnivorous fish adapted to lower levels of light and higher pressures.
1000–bottom: Animals adapted to zero light and high pressure. Some create their own light through bioluminescence to attract prey or avoid predators.
Bottom: Slow moving scavengers, survive on dead organic matter from above.
Hydrothermal vents: volcanic heat and sulphur support a wide range of organisms.

Coral reefs

0.28	Varies, ideal water temperature 26 °C–27 °C	n/a	2000			0.3

Location and climate: Shallow, warm equatorial waters
Structure: "Rainforests of the ocean" – complex structure with high species number and diversity. Polyps create the skeleton of the reef. This provides a good holding for many sea plants and therefore a rich environment for fish.

2.3 Ecosystems

Biomes are composed of multiple ecosystems. An **ecosystem** is a community and the physical environment with which it interacts, linked together by energy and matter flows. A **community** is a group of populations living and interacting with each other in a common habitat.

Ecosystems can be divided into three types:

1. **Marine ecosystems**: the sea, estuaries, salt marshes, and mangroves. Marine ecosystems all have a high concentration of salt in the water.
2. **Freshwater ecosystems**: rivers, lakes, and wetlands.
3. **Terrestrial ecosystems**: all land-based ecosystems.

2.3.1 Zonation

Within biomes there are differences in temperature, precipitation, solar insolation and soil composition, and therefore there will be variation in the species that live there. Often there are clear boundaries between zones.

Zonation is the clear change in ecosystems along an environmental gradient.

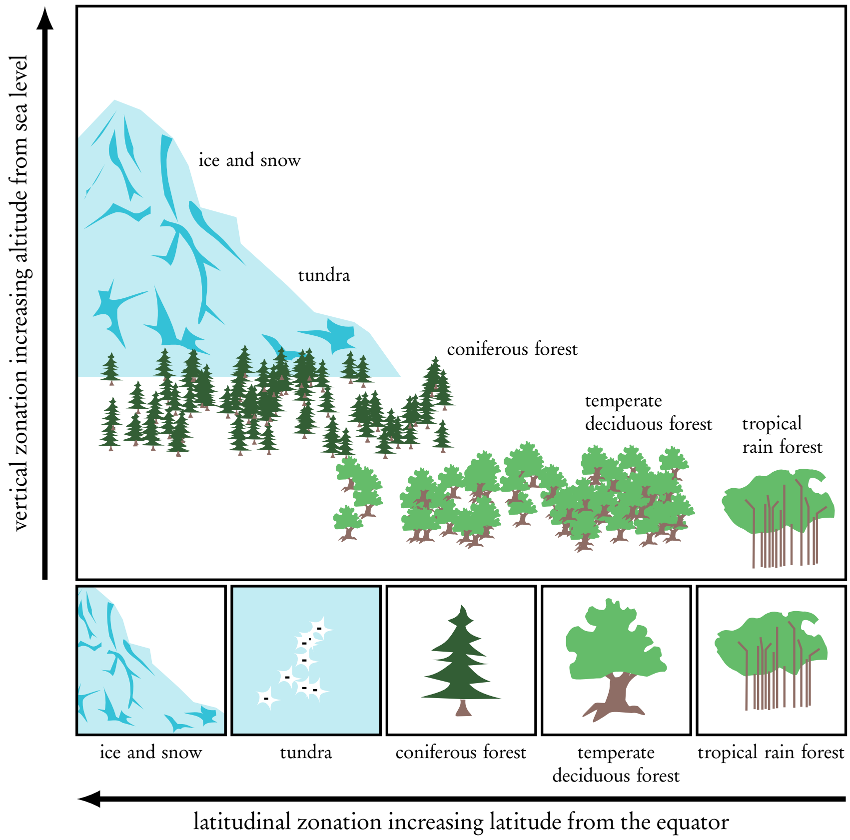


Figure 2.1: Zonation

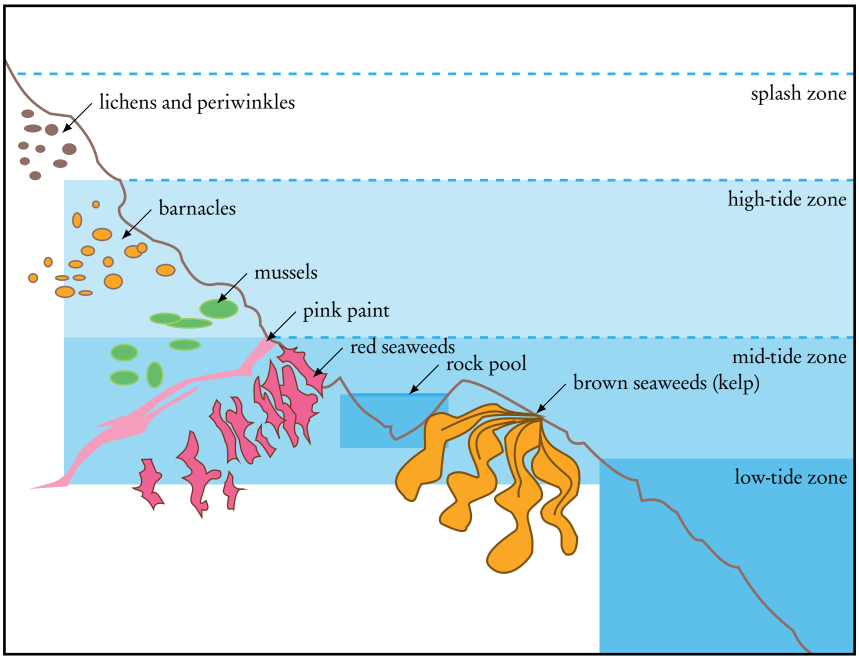


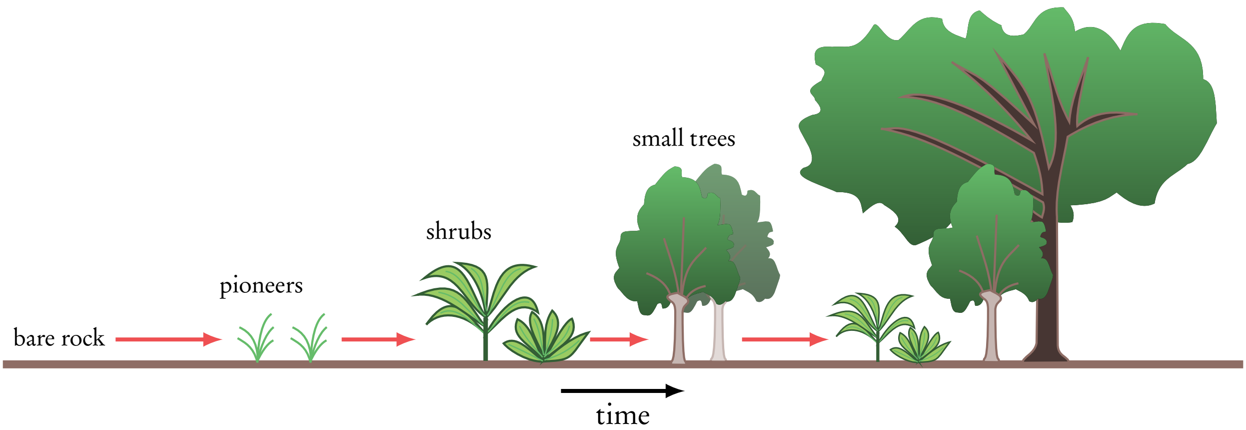
Figure 2.2: Zonation

2.3.2 Succession

Succession is the change of an ecosystem over time and is most clearly seen when an environment is low in species diversity and population:

1. either new rock formed after volcanic eruptions – lithosere, disposition of dry soils/sands – xerosere or drying of river deltas – hydrosere (primary succession);
2. or areas where the community is destroyed due to fire, flood or human activity (secondary succession).

Succession may be arrested at a stage by abiotic or biotic limiting factors, resulting in a **sub-climax community**. Humans may deliberately stop succession when NPP is high and crops are harvested or by deforestation, grazing with animals or controlled burning.This results in in a **plagioclimax**.



Disturbance (fire, flood, etc.) Secondary

Bare inorganic surface	Stage 1 colonization (pioneer community)	Stage 2 establishment	Stage 3 competition	Stage 4 stabilization	Climax community (for that environment)
– nutrient poor – water poor	Minerals from outside Hardy species able to withstand harsh environments Typically r – selected species	– simple animal pioneers	– larger plants – some k-selected species – loss of some pioneer species	– late colonising species – complex food webs	– stable equilibrium
	GPP increasing	GPP increasing more	GPP flattens	GPP decreases	Stable GPP
	NPP increasing	NPP high	NPP decreasing	NPP stabilizing	NPP approaches one

Increasing soil depth and humus content

Increasing size of supported organisms

Increasing biodiversity

Increased mineral cycling and amount of minerals stored in the ecosystems

Figure 2.3: In early stages of succession, gross primary productivity (GPP) is low due to the unfavourable initial conditions and low density of producers. The proportion of energy lost through community respiration is relatively low too, so net primary productivity (NPP) is high-that is, the system is growing and biomass is accumulating. In later stages of succession, with an increased consumer community, gross productivity may be high in a climax community. However, this is balanced by respiration, so net productivity approaches 0 and the productivity-respiration (P:R) ratio approaches 1.

r- and K- strategist species

These two reproductive strategies represent the extremes on a spectrum. r-strategists are ideal pioneer species where as K-strategists require a more established environment.

r- strategist

- Examples: rabbits, weeds, bacteria
- Short lifespan with high mortality in early life
- Rapid growth and early maturity
- Many small offspring
- Little parental care or protection
- Highly adaptable
- Can colonise new habitats quickly and make use of short-lived resources

K- strategist

- Examples: elephants, people, whales
- Long lifespan with mortality in later stages
- Slow growth and late maturity
- Fewer large offspring
- High parental care or protection
- Specialists
- Enables them to survive in long-term climax communities

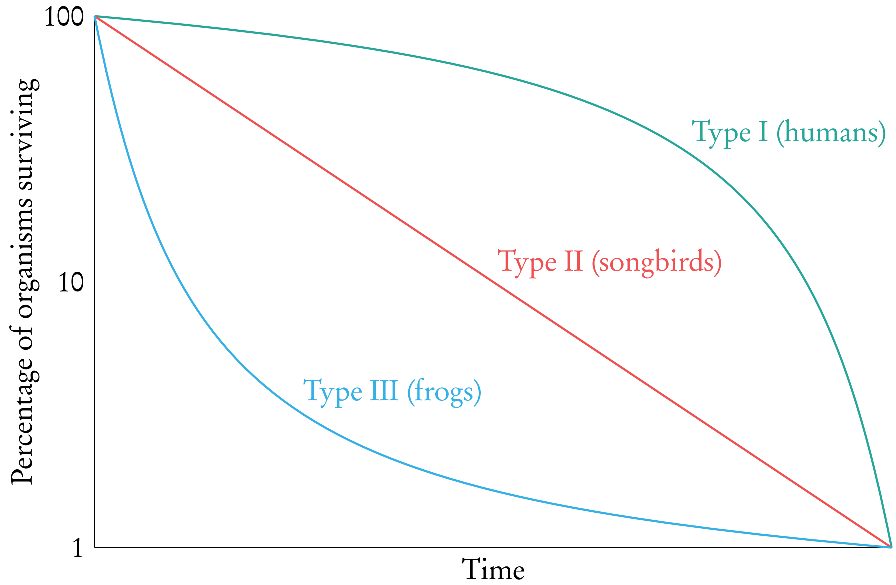


Figure 2.4: Survivorship curves

2.4 Species

2.4.1 Definitions

A species is a group of organisms that share common characteristics and that interbreed to produce fertile offspring.

A habitat is the environment in which a species normally lives.

A population is a group of organisms of the same species living in the same area at the same time, and which are capable of interbreeding.

A community is a group of populations living in the same area at the same time.

The non-living, physical factors that influence the organisms and ecosystem-such as temperature, sunlight, pH, salinity, and precipitation are termed **abiotic factors**. The interactions between the organisms such as predation, herbivory, parasitism, mutualism, disease, and competition are termed **biotic factors**.

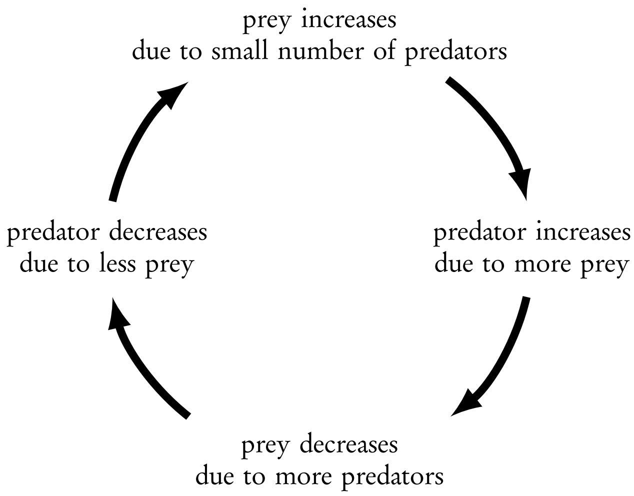
A niche describes the particular set of abiotic and biotic conditions and resources to which an organism or population responds. The **fundamental niche** describes the full range of conditions and resources in which a species could survive and reproduce. The **realized niche** describes the actual conditions and resources in which a species exists due to biotic interactions.

Biotic interactions

One organism can interact with another organism in the following ways:

Predation One animal (or occasionally plant) hunts/eats another.
Herbivory animal feeds on plant
Parasitism a symbiosis where an organism (the parasite) benefits at the expense of another (the host)
Mutualism a symbiosis where both organisms benefit from the relationship.
Disease a organism (usually a virus, bacteria, or fungi) inhibits or kills another organism.
Competition where two organism are competing for a resource (or niche). The organisms can be in the same species (intraspecific) or different species (interspecific).

These interactions tend to be **density dependent** (dependent on the population densities of the species) and so help to control population density through a negative feedback loop. For example, where two animals have a close predator – prey relationship (the prey is the predator's main food source, and the predator is the prey's main predator) they regulate one another's population as shown below.



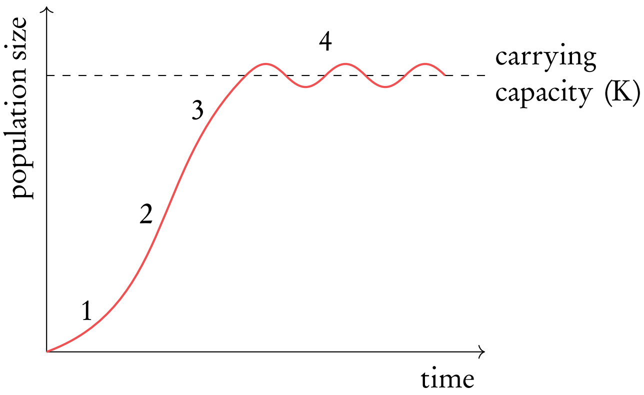
2.4.2 Changes in species population

Populations change and respond to interactions with the environment. Interactions should be understood in terms of the influences each species has on the population dynamics of others, and upon the carrying capacity of the others' environment. S and J population curves describe a generalized response of populations to a particular set of conditions (abiotic and biotic factors). Any system has a carrying capacity for a given species. Limiting factors will slow population growth as it approaches the carrying capacity of the system.

S curve

S-curves start with exponential growth. No limiting factors affect the growth at first. However, above a certain population size, the growth rate slows down gradually, finally resulting in a population of constant size.

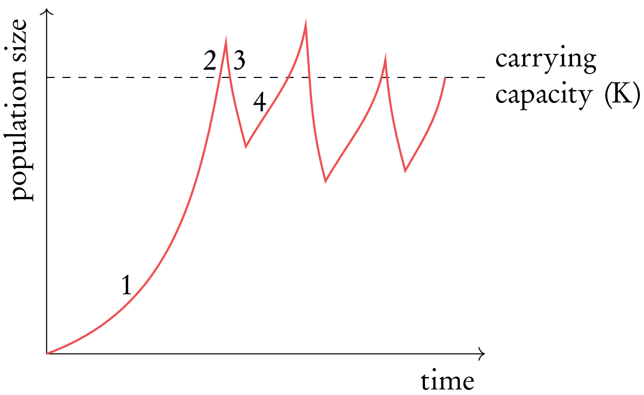
1. **Lag phase** – population numbers are low and so birth rates are low.
2. **Exponential growth phase** – population grows at an increasingly rapid rate unrestricted by limiting factors.
3. **Transitional phase** – population growth slows down considerably as limiting factors are reached.
4. **Stationary phase** – population growth stabilizes and then population fluctuates around a level that represents the carrying capacity.



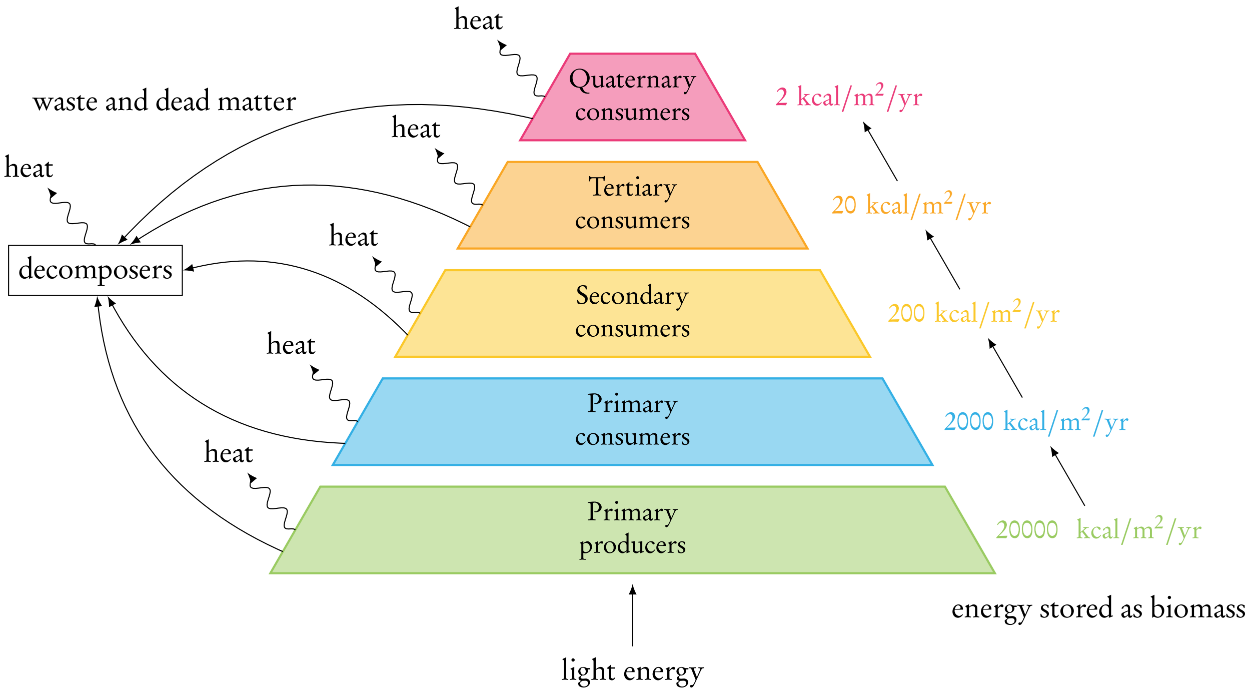
J-curve

J-curves show exponential growth in a population past the carrying capacity. These are followed by sudden population collapses known as diebacks.

1. **Exponential growth** – population grows at an increasingly rapid rate unrestricted by limiting factors.
2. **Overshoot** – population grows past its carrying capacity.
3. **Dieback** – population suddenly collapses usually due to a lack of food. The population declines below its original carrying capacity as the limiting factor is depleted.
4. **Renewed growth** – growth starts again once the depleted factor has recovered.



2.4.3 Trophic levels



The trophic level is the position that an organism occupies in a food chain

1. **Primary producers.** *Green plants.*
   A few organisms are autotrophs: Make their own food from solar energy, carbon dioxide and water.
   Chemosynthetic organisms which make their own food from other simple compounds (e.g., ammonia, hydrogen sulphide or methane) do not require sunlight and are often bacteria found in deep oceans.
2. **Primary consumers.** *Herbivores and omnivores.*
   Heterotrophs: Consume primary producers.
3. **Secondary consumers.** *Carnivores and omnivores.*
   Heterotrophs: Consume herbivores and other carnivores, sometimes primary producers.
4. **Tertiary consumers.** *Carnivores and omnivores.*
   Heterotrophs: Consume herbivores and other carnivores, sometimes primary producers.

Decomposers. *Bacteria and fungi.*
Obtain their energy from dead organisms by secreting enzymes that break down the organic matter.

Detritivores. *Snails, slugs, blowfly maggots, vultures.*
Derive their energy from detritus or decomposing organic material. Dead organisms or feces or parts of an organism.

The relationships between these species can been shown in food chains and food webs, where arrows indicate the flow of energy (or more bluntly who eats who). As mentioned in the previous chapter energy is passed up the food chain with a large proportion lost as heat, due to entropy. Other things are also passed up the food chain.

Persistent or non-biodegradable pollutants can build up in an organism or trophic level because they cannot be broken down (**bioaccumulation**). These can then be passed up the food chain and commonly, due to the decrease of biomass and energy, increase in concentration (**biomagnification**). They can be natural pollutants such as mercury or manmade such as DDT.

Case study.

DDT was a popular insecticide introduced to the market in 1945. It was used in agriculture and to eradicate malaria by controlling mosquito populations. However the chemical passed in to aquatic environments and up the food chain and had serious impacts on many marine and bird species. A by-effect was the thinning of the eggshells of some of the effected bird species putting a further pressure on these species. These effects where highlighted in Rachel Carson's book *Silent Spring* (1962) leading to increased public opposition to the use of DDT. DDT was banned for agricultural use in most developed countries between 1970-80. A global ban came into effect in 2004 while still allowing for some use in malaria control.

Photosynthesis

Most primary producers convert light energy into chemical energy by the process of photosynthesis. Photosynthesis produces the raw material for producing biomass.

The photosynthesis reaction:

$$\text{carbon dioxide} + \text{water} + \text{energy (from the sun)} = \text{glucose} + \text{oxygen}$$

Respiration

Respiration is the release of energy from converting organic matter into carbon dioxide and water in all living organisms, releasing energy.

Aerobic respiration reaction:

$$\text{glucose} + \text{oxygen} = \text{carbon dioxide} + \text{water} + \text{energy}$$

During respiration, large amounts of energy are dissipated as heat, increasing the entropy in the ecosystem while enabling organisms to maintain relatively low entropy and so high organization.

2.5 Biodiversity within systems

Biodiversity is a general term describing the variability in a community, ecosystem or biome. It can be defined as the combination of:

Habitat Diversity – the range of different habitats in an ecosystem or biome. This has the greatest effect on the other two. Great habitat diversity will usually lead to greater species and genetic diversity.

Species Diversity – defined by two variables: the number of species (richness) and their relative proportions (evenness). Communities can be described and compared through the use of diversity indices. When comparing communities that are similar, low diversity could be indicative of pollution, eutrophication or recent colonization of a site. The number of species present in an area is often indicative of general patterns of biodiversity. Species diversity within a community is a component of the broader description of the biodiversity of an entire ecosystem.

Genetic Diversity – the range of genetic material present in a population of a species. Larger populations in many locations tend to have greater genetic diversity. Humans can alter diversity through breeding and genetic engineering. In general, greater genetic diversity improves the resilience of a species.

Biodiversity can be used to evaluate the health and complexity of an ecosystem. Comparison can be made, however only in similar ecosystems.

It is worth noting that interpreting diversity is complex. In general, higher biodiversity (for example, tropical rainforests) creates complex and resilient ecosystems. However, low biodiversity can be present in natural, ancient and unpolluted sites (for example, in Arctic ecosystems).

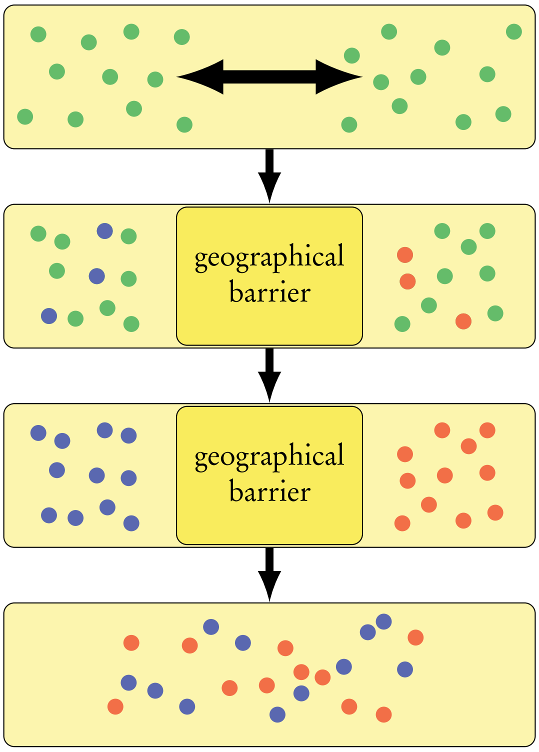
2.5.1 Natural Changes in Biodiversity

Biodiversity is a result of the evolutionary process. **Evolution** is a gradual change in the genetic character of populations over many generations, achieved largely through the mechanism of natural selection; Biological variation arises randomly and can either be: beneficial to, damaging to, or have no impact on, the survival of the individual. **Natural selection** is an evolutionary driving force, sometimes called "survival of the fittest". In this context, the meaning of "fittest" is understood to be "best-suited to the niche". Natural selection occurs through the following mechanism.

1. Within a population of one species, there is genetic diversity, which is called variation.
2. Due to natural variation, some individuals will be fitter than others.
3. Fitter individuals have an advantage and will reproduce more successfully than individuals who are less fit.
4. The offspring of fitter individuals may inherit the genes that give that advantage, and so these genes will remain in the gene pool.

Environmental change gives new challenges to species, which drives the evolution of diversity. Those that are suited will survive, and those that are not suited will not survive. There have been major mass extinction events in the geological past caused by various factors, such as tectonic plate movements, super-volcanic eruption, climatic changes (including drought and ice ages), and meteorite impact-all of which resulted in new directions in evolution and therefore increased biodiversity. Less than 1 per cent of all species that have ever existed are still alive today.

Speciation is the formation of new species when populations of a species become isolated and evolve differently from other populations. Isolation of populations can be caused by environmental changes forming barriers, such as: mountain formation, changes in rivers, sea level change, climatic change or plate movements. The surface of the Earth is divided into crustal, tectonic plates that have moved throughout geological time. This has led to the creation of both land bridges and physical barriers with evolutionary consequences.



two populations of one species can interbreed and mix genes (gene flow occurs)

populations separated by a geographical barrier cannot interbreed; each develops its own variations (gene flow interrupted)

eventually two separate species develop in response to different selection pressure

even without a geographical barrier, two species remain genetically distinct

The distribution of continents has also caused climatic variations and variation in food supply, both contributing to evolution.

INVESTIGATING ECOSYSTEMS (EXPERIMENTAL METHODS)

3

3.1 General data collection rules

Naming The study of an ecosystem requires that it be named and located (e.g., Deinikerwald, Baar, Switzerland, a mixed deciduous-coniferous managed woodland).

Sampling and extrapolation Ecosystems are large and complex and therefore impossible to measure completely. Thus a key step when planning an experiment is in how much of an area will be sampled. There is a balance to strike between increasing accuracy with increasing size; and time available and the number of samples. Measurements should be repeated to increase reliability of data. The number of repetitions required depends on the factor being measured. With almost all the following techniques, there are limitations. A key skill when planning experiments is to understand the limitations of your experiment and account for it.

3.2 Measuring abiotic factors

There are various experimental tools used to quantify the non living factors in a ecosystem. By measuring at numerous points/times, it is possible to show: change along an environmental gradient, or change over time through succession, or change before and after a human impact. We have outlined some experimental methods in a table below. This will be a useful reference when conducting your internal assessment. Detailed knowledge of these is rarely required in exams.

Type of ecosystem		
Factor	Experimental equipment / technique	Method
Marine		
Salinity	Electrical conductivity of density	
pH	pH meter	
Temperature	Thermometer	
Dissolved oxygen	Oxygen selective electrode / data logging / Winkler titration	
Wave action	Dynamometer	Must use averages over a long time
Freshwater		
Turbidity (cloudiness of water)	Optical instruments / Secchi disc	
pH	pH meter	
Temperature	Thermometer	
Dissolved oxygen	Oxygen selective electrode / data logging / Winkler titration	
Flow velocity	Flow meter / Impellers / Float timed between two points	$\text{Average flow} = \frac{\text{surface flow}}{1.25}$
Terrestrial		
Temperature	Thermometer	
Light intensity	Electronic light meter	Account for natural variation when taking measurements
Wind speed	Anemometer / Ventimeter	
Soil: Particle size	Sort and measure particles	Large particles can be measured by hand. Smaller particles can be measured with sieves Sediment can be measured using optical techniques
Soil moisture	Weigh wet and dry (scales)	Take one weight measurement. Dry the soil completely and then take another measurement. The difference is the soil; moisture.
Soil: Organic content	Measure Loss on Ignition (LOI)	Take weight measurement of original sample. Heat at high temperature (500–1000 °C) to burn off any organic material. Continue to heat until mass is constant. Weigh again. The difference in mass is the organic content.
Slope	Surveying equipment	
Soil: Mineral Content/pH	Soil testing kits / pH meter	
Rainfall	Rain gauge	Record amount every 24 hours, emptying each time.

3.3 Measuring biotic factors

We often want to measure diversity and species abundance within an ecosystem. Because it is unfeasible to measure an entire ecosystem, we take samples and extrapolate results. Two common sampling methods are point (quadrat) and line/belt transects. Sampling can be:

Continuous – where every thing is measured: the entire line transect of the entire area.
Interrupted (transect) – points at regular intervals are measured.
Random – points are determined by random. A good practice is to draw a grid (at the size of your quadrat) over an area, giving a number to each square. A list of random numbers can then be generated by a computer or using a table. These should then be sampled.
Stratified random – where an area has two or more distinct areas, each area should be treated separately using the random method above.
Systematic – points/transects are placed at a set distant. Often the first is place randomly and then the rest by a systematic method.

3.4 Collecting organisms

For non motile (non or slow moving) organisms we can count organisms using quadrats. The size of the quadrat should be determined by the size of the organisms being sampled. We can chose to count actual numbers, percentage cover (% of the quadrat in which the organism — usually a plant — occurs), or percentage frequency (% of squares in a quadrant in which the organism occurs)

For motile (moving organisms) we can use traps. Examples of traps include:

pitfall traps beakers or pots buried in the soil which animals walk into and cannot escape from
nets sweep, butterfly, seine, and purse
flight interception traps fine-meshed nets that intercept the flight of insects – the animals fall into trays where they can be collected
small mammal traps often baited, with a door that closes once an animal is inside
light traps a UV bulb against a white sheet attracts certain night flying insects
Tullgren funnels paired cloth funnels, with a light source at one end, a sample pot the other, and a wire mesh between: invertebrates in soil samples placed on the mesh move away from the heat of the lamp and fall into the collecting bottle at the bottom
Pooters sucks insects from vegetation
Kick sampling (water) disturbing a river bed and collecting the animals downstream in a net.

3.5 Identifying organisms

We need to identify organisms so we can count them correctly. Methods to do this include:

- Keys. These can be:

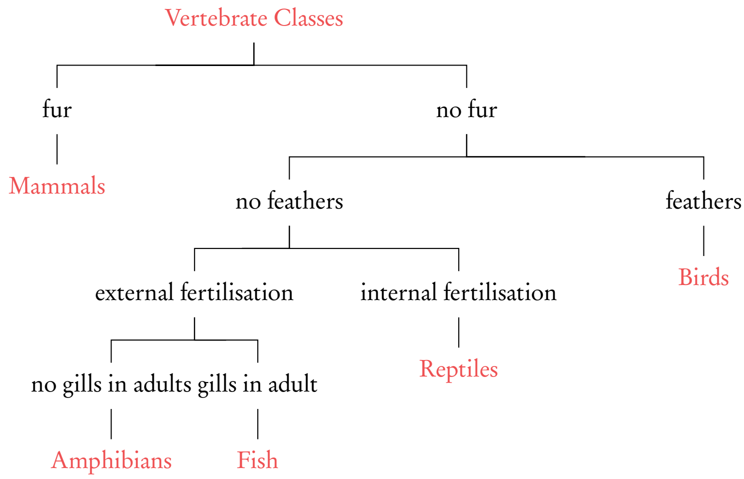
Paired statement key

written list

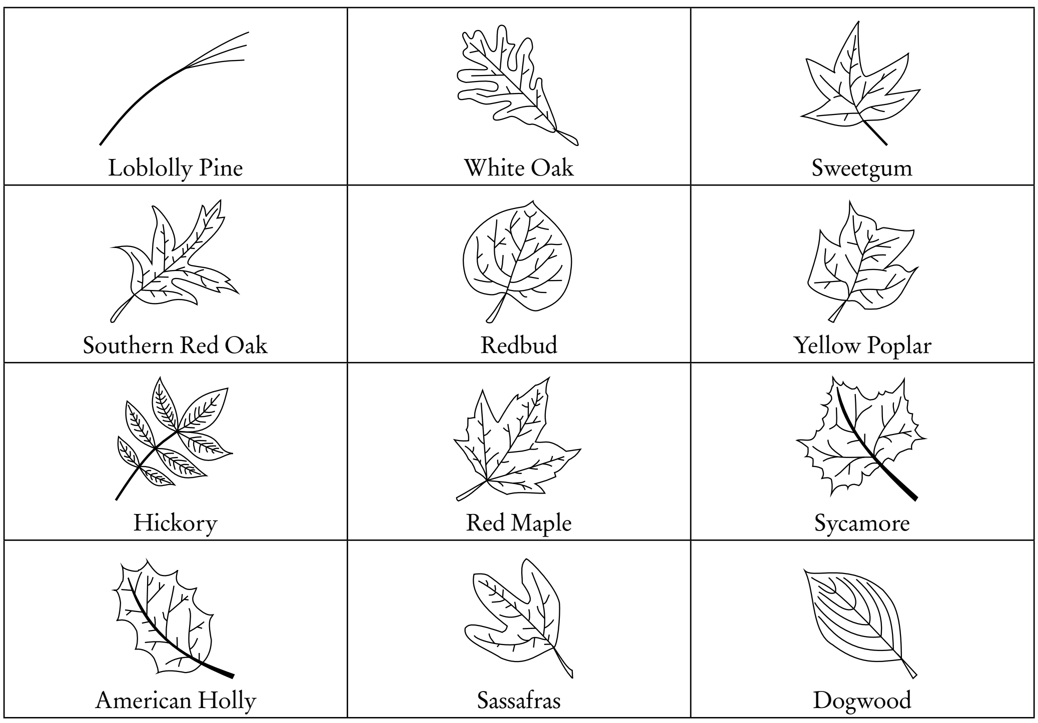
1. single leaf	got to 2
several leaflets	got to 6
2. leaf with prickles	holly
leaf with no prickles	got to 3
3. leaf edge with lobes	got to 4
leaf edge with no lobes	got to 5
4. lobes sharp pointed	sycamore
lobes rounded	oak
5. leaf with smooth edge	beech
leaf with serrated edge	elm
6. leaflets in fan shape	horse chestnut
leaflets in pairs	got to 7
7. leaf edge serrated	rowan
leaf edge plain	ash

Dichotomous

done in steps with two options at each step



Diagrammatic

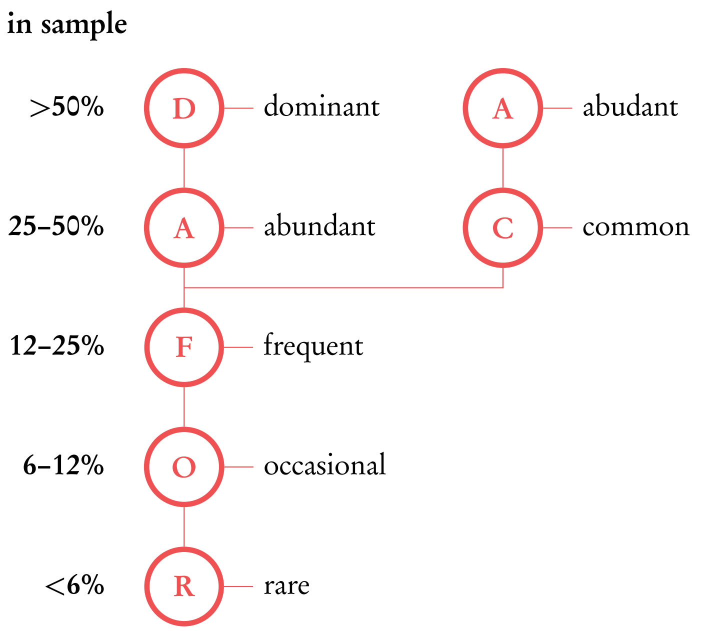


Keys are limited by the number of organisms they contain.

- Comparison to herbarium or specimen collections in museums.
- Technologies such as DNA profiling.

3.6 Species abundance (Lincoln index)

Species abundance refers to the number of organisms in a species relative to its environment. We can count the number of organisms of each species in a sample and then compare their number. For plants, it is often easier to measure the percentage cover. These numbers can then be used to grade a species on the DAFOR/ACFOR scale



Often direct counts are too great an undertaking, we therefore use an indirect method such as the Lincoln index.

This method requires the use of capture-mark-release-recapture with the application of the Lincoln index.

$$\text{Lincoln index} = \frac{n_1 \times n_2}{n_m}$$

where n_1 is the number caught in the first sample, n_2 is the number caught in the second sample and n_m is the number caught in the second sample that were previously marked.

3.7 Species diversity (Simpson index)

A function of the number of species and their relative abundance can be compared using the Simpson index. This indication of diversity is only useful when comparing two similar habitats or the same habitat over time.

$$\text{D} = \frac{N(N-1)}{\sum n(n-1)}$$

where D is the Simpson diversity index, N is the total number of organisms of all species found and n is the number of individuals of a particular species. The sigma notation, $\sum$, means the denominator is the sum of $n(n-1)$ for all the species that make up N. Using this formula, the higher the result, the greater the species diversity.

Species richness is the number of species in a community and is a useful comparative measure.

3.8 Productivity and biomass

3.8.1 Definitions

Gross Primary Productivity (GPP): the amount of energy/biomass converted by producers per unit area per unit time. (g/m^2 year)

Net Primary Productivity (NPP): the gain (after respiration) by producers in energy/biomass per unit area per unit time. (g/m^2 year)

$$\text{NPP} = \text{GPP} - \text{R}$$

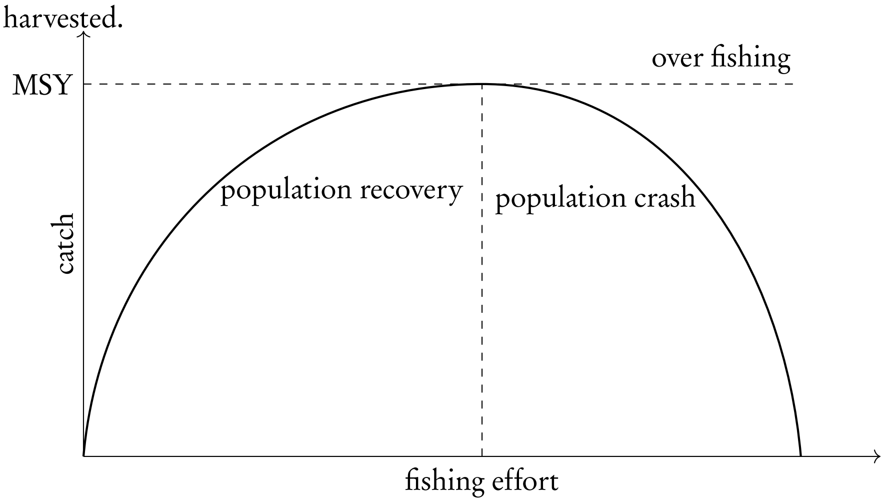
Gross Secondary Productivity (GSP): the total energy/biomass assimilated by consumers through feeding and absorption per unit area per unit time. (g/m^2 year)

$$\text{GSP} = \text{food eaten} - \text{fecal loss}$$

Net Secondary Productivity (NSP): the gain (after respiration) by consumers in energy/biomass per unit area per unit time. (g/m^2 year)

$$\text{NSP} = \text{GSP} - \text{R}$$

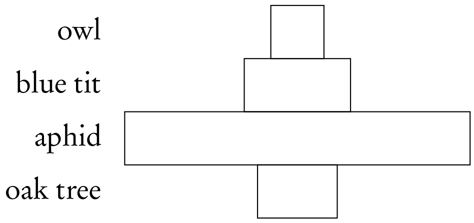
Maximum sustainable yields are those that are less than or equivalent to the net primary or net secondary productivity of a system. It is sustainable as the rate implies that the resource will not have a biomass smaller than it original had when harvested.



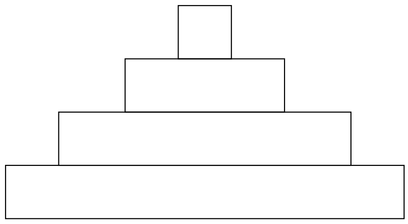
3.8.2 Pyramids

Pyramids are graphical models of the amount of living material stored at each trophic level of a food chain by either numbers, biomass or productivity for a given area and time. Quantitative data for each trophic level are drawn to scale as horizontal bars arranged symmetrically around a central axis. Generally, due to the loss of energy up the food chain, pyramids have a wide base and become narrower towards the apex. One common issue with pyramids is the difficulty in assigning some species (particularly omnivores) a trophic level.

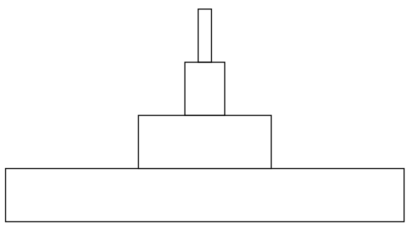
Pyramid of numbers record the number of individuals at each trophic level. They are a simple, easy method of giving an overview and are good at comparing changes in population numbers with time or season. However they do not account for size, so a tree is counted the same as an ant. This means pyramids of some ecosystems are inverted.



Pyramid of biomass represents the biological mass of the standing stock at each trophic level at a particular point in time measured in units such as grams of biomass per square metre ($g\,m^{-2}$). Biomass may also be measured in units of energy, such as $J\,m^{-2}$. However as organisms must be killed to measure dry mass, samples are made and extrapolated. Therefore results are not exact. Furthermore the measure is susceptible to seasonal differences in fast growing species (e.g., algae)



Pyramid of productivity Two organisms with the same mass do not have to have the same energy content. Pyramid of productivity shows the flow of energy (starting from solar radiation – *optional*) through each trophic level of a food chain over a period of time. Productivity is measured in units of flow ($g\,m^{-2}\,yr^{-1}$ or $J\,m^{-2}\,yr^{-1}$). Unlike the first two, this type of pyramid allows for comparison between ecosystems but is limited in comparing seasonal differences. It is impossible for these pyramids to be inverted. However, they are also the most complicated to collect data for.



3.9 Estimating biomass and productivity

To find biomass, it is necessary to capture and kill part of a population and then extrapolate results. The organism should be heated at around 80 °C so that only the dry mass is measure. After weighing the dry mass, it can by combusted under controlled conditions to find the amount of energy. Data from these methods can be used to construct ecological pyramids.

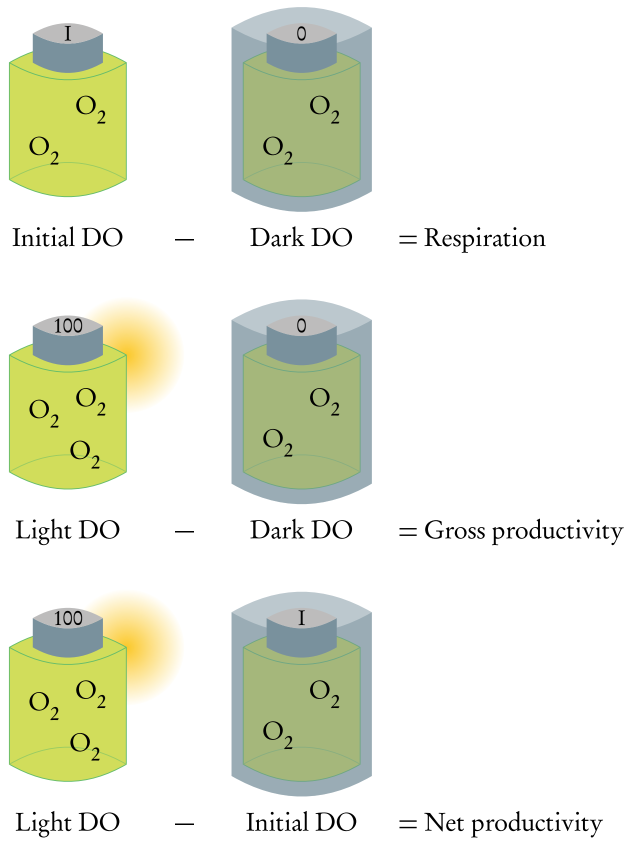
To find primary productivity on land, we require 3 similar patches of the vegetation in question. One is harvested and measured as above (Sample 1); another is covered with black plastic to prevent photosynthesis (Sample 2); and the third is left as it is (Sample 3). After a set time period, the other two are harvested and measured. From these three we can determine the GPP, NPP and amount of respiration.

$$\text{GPP} = \frac{\text{Sample 3} - \text{Sample 1}}{\text{time period}}$$

$$\text{Respiration} = \frac{\text{Sample 2} - \text{Sample 1}}{\text{time period}}$$

$$\text{NPP} = \frac{(\text{Sample 3} - \text{Sample 1}) - (\text{Sample 2} - \text{Sample 1})}{\text{time period}}$$

To find primary productivity in water, a light (open to light) and dark (covered from light) bottle technique can be used. The oxygen concentration of the water should be measured. The water should then be split between two bottles with no air present. An equal amount of the aquatic species should be placed in both. The oxygen concentration should be measured after several hours.



Secondary productivity can be found by monitoring the weight of an animal, its food and its feces over a set period of time.

$$GSP = \frac{\text{Weight of food} - \text{weight of feces}}{\text{time period}}$$

$$NSP = \frac{\text{Weight of animal before} - \text{Weight of animal after}}{\text{time period}}$$

$$\text{Respiration} = GSP - NSP$$

SYSTEMS IN THE HUMAN WORLD

4

4.1 Human population dynamics

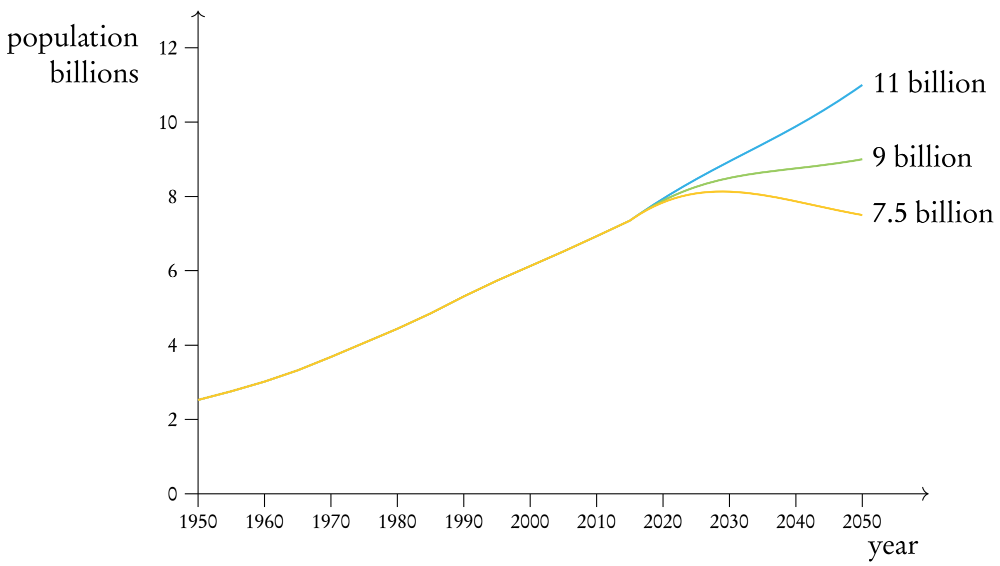
Demographic tools for quantifying human population include

Crude Birth Rate (CBR) – Number of births per 1000 people, per year
Total Fertility Rate – Average number of births per 1000 women of childbearing age (usually 15-49).
Crude Death Rate (CDR) – Number of deaths per 1000 people per year.
Natural Increase (NIR)

$$\text{Natural Increase} = \text{Crude Birth Rate} - \text{Crude Death Rate}$$

This can then be divided by 10 and expressed as a percentage
Doubling time (DT) – number of years for a population to double in size assuming the natural growth rate remains constant. $= 70/\text{NIR}$ (%).

Global human population has followed a rapid growth curve but there is uncertainty as to how this may be changing. As the human population grows, increased stress is placed on all of Earth's systems.



4.1.1 Demographic Transition Model

The Demographic Transition Model tries to combine patterns in birth and death rates to explain and predict current demographics.

High birth rate

Parents want children:

- for labour
- to look after them in old age
- to continue the family name
- prestige
- to replace other children who have died

Low birth rate

Birth rates decline because:

- children are very costly
- the government looks after people through pensions and health services
- more women want their own career
- there is more widespread use of family planning
- as the infant mortality rate comes down there is less need for replacement children

High death rate

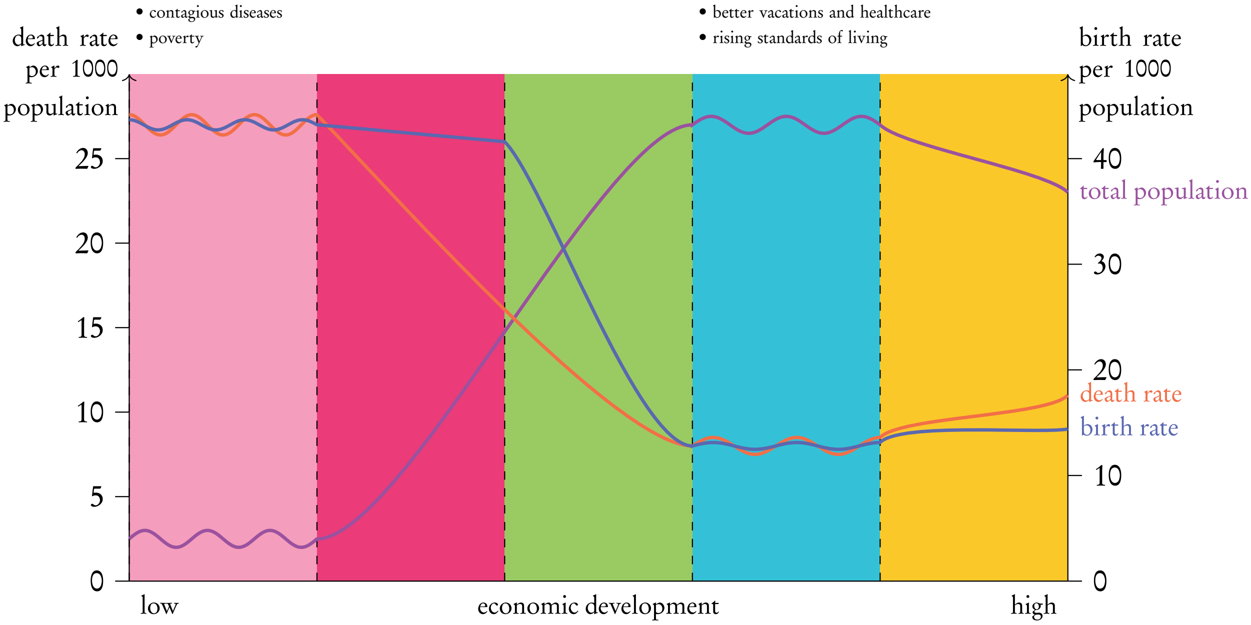
People die from:

- lack of clean water
- lack of food
- poor hygiene and sanitation
- overcrowding
- contagious diseases
- poverty

Low death rate

Death rates decline because:

- clean water
- reliable food supply
- good hygiene and sanitation
- lower population densities
- better vacations and healthcare
- rising standards of living



Stage 1

High and variable:

- birth rates and death rates are high and variable
- population growth fluctuates, only some indigenous (primitive) tribes still at this stage
- UK at this stage until about 1750

Stage 2

Early expanding:

- birth rate remains high but the death rate comes down rapidly
- population growth is rapid
- Afghanistan and Sudan are at this stage
- UK passed through this stage by 1850

Stage 3

Late expanding:

- birth rate drops and the death rate remains low
- population growth continues but at a slower rate
- Brazil and Argentina are at this stage
- UK passed through this stage in about 1950

Stage 4

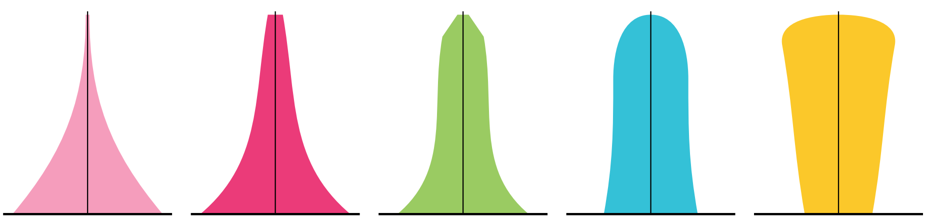
Low and variable:

- birth rates and death rates are low and variable
- population growth fluctuates
- UK and most developed countries are at this stage

Stage 5

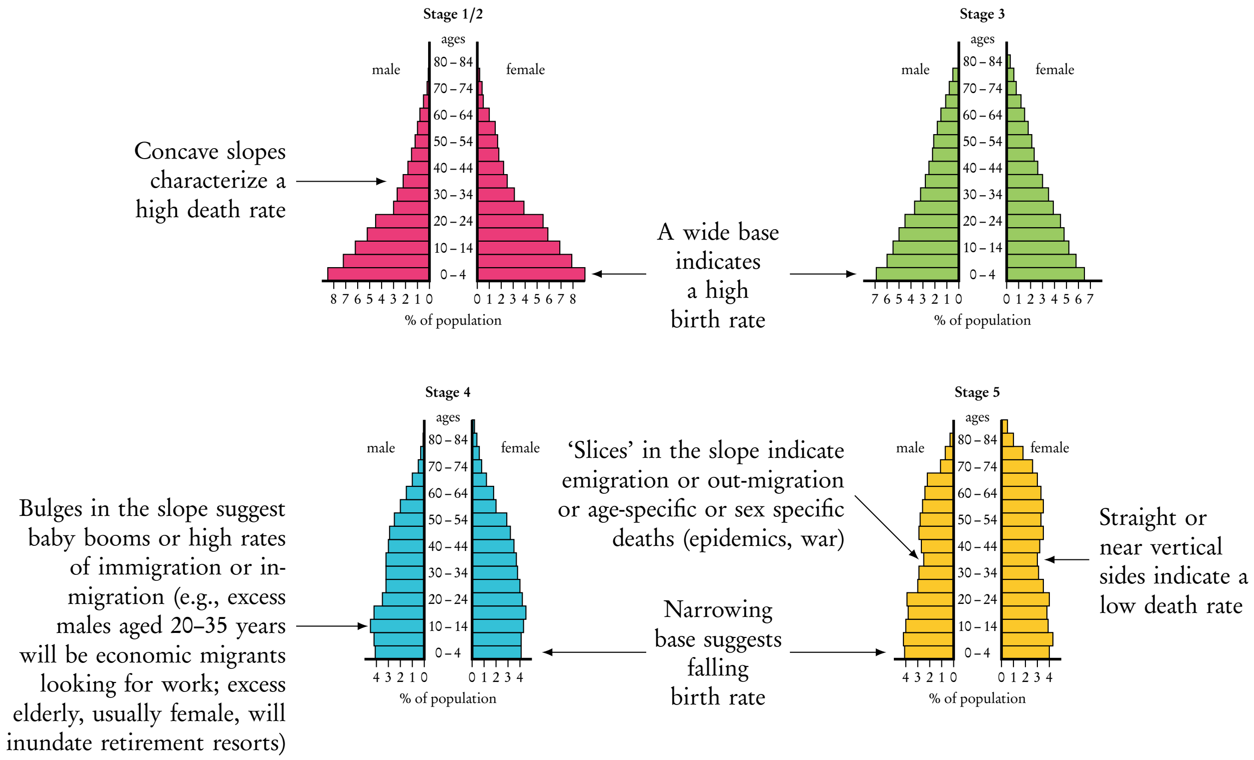
Slow declining:

- the birth rate is lower than death rate
- the population declines
- Japan and Sweden are in this stage



4.1.2 Population pyramids

Population pyramids display information about the age and sex structure of a population.



4.1.3 Factors that affect fertility

The general pattern for fertility is that it is lower in MEDCs and higher in LEDCs

- Status of women – Higher status = lower birth rate.
- Level of Education – Higher education = lower birth rate.
- Wealth – Middle-income families who aspire to live well tend to limit the number of children they have. Those with lower ambitions or those with more wealth do not.
- Urban vs Rural – Relates to factors above. Also children are more of an asset in rural areas.
- Religion – Many religions are pro-natalist, however other factors tend to be stronger. For example Italy has one of the lowest birth rates in Europe despite being strongly catholic.
- Health – Good health care can result in more successful pregnancies, but birth rates tend to be higher in areas with poor healthcare (higher infant mortality) to offset children that have been lost.

- The cost of children – Economic prosperity allows for more children, however as countries develop the cost of children also increases, and therefore birthrates decrease. In the UK the average child costs £230,000
- National and international development policies may also have an impact on human population dynamics.
- Governments often attempt to control the population structure in order to avoid some of the disadvantages above. These policies are either pro-natalist (wish to increase birth rate) or anti-natalist (wish to decrease birth rate). Many LEDCs are aiming at reducing birth rates through better family planning and support for birth control.

Case study.

The most well know anti-natalist policy is China's Infamous "One child Policy" put into place in 1979. The policy can be heralded as a success, claimed to of negated a potential 300 million people over 20 years. However the policy was heavy handed, including forced abortion and sterilisation and due to the social preference for boys, led to infanticide of girls (show in current gender ratio of 114 males : 100 Females).

Many developed countries have pro-natalist policies in place, ranging from economic incentives / tax breaks to more extreme measures such as government arranged "Love cruises" (Singapore) or banning contraceptives (Romania). However few have managed to raise birth rate for more than a few years, finding it hard to reverse the trends due to economic development we examined earlier. Attracting economic migrants is currently a more effective method to balance ageing populations, but often this just moves the problem on.

4.1.4 Factors that affect mortality

There is no clear global pattern for CDR, however in general MEDCs have higher life expectancies, while LEDCs have higher rates of child and infant mortality. Infant deaths are often preventable and can therefore indicate poor water supply, sanitation, healthcare and nutrition.

- Age structure – Quite simply, if a country has a proportionally large elderly population it will have a higher death rate than a country with a proportionally large younger population.
- Social class and occupation – Within a country, those of a lower social class, who most likely work in manual jobs, have higher mortality rates. Similarly lower classes can be disadvantaged by poorer access to healthcare (physical or financial), and overcrowding and pollution in cities.
- Disease and war – Prevalence of certain diseases, most recently HIV Aids, can have huge impacts of death rates in relatively short periods of time. Wars have a similar effect but tends to only effect the young adult male population.

4.2 Human resource use

Natural capital is a term used for natural resources that can produce a sustainable natural income of goods or services. **Natural income** is the yield obtained from natural resources

Humans draw many goods (marketable commodities like timber and minerals) and life supporting services (e.g., photosynthesis, decomposition) from the earth. Anything that is regarded as being of value to us is a resource and has a natural capital. This value may be aesthetic, cultural, economic, environmental, ethical, intrinsic, social, spiritual, or technological. Note that the value of a resource can differ by location and change over time.

Renewable natural capital can be generated and/or replaced as fast as it is being used.
Non-renewable natural capital is either irreplaceable or only replaceable over geological timescales (e.g., fossil fuels, soil, and minerals).

The rate at which these resource can be replaced is know as their natural income. If natural capital is used beyond its natural income, this use becomes unsustainable. The analysis must be holistic as The impacts of extraction, transport, and processing of a renewable natural capital may cause damage making this natural capital unsustainable. Similarly through methods of conservation, reuse and recycling we can sustain resources.

All of the challenges we currently face are due to either our over use / exploration of resources (cover in the following chapters) or the waste they produce. However it must be noted that in many (particularly developing countries) there is a conflict of interest between environmental, economic and social concerns. Countries strive to make life better for their inhabitants and often environmental degradation is seen as a small price to pay for a strong economy that can lead to better education, healthcare and quality of life.

4.3 Pollution

Pollution is the addition of a substance or an agent to an environment by human activity, at a rate greater than that at which it can be rendered harmless by the environment, and which has an appreciable effect on the organisms within it. Pollutants may be in the form of organic/inorganic substances; light, sound, or heat energy; biological agents, or invasive species; and derive from a wide range of human activities including the combustion of fossil fuels. It is rarely a malicious process. Most pollutants are generated from a useful process and sometime their negative effects are not noticeable until a large quantity is being produced. For example DDT is a useful pesticide but due to its widespread use it became a pollutant (see page 26).

Pollution may be:

- non-point (coming from many places) or point source
- persistent (pollutant can not be naturally broken down) or biodegradable
- acute (effect is seen shortly after pollutant is present) or chronic (pollutant has an effect over a long time).
- primary (active on emission) or secondary (arising from primary pollutants undergoing physical or chemical change).
- We must take these characteristics into account when managing pollution as different strategies are require for different characteristics.

The management strategy for combating pollution can be generalised into 3 steps, which should be attempted in descending order.

1. Alter human activity to replace the pollutant – Promote alternative technologies, lifestyles and values through education and government legislation.
2. Regulate to minimise the release of pollutant – Extract the pollutant from the waste and store securely.
3. Recover the pollutant and restore the natural environment

Often the measures become increasingly expensive as you go down the list. Here an ounce of prevention is worth a pound of cure. Removing pollution from the environment is far more costly than treating the pollutant before entry or reducing its use.

4.3.1 Solid Domestic Waste (SDW)

The most visually emotive type of pollution is the discarded items from our own homes, official termed Solid domestic waste. Although only 5% of all waste it is something we can all control. In the EU we produce 1.4 kg of SDW per person per day.

There are different types of SDW of which the volume and composition changes over time. Recently, the abundance and prevalence of non-biodegradable (e.g., plastic, batteries, e-waste) pollution in particular has become a major environmental issue. Plastic waste in the sea is being broken down in to small pieces by wave actions. These are then ingested by fish and birds. Our electronics contain valuable metals (copper, zinc, etc), lithium batteries and various toxic substances (lead, mercury, arsenic, etc.) However due to their increasing complexity very little is recycled, and many of these substances can leak into the environment. In 2016, 44.7 million tonnes of E-waste was generated with an estimated raw material value of 55 billion euros.

Below is a list or waste disposal options from best to worse for the environment. However where our SDW goes is influenced by cultural (attitude to disposal), economic (cost of disposal), technological (methods of disposal), and political (legislation and taxes) factors.

1. Non-disposal – dispose of less through the following
    - Reduce – minimise waste through consuming less/ choosing options with less packaging;
    - Reuse – repair items, or give to others so they can be used again in their current form
    - Recycle – the raw materials of the item can be used to make new ones.
2. Composting – Naturally breaking down organic waste with microorganism This can be done in your back garden are in large scale anaerobic biodigesters. These can collect methane to be used as a fuel and the remaining solids make good fertiliser.
3. Incineration – burning waste. It is possible to generate energy and the ash can be used in road building. However incineration does realise carbon dioxide and sometimes worse chemicals from the burning of plastics and electronics. The extra filtering required makes incineration plants expensive to build.
4. Landfill – about 40% of our waste goes to big holes in the ground, where unsorted waste is disposed of. They are strategically located so as not to effect human population or leak out into the environment, but are becoming harder to find. Increasingly landfill is being placed in LEDCs where the environmental protection is less strict and so pollute the areas around them. Methane gas can be recovered and used as a power source. It is also possible to eventually build on top of.
5. Dumping in the sea.

Going a step further, there are ideas of removing waste completely. Waste as a term is subjective: one person's waste can be another person's resource. This is the principle of a circular economy where by keeping technological and biological materials separate, we can endlessly recycle them to provide everything we need.

HUMANS AND THEIR EFFECT ON THE BIOTIC WORLD

5

Through our increasing numbers, increasing land use and increasing pollution, we are outcompeting the animal world. While global biodiversity is difficult to quantify, it is decreasing rapidly due to human activity.

The total number of classified species (1.8 millions) is a small fraction of the estimated total of species (from 5–100 million). They are based on mathematical models, which are influenced by classification issues and a lack of finance for scientific research, resulting in many habitats and groups being significantly under-recorded. Small organisms (insects, microbes, fungi, bacteria etc.) and those that live in inaccessible environments (deep ocean).

The composition of species is ever changing with the natural loss (extinction) of species between 10–100 species lost per year. Estimates of extinction rates are also varied, but current extinction rates are thought to be between 100 and 10 000 times greater than background rates, due to increased human influence. Put another way this is about 3 species lost every hour. There have been high periods of species loss (mass extinction) before but this was due to volcanic eruptions, see level changes or other major natural events. Many have said that we are in the middle of a mass extinction due to humanity.

The human activities that cause species extinctions include:

Habitat destruction – degradation, fragmentation (the division of land) and loss of habitat mostly through modern agriculture and resource extraction. Habitat can also be altered indirectly through climate change causing biome shifts.

Introduction of invasive species – both species which compete against native species, and diseases which can wipe out species.

Pollution – making a habitat less habitable.

Over-harvesting and hunting – taking the natural biotic resource faster than replacement.

5.1 The value of biodiversity

Biodiversity is a resource with natural capital that only becomes clear when we imagine a world without it. The various impacts will resonate with different environmental value systems (see Chapter 6). Direct values are easy to quantify, indirect are more subjective.

Aesthetic

People enjoy being in nature and travel to places of beauty.

Ecological

- Environmental stability and mineral cycles.
- Soil aeration by worms.
- Fertilisation and pollination by insects.
- Unique habitats and species.
- Natural decomposition of waste.
- Biological control of pests.

Economic

Food – Although our diets have narrowed, we still eat a large variety of plants and animals. Within these are many strains. This diversity is vital in order that our food is resilient of disease and pests. We are beginning to see the value of this with farmers and breeder given focus to historical varieties.

Products – we get many medicines, fertilisers, oils, rubber, linen, rope, cotton, silk, honey, rattan, perfumes, timber and pesticides form the natural world.

Ethical and social

- Each species has a right to exist.
- Indigenous tribes and strongly connected to their environments.
- There is scientific value.

Possibly the strongest argument is that we do not yet know what we be valuable to us in the future, and therefore we should aim to conserve biodiversity regardless of its current usefulness to us.

5.2 Conservation of biodiversity

Conservation is the act of preserving something for future generations. It is a two stage process. First vulnerable species and/or habitats are identified, then strategies are put in place to protect them.

Identify

Quantification of biodiversity is important so that areas of high biodiversity may be identified, explored, and have appropriate conservation put in place. Similarly, the ability to assess changes to biodiversity in a given community over time can be used to assess the impact of human activity in the community. See Chapter 3 for experimental methods for this.

(Designate)

This intermediate step is not needed but is now common practice. Designating a species or habitat with a special status (for example endangered species, national park) can help to publicise the need to protect it.

The International Union of Conservation of Nature (IUCN) publishes data in the "Red List of Threatened Species". A species can be given one of the following statuses ranging from extinct to numerous:

EX	Extinct	
EW	Extinct in the wild	only alive in captivity
CR	Critically endangered	extremely high risk of extinction
EN	Endangered	very high risk of extinction
VU	Vulnerable	high risk of extinction
NT	Near threatened	close to qualifying for the above
LC	Least concern	widespread and abundant

Factors used to determine the conservation status of a species include:

Population size – smaller populations have fewer individuals to lose and likely have lower genetic diversity so have a lower ability to adapt to change. If a population is decreasing it can indicate that it is under threat. Further more if a population is fragmented, this reduces the chance for reproduction and reduces the species

Geographic range and degree of specialization – highly specialised species are more vulnerable as they are dependent on a niche. Similarly species that occupy small habits are more likely to be wiped out.

Distribution – Species spread across a smaller area are more prone to extinction.

Reproductive potential and behaviour – some animals (elephants, rhinos, orang-utans) have low reproductive rates, and therefore take a long time to replace their populations.

Quality of habitat – a reduction in the quality of a habitat puts pressure on a species.

Trophic level – Animals higher up the food chain are more sensitive to changes lower down. They also tend to have smaller population numbers.

Probability of extinction – some species are naturally going extinct (excluding human impact).

Conserve

Conservation is often a large and ongoing task, therefore organisations, both governmental and non-governmental, are important parts of managing the process.

Non-governmental organisations (NGOs)	Intergovernmental organisations (IGOs)	Government organisation
Example		
Greenpeace, WWF	European Environment Agency (EEA), United nations environment program (UNEP), International Union of Conservation of Nature (IUCN)	Environmental Protection Agency o. the USA (EPA)
Common traits		
Radical often grassroots, in the field. Often will focus on local issues	More conservative. More focus scientific research and cataloging Organised as businesses with clear duties and approach	Research and publicise the environmental policies of a national government

Agenda		
Protect the environment, through direct protection and lobbying political change	To provide guidelines and implement international treaties	Research, regulation, monitoring and control activities within a country
Speed of Response		
Quick to respond as organisations represent groups of like minded people	Slow to respond as require a consensus of all parties involved with differing political agendas (more bureaucratic)	Varies, depending on political agenda
Financial Resources		
Funding from charitable donations	Funded by government and international funds	Funded by national government
Political influence		
Focus on the environment, can be idealistic and extreme They can check the actions of governments and businesses against the environment Often have no direct political power	Decisions can be effected by political and economic factors	Strongly influenced by the government in power
Use of Media		
Have to attract media attention through action (protests, campaigns). + These can be used to put pressure on governments to act – Often only focuses on "cute" animals for more public appeal – Can be censored in some countries	Can use national media to communicate policies effectively to the public	Uses national media to promote prepared information

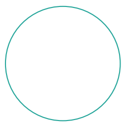
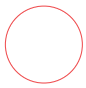
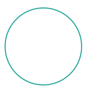
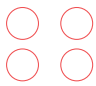
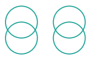
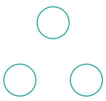
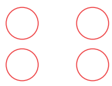
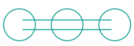
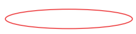
Furthermore international conventions on biodiversity work to create collaboration between nations for biodiversity conservation. In 1980, the IUCN launched the World conservation strategy, outlining global priorities and encouraging countries to incorporate these in to their national development strategy. At the same time, it stressed the importance of local community, especially those who closely depend on natural resource, in achieving these priorities. The convention focused on three points that could be scientifically quantified and were therefore easier to agree on:

- maintaining life supporting systems and ecological processes
- preserving genetic diversity
- sustainable use of species and ecosystems.

The convention was updated in 1991, to include the benefits of sharing and sustainable use of natural resources.

Conservation strategies

The strategy for conservation can focus on conservation of the habitat, conservation of certain species, or a mixture of both.Often a mixture leads to the best results as habitats and their species are strongly interconnected.

Better	Worse	When conserving a habitat the following criteria are considered:
		**Bigger is better** as the increased area allows for more species and large populations.
		**SLOSS debate** (single large or several small) One large area can support more habitats and species, especially top predators, than several smaller areas of a similar total size. Similarly it is good practice to minimise fragmentation of a large reserve. Sometimes smaller reserves are the only option. Several smaller reserves can reduce the risk of the total decline of the ecosystem due to natural or man-made disasters.
 	 	**Arrangement/Distribution and proximity to potential human influence** Close and arranged in a cluster is preferable to isolated and in a line; because animals can disperse and recolonize if a reserve loses stock through disturbance. A buffer zone can be placed around the conservation area to reduce human disturbance. Some low impact activities such as farming and selective logging can happen here.
		**Corridors** Connecting reserves is good to facilitate dispersal of species and seasonal migrations. A wider corridor is better than a narrow one as it has a smaller edge. Corridors have the potential downside of spreading disease between reserves. Narrow corridors can provide an easier hunting ground for poachers.
		**Shape and edge effects** Although dictated by the landscape, the best shape for a reserve is circular as this has the smallest edge to area ratio. Minimising edges is important because they are the border of two habitats. They therefore have different abiotic factors and more competition than the main conservation area. Often the most vulnerable species will not be able to survive her.

When conserving species the following strategies can be used:

Promotion of flagship species to gain public support. These are charismatic species that people will like and so support a conservation effort. In the process other (less charismatic) species will be protected. One disadvantage is that these flagship species can take priority, despite not often being the most important part or the ecosystem.

Selection of keystone species to protect the integrity of the food web. A small change in the population of a keystone species can have a large effect on the rest of the ecosystem.

The Convention on International Trade in Endangered Species (CITES). This very successful voluntary international convention aims to restrict the trade of species, where that trade threatens their survival. Species are can be put into one of three groups:

- Appendix I: species cannot be traded internationally as they are threatened with extinction.
- Appendix II: species can be traded internationally but within strict regulations ensuring its sustainability.
- Appendix III: a species included at the request of a country which then needs the cooperation of other countries to help prevent illegal exploitation.

Captive breeding and reintroduction programmes, and zoos. Keeping animals in captivity helps to maintain species that are threatened in the wild. Zoos allow more people to see exotic animals and so increase support for their conservation. It is possible to reintroduce captive species back to the wild but this is a difficult and costly strategy. To be successful, attempts must engage the local community to help support the species in their early stages and not exploit them too quickly.

DNA and seed banks. Stores of plant and animal DNA are maintained as both a record of the species and as a potential way to bring species back in the future.

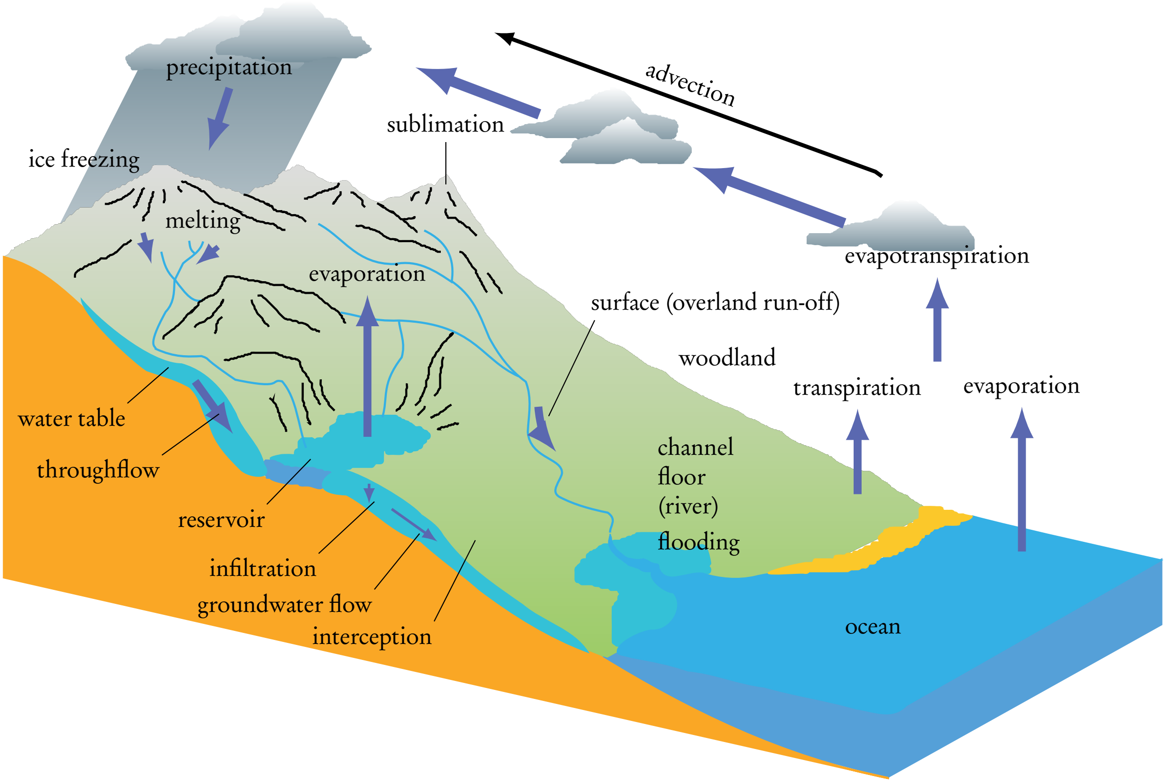
Even taking all of these factors into account, success of conservation efforts are strongly influenced by the amount of community support, funding and proper research.

WATER, SOIL AND FOOD PRODUCTION

6

6.1 Water

The hydrological cycle is a system of water flows and storages driven by solar radiation.



Storages: organisms, soil and various water bodies, including oceans, groundwater (aquifers), lakes, rivers, atmosphere, glaciers and ice caps. Fresh water makes up only a small fraction (approximately 2.6% by volume) of the Earth's water storages. 68.7% of this is in ice. Only 0.3% of all water is accessible for us. The amount of time water is stored (the turnover time) varies greatly between a few days and tens of thousands of years. Therefore depending on location water can be both renewable and nonrenewable capital.

Flows: evapotranspiration, sublimation, evaporation, condensation, advection (wind-blown movement), precipitation, melting, freezing, flooding, surface runoff, infiltration, percolation, and stream- flow or currents.

Human activities often affect the hydrological cycle by changing the amounts of surface runoff and infiltration.

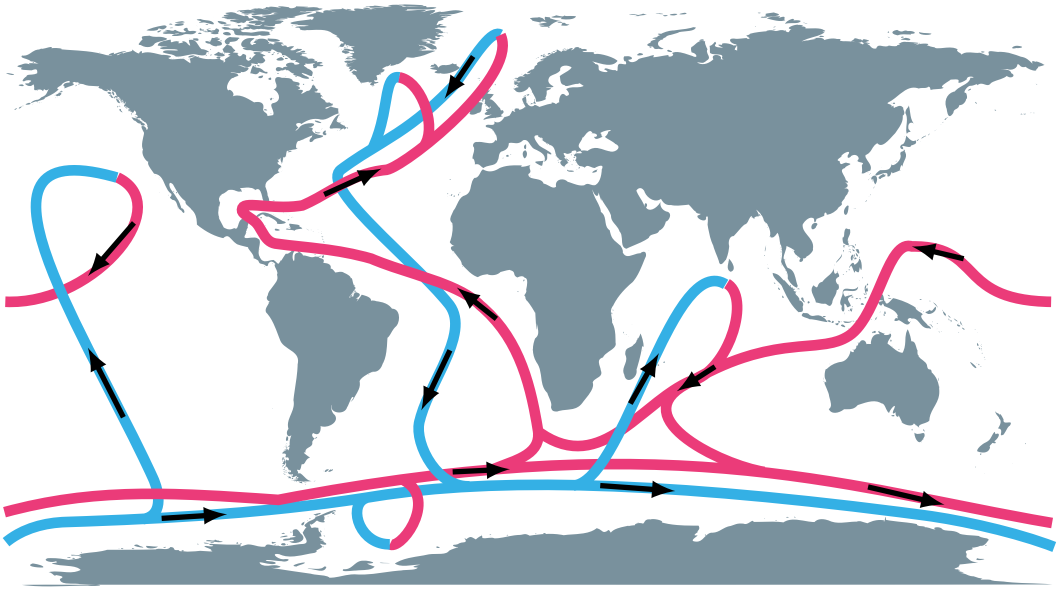
Agriculture – To irrigate crops, humans have diverted rivers, and extracted water from surface stores and ground water. Furthermore cropland and grazing pastures intercept less rain and allow for less infiltration. Combined this can lead to greater surface runoff, leaching of minerals and flooding. Agricultural chemicals can be carried in the runoff and discharged into rivers.

Deforestation – trees intercept large volumes of precipitation and their roots stabilise the soil, increasing the volume of water infiltrated into the ground. When they are removed most of the precipitation becomes surface runoff, eroding the soil and raising flood levels. If not quickly replenished with new vegetation, a positive feedback loop forms as the soil becomes degraded, vegetation decreases and surface runoff increases.

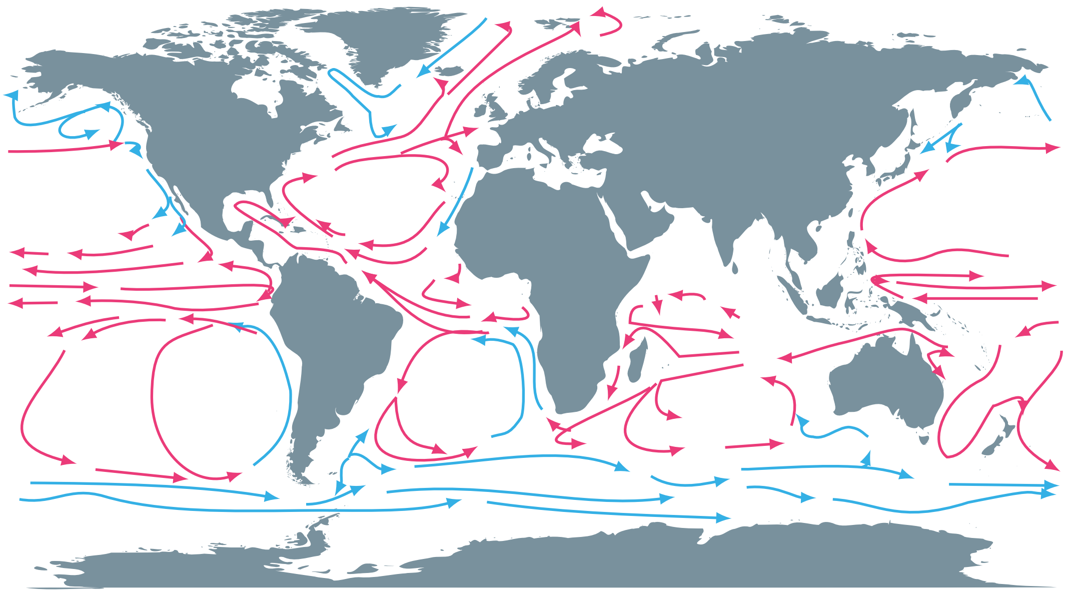
Urbanization – The effects can vary from city to city. In general urban areas have more impermeable areas and less vegetation. During dry periods, evaporation is increased and more strain put on water stores, depleting aquifers/lowering the water table; where as, in wetter periods, surface runoff and the chance of flash floods increases. This can be offset by greater water management such as: diverting rivers, building storm drains and urban basins and encouraging the use of urban greenery and permeable surfaces. However, these measures sometimes just move the problem downstream.

Ocean circulation

The water in our oceans is constantly circulating, driven by differences in temperature and salinity which effect the density of sea water. Warmer, less salty water rises and colder, saltier water sinks. These thermocline currents move water in a global loop known as the great oceanic conveyor belt (OCB).



These currents are overlaid by smaller currents driven by the OCB, salinity and wind. Together they are key to climate as they distribute heat around the world.



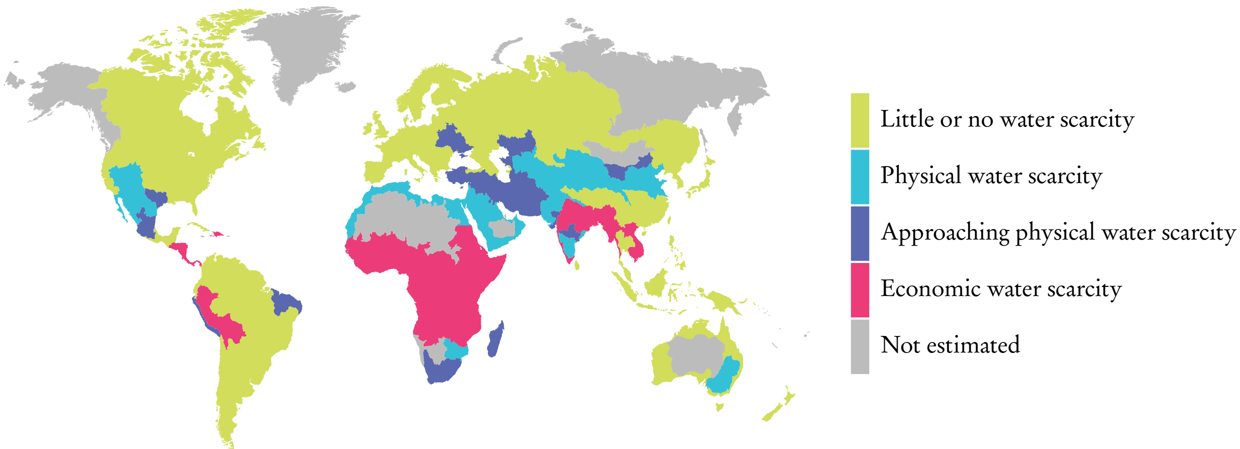
Freshwater access

Up to 40% of humans alive today live with some level of water scarcity. Either:

Physical scarcity of water – there is not enough water.
Economic scarcity of water – there is enough water but it is too expensive to access.

The supplies of freshwater resources are inequitably available and unevenly distributed, About three-quarters of annual rainfall occurs in areas containing less than a third of the world's population.

This can lead to conflict and concerns over water security, particularly where sources are shared. Freshwater supplies may become further limited through contamination and unsustainable extraction. As populations, irrigation and industrialisation increase, the demand for fresh water is increasing. Furthermore climate change may disrupt rainfall patterns and further affect this access.



Freshwater resources can be sustainably managed using a variety of different approaches. Water supplies can be enhanced through reservoirs, redistribution, desalination (expensive and energy intensive), artificial recharge of aquifers and rainwater harvesting schemes. Water conservation (including grey-water recycling) can help to reduce demand but often requires a change in attitude by the water consumers.

Aquatic food production

The worlds oceans have been regarded as a seemingly abundant source of food. The oceans have a variety of complex ecosystems, most are supported by photosynthesis by phytoplankton. The highest rates of productivity are found near coastlines or in shallow seas, especially where upwellings and nutrient enrichment of surface waters occurs. Aquatic (freshwater and marine) flora and fauna are harvested by humans. However due to both human population growth (1.7% per year) and changing diets (aspiration for more animal protein in NICs/LEDCs and food fashions ("health foods")), recent demand for aquatic food resources has grown at an average of 3.2% per year.

To meet this demand, fishing equipment has developed and fishing methods have changed. However this has also lead to dwindling fish stocks and damage to habitats. For example modern trawling techniques do not distinguish between adult and young fish, removing the next generation before it can mature. Furthermore there is by-catch of "unwanted" species that often are thrown back dead into the ocean.

Many fishing areas are over exploited (the capture of fish is higher than the maximum sustainable yield). In the worst cases this has lead to environmental degradation and collapse of wild (capture) fisheries. According to the FAO (Food and Agriculture Organization) , more than 70% of the world's fisheries are fully exploited, in decline, seriously depleted or too low to allow recovery.

Unsustainable exploitation of aquatic systems can be mitigated at a international, national, local and individual level through policy, legislation and changes in consumer behaviour.

- Environmental pressure by the public has lead to new rules on discarding by-catch.
- Severely depleted areas have been closed to fishing to allow them to recover.
- Fish quotas are being implemented internationally to help guarantee that fish are not being caught above MSY.
- New techniques such as wider mess nets, and improved fish sonar, allow for more selective catches.

Due to these measures wild catch has stabilised at 90 million tonnes per year.

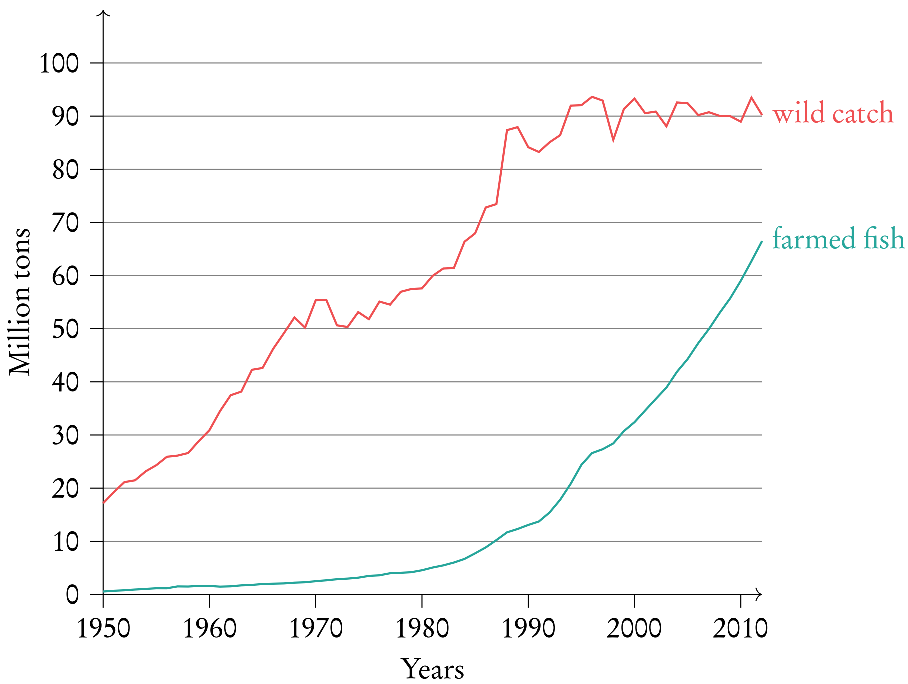


Figure 6.1: World wild fish catch and fish farming 1950–2012

Much of the continued demand increase is being met with farmed fish. Aquaculture provides potential for increased food production and also economic development. It involves intervention in the rearing process to enhance production. Issues around aquaculture include:

- Loss of habitats,
- Pollution (with feed, antifouling agents, antibiotics and other medicines added to fish pens)
- Spread of diseases and escaped species (some involving genetically modified organisms).
- It has also been noted that the feed for the farmed fish (particularly salmon) can come from wild catch of smaller species and so still indirectly put pressure on natural reserves.

Controversial species

There are certain species, such as seals, sharks and whales, where hunting is more controversial. The ethical issues arise over the biorights of these unique and sometime endangered animals. Under the International Whaling Commission, whaling has been banned since 1986 because of the commercial hunting was unsustainable and barbaric. Several countries with a historic culture for whale hunting (Japan, Norway) would like the ban lifted. Japan continues to hunt whales under the guise of scientific research. However NGOs and counties have protested against this. In comparison small scale hunting is still carried out by Inuits. For many this is seen as acceptable because indigenous cultures should have the rights to their traditions.

Water pollution

Despite being so reliant on both fresh water and the oceans, we have strangely been using water stores as a massive dump for our waste. Pollution both to groundwater and surface water, is a major global problem, the effects of which influence human and other biological systems. Types of aquatic pollutants include:

- floating debris
- organic material
- inorganic plant nutrients (nitrates and phosphates)
- toxic metals
- synthetic compounds
- suspended solids
- hot water
- oil
- radioactive pollution
- pathogens
- light
- noise
- biological pollutants (invasive species).

Source of aquatic pollutants include:

- surface run-off
- sewage
- industrial discharge/ pipelines
- power station waste
- solid domestic waste
- recreation and tourism
- rivers, atmosphere
- oil spills
- deliberate and accidental discharges from ships
- aquaculture farms

Note: Storm water that washes off the roads and roofs can be a worse source of pollutants than sewage. Such water may contain high levels of heavy metals, volatile solids, and organic chemicals.

Measuring water pollution

In Chapter 3 we looked at various measures we can take to measure the environmental condition of the water. When measuring for pollution, a polluted and an unpolluted site should be compared (for example, upstream and downstream of a point source). We can determine water pollution through directly measured samples of water for:

- pH less than 6.5 or greater than 8.5.
- High concentrations of chemical indicators – nitrite, free chlorine, chloride, fluoride, hardness, phosphates, and heavy metals such as lead.
- Percentage saturation of dissolved oxygen – less than 50% can be considered polluted.

Water quality can also be indirectly measured by examining the fish and insects that live in and around the water. Certain species, termed **indicator species**, are tolerant to certain pollutants and therefore a high relative abundance can be indicative of polluted waters. Often this is faster and cheaper than direct methods.

Eutrophication

Certain pollutants can help a few well adapted organisms dominate an ecosystem. A prime example is **eutrophication** — excessive nutrient enrichment, often from leached agricultural fertilisers, leading to rapid growth in algae, plants and phytoplankton populations.

These large blooms of algae can be seen as a green surface on the water. One exception is a marine algae species which creates huge red tidal blooms and produces dangerous toxins.

Where the eutrophication is small, negative feedback will stabilise the system. Increase in algae ⟶ Increase in fish ⟶ Decrease in algae.

When there is a sufficient amount of organic material and organisms to break it down, a positive feedback loop occurs. The biodegradation of nitrates and phosphates utilises oxygen. **Biochemical oxygen demand (BOD)** is a measure of the amount of dissolved oxygen required to break down the organic material in a given volume of water through aerobic biological activity. The increased BOD can lead to a lack of oxygen in the water (anoxic), which in severe cases leads to formation of methane, hydrogen sulfide and ammonia (toxic gases). Furthermore the algae blooms reduce light penetration to river beds, preventing aquatic plants from photosynthesising and replacing the lost oxygen. This kills the life in the water leaving 'dead zones'. Eventually the algae will die back and nothing is left. This effect is exaggerated in warmer waters, as the water can hold less oxygen and the rate of respiration is higher.

Management strategies

Altering human activity

- limiting fertilisers and detergents by encouraging better methods and legislation.
- educating people to care for the ocean. eg stopping plastic waste.

Controlling release of pollutant

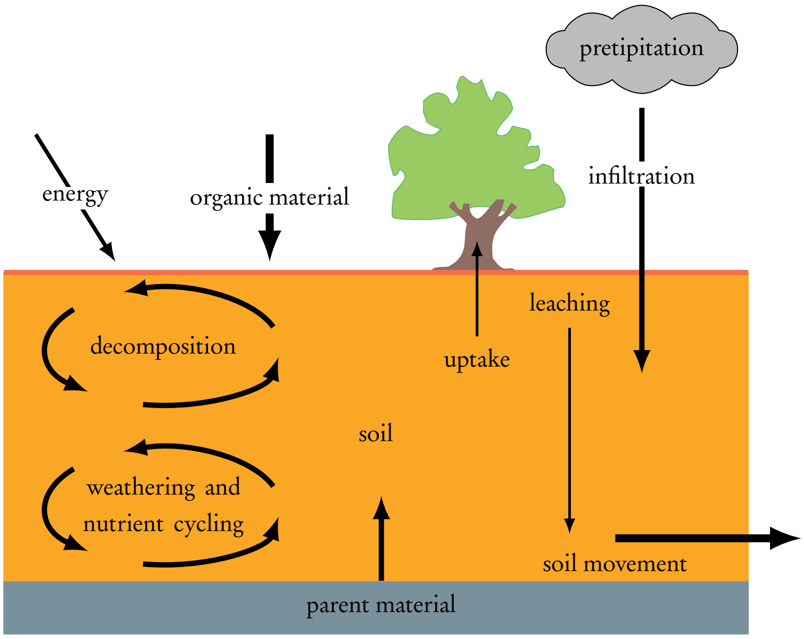
- waste water treatment to remove nitrates and phosphates.

Clean-up and restoration of damaged systems

- precipitation of phosphates.
- removal of nutrient rich mud from eutrophic lake.
- reintroduction/management of plant and fish species.

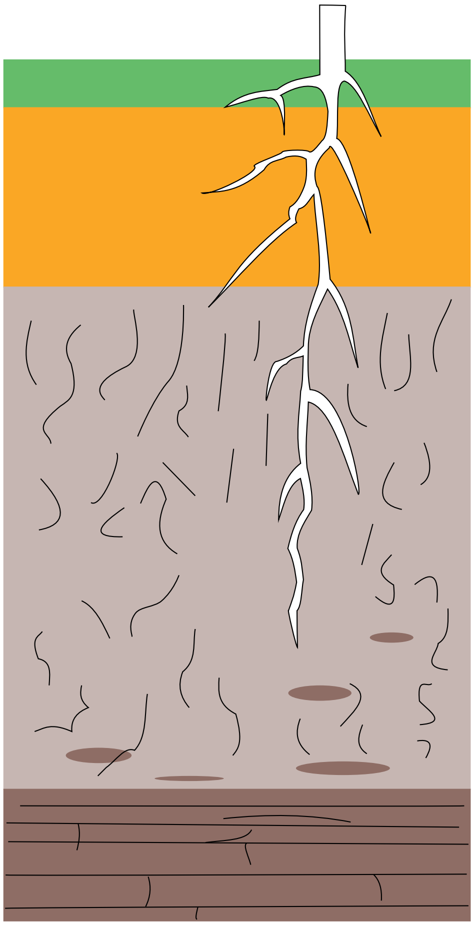
6.2 Soil

The ground beneath our feet is very easy to overlook, but it is an essential part of the global system. It is a habitat for many micro-organisms; provides peats, clays, sand and gravel; and most notably it is the medium in which most of our food is produced.



Inputs: organic material including leaf litter and inorganic matter from parent material, precipitation and energy
Outputs: uptake by plants and soil erosion
Storages: organic matter, organisms, nutrients, minerals, air and water
Flows: Transfers of material within the soil, including biological mixing and leaching (minerals dissolved in water moving through soil), contribute to the organization of the soil. Transformations include decomposition, weathering and nutrient cycling.

Soil may be illustrated by a soil profile that has a layered structure known as soil horizons. Soils vary in the number of horizons they contain and how visually different each horizon is.

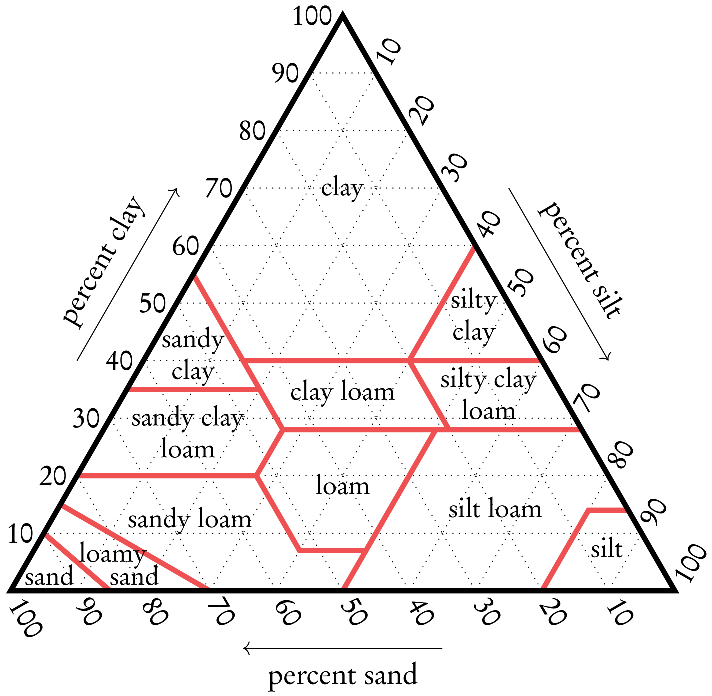


O organic horizon		
l	un-decomposed litter	
f	partly decomposed (fermenting) litter	
h	well-decomposed humus	
A mixed mineral–organic horizon		
h	humus	Generally a dark colour due to the organic material
p	ploughed, as in a field or a garden	
g	gleyed or waterlogged	
E eluvial or leached horizon		
a	strongly leached, ash coloured horizon, as in a podzol	Slightly lighter due to the leaching
b	weakly bleached, light brown horizon, as in a brown earth	
B illuvial or deposited horizon		
Fe	iron deposited	Contains the material from the leached layer
t	clay deposited	
h	humus deposited	
C bedrock or parent material		
r	rock	
u	unconsolidated materials	
R bedrock		
	hard bedrock	

Soil can also be classified using a soil texture triangle which illustrates the composition of the soil based on the percentage of sand (Particles with diameter 0.05 mm–0.2 mm), silt (0.02 mm–0.05 mm), and clay ($<$ 0.002 mm). This composition is a good indication of the properties of the soil such as: mineral and nutrient content, drainage, water-holding capacity, air spaces, biota and potential to hold organic matter; and therefore can help to determine the ability of the soil to promote primary productivity. The ideal soil for cultivation is a loam in which there is a balance between water holding ability and freely draining, aerated conditions.

Sandy soil – low primary productivity due to poor water-holding capacity and low nutrient status.
Clay soil – quite low primary productivity due to poor aeration and poor water infiltration.
Loam soil – high primary productivity due to medium infiltration rate, water-holding capacity, nutrient status, aeration, and ease of working.

Fertile loam soils take a long time to naturally build up through the process of succession and are therefore considered a non-renewable resource. Organisms within the soil provided nitrogen (nitrogen fixing bacteria) and nutrients (decomposition); as well as mixing the soil and aerating it. By maintaining functioning nutrient cycles, this community of organisms make soils resistant to soil erosion.



Humans can have a large impact on the composition of soils. We have learned how to improve soils for food production both naturally (irrigation techniques, natural compost) and more recently artificial measures. But we can also severely degrade soils through urbanisation (compactions), mining, deforestation, and intensive agriculture (grazing, monoculture, over irrigation). The loss of vegetation makes the soils more prone to erosion and the leaching of minerals. Compaction of soils by machinery or large grazers can make soils imporous and so increase surface runoff. In extreme cases soils can become biologically irreparable through: toxification, salination and desertification.

6.3 Terrestrial food production

Due to both increased human population and improved diets, there is growing pressure on our soils. The number of people an area of land needs to feed is growing and we are decreasing the amount of this productive land. Furthermore there is a current cultural trend towards greater consumption of meat and dairy. These foods come from a higher trophic level and therefore require a high proportion of land, energy and water to produce. Socio-economic, cultural, ecological, political and economic factors can be seen to influence societies in their choices of food production systems.

To meet the demand, commercial, industrialised food production systems (which generally tend to reduce soil fertility) are replacing small-scale subsistence farming methods.

The sustainability of terrestrial food production systems is influenced by factors such as:

- scale
- industrialisation
- mechanisation
- fossil fuel use
- seed, crop and livestock choices
- water use
- fertilisers
- pest control
- pollinators
- antibiotics
- legislation
- ratio of commercial versus subsistence food production

A real paradox in our current food production system is that we have both overproduction and food waste and malnourishment. This is due to the uneven distribution of fertile land and food. Food waste is an issue arising in MEDCs, where regulatory standards may be set according to commercial preferences so that consumable food is discarded. It can also be an issue in LEDCs, where the necessary refrigeration and transport infrastructure is insufficient to avoid food spoilage. These inequalities can lead to conflict.

6.4 Management strategies

It should be apparent that our current approach is unsustainable. The solution is to reduce the demand on the soils and better conserve them. Increased sustainability may be achieved through:

Altering human activity

- convincing consumers to reduce meat consumption and increase consumption of organically grown and locally produced terrestrial food products
- improving the accuracy of food labels to assist consumers in making informed food choices

Controlling release of pollutant

- monitoring and control of the standards and practices of multinational and national food corporations by governmental and intergovernmental bodies
- planting of buffer zones around land suitable for food production to absorb nutrient runoff.

Clean-up and restoration of damaged systems

- Soil conservation measures include soil conditioners (such as organic materials and lime), wind reduction techniques (wind breaks, shelter belts), cultivation techniques (terracing, contour ploughing, strip cultivation) and avoiding the use of marginal lands.

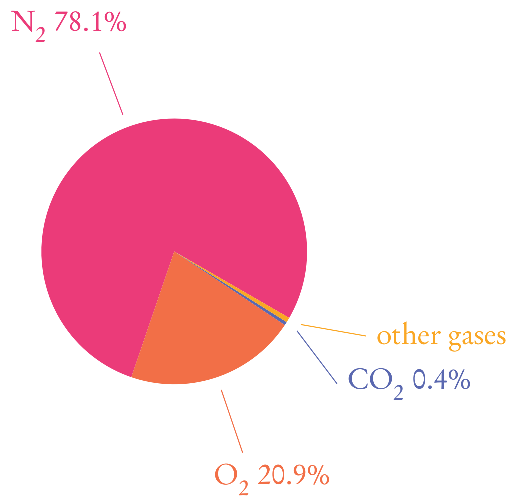
ENERGY AND THE ATMOSPHERE

7

7.1 Atmosphere

The atmosphere is a dynamic system that is essential to life on Earth. The behaviour, structure and composition of the atmosphere influences variations in all ecosystems.

The atmosphere is predominantly a mixture of nitrogen (78.1%), oxygen (20.9%), carbon dioxide (0.4%), argon, water vapour and other trace gases. But this mixture has undergone changes throughout geological time due to the atmosphere's relationship with the biosphere. Biotic components have effected inputs, outputs, flows and storages in the atmosphere and vice versa. The atmosphere is approximately 1100 km in depth, but we shall focus on the two lower levels. The stratosphere (10 km–50 km) which contains the Ozone layer and the troposphere (less than 10 km) where most clouds form. As we saw in the first chapter both of these layers are important for the solar radiation in the planet with clouds affecting albedo levels and trapping heat.



We will now look at how Human activities impact atmospheric composition through altering inputs and outputs of the system. These changes in the concentrations of atmospheric gases — such as ozone, carbon dioxide, and water vapour — have significant effects on ecosystems.

Ozone

Stratospheric ozone is a key component of the atmospheric system because it protects living systems from the negative effects of ultraviolet radiation from the Sun. Ultraviolet radiation reaching the surface of the Earth damages human living tissues, increasing the incidence of cataracts, mutation during cell division, skin cancer and other subsequent effects on health. The effects of increased ultraviolet radiation on biological productivity include damage to photosynthetic organisms, especially phytoplankton, which form the basis of aquatic food webs.

Some ultraviolet radiation from the Sun is absorbed by stratospheric ozone causing the ozone molecule to break apart. Under normal conditions the ozone molecule will naturally reform. This ozone destruction and reformation is an example of a dynamic equilibrium.

Human activities have disturbed the dynamic equilibrium of stratospheric ozone formation. Ozone depleting substances (including halogenated organic gases such as chlorofluorocarbons CFCs) are used in aerosols, gas-blown plastics, pesticides, flame retardants and refrigerants. Halogen atoms (such as chlorine) from these pollutants increase destruction of ozone in a repetitive cycle, allowing more ultraviolet radiation to reach the Earth.

Management strategies

The Montreal Protocol on Substances that Deplete the Ozone Layer (1987) and subsequent updates is an international agreement for the reduction of use of ozone-depleting substances signed under the direction of UNEP. National governments complying with the agreement made national laws and regulations to decrease the consumption and production of halogenated organic gases such as chlorofluorocarbons (CFCs). Methods for this reduction include:

Altering human activity

- reducing the manufacture and release of ozone-depleting substances.
- developing alternatives to gas-blown plastics, halogenated pesticides, propellants and aerosols
- developing non-propellant alternatives.

Controlling release of pollutant

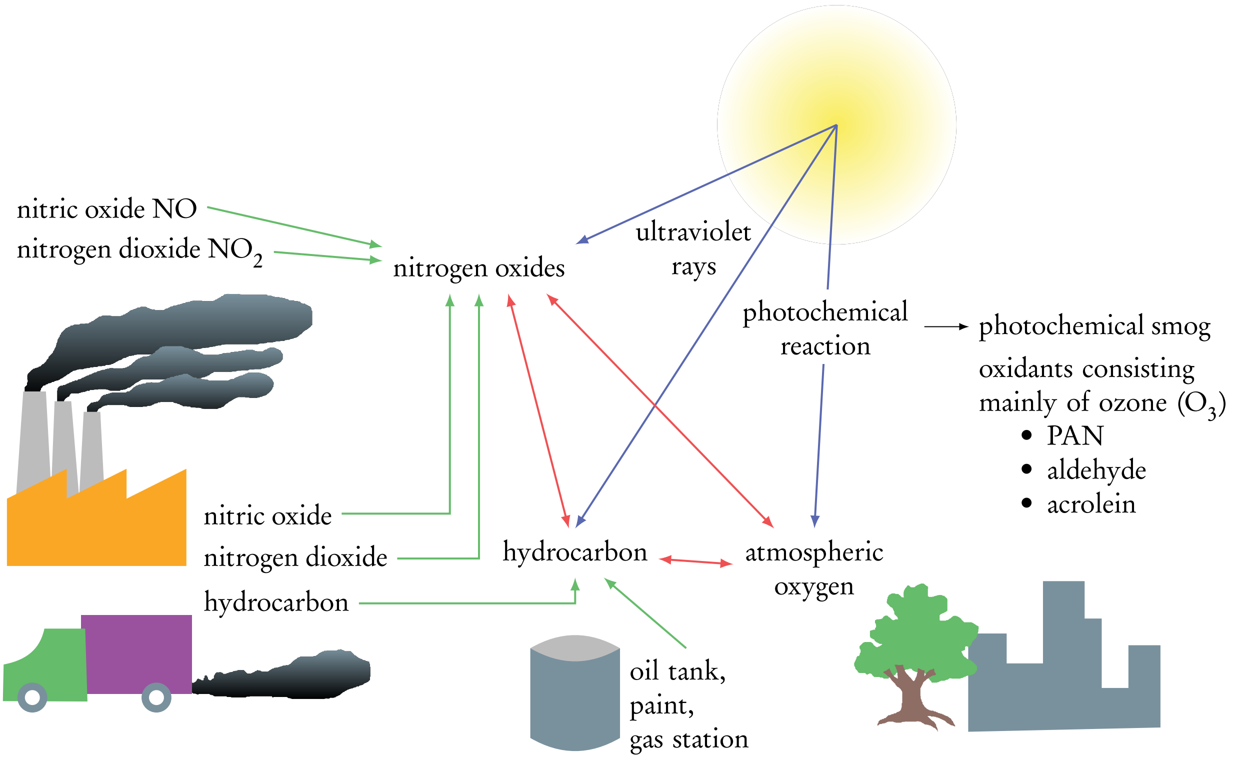
- recycling refrigerants
- UNEP has had a key role in providing information, and creating and evaluating international agreements, for the protection of stratospheric ozone.
- An illegal market for ozone-depleting substances persists and requires consistent monitoring.

Clean-up and restoration of damaged systems

- the holes in the ozone have been observed to be healing.
- atmospheric scrubbing methods have been proposed but are too costly to implement.

Photochemical smog and acid deposition

The combustion of fossil fuels produces primary pollutants (carbon monoxide, carbon dioxide, black carbon or soot, unburned hydrocarbons, oxides of nitrogen, and oxides of sulfur). These can then generate secondary pollutants which lead to photochemical smog and/or acid deposition.

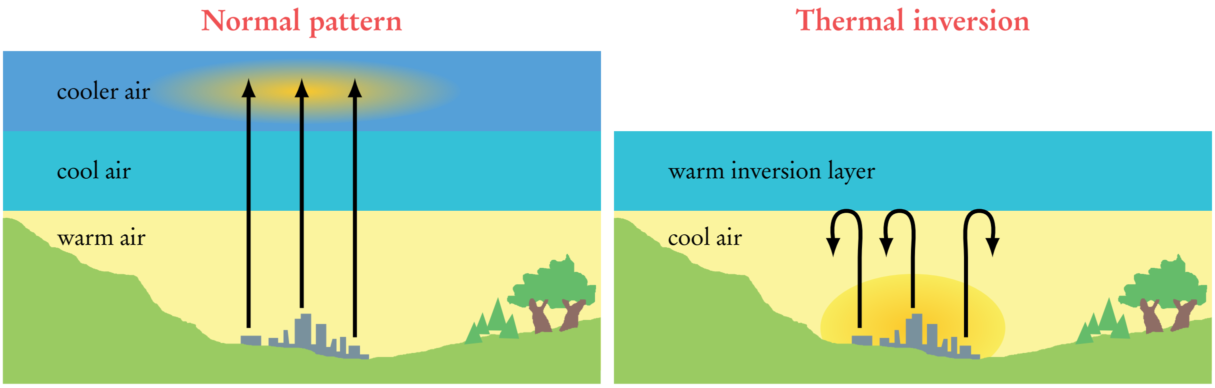


Photochemical smog is a complex mixture of primary and secondary pollutants, of which tropospheric ozone is the main pollutant. Now although, considering the last section, this would appear to be a good thing, Tropospheric ozone is highly reactive and has significant impacts on societies and living systems.

Primary pollutants react with chemicals in the atmosphere, under the presence of sunlight, to generate tropospheric ozone. Oxygen molecules react with oxygen atoms that are released from nitrogen oxides in the presence of sunlight. Deforestation and burning, may also contribute to smog.

Photochemical smog damages plants (crops and forests), irritates eyes, creates respiratory illnesses and damages fabrics and rubber materials. Economic losses caused by urban air pollution can be significant.

The frequency and severity of smog in an area can be exaggerated by local topography and climate. Thermal inversions occur due to a lack of air movement when a layer of dense, cool air is trapped beneath a layer of less dense, warm air. This causes concentrations of air pollutants to build up near the ground instead of being dissipated by "normal" air movements.



Acid deposition occurs when sulfur dioxide and oxides of nitrogen are converted into secondary pollutants sulphuric acid and nitric acid. These fall as either dry deposition (such as ash and dry particles) or wet deposition (such as rain and snow).

The acid deposition acidifies the soil and water, which in turn kills organisms that cannot tolerate the change in pH. The acidic water increased solubility of aluminium turning lakes and streams toxic. The combination of acid and aluminium kills much of the aquatic ecosystems. The acid rain leaches nutrients from the soils such as calcium. The lack of calcium can lead to reductions in snail populations and so in turn affect bird populations. Plants can struggle to get the nutrients required to photosynthesise. Acid rain also directly damages the leaves of coniferous trees as it falls.

The impacts of acid deposition may be limited to areas downwind of major industrial regions but these areas may not be in the same country as the source of emissions. Therefore in certain cases, the pollution management of acid deposition often involves cross-border issues. For example Scandinavian forests were affected by the acid depositions of pollutants from British coal power stations.

Management strategies

Altering human activity

- reducing use, or using alternatives to, fossil fuels — example activities include the purchase of energy-efficient technologies, the use of public or shared transit, and walking or cycling
- international agreements and national governments may work to reduce pollutant production through lobbying

Controlling release of pollutant

- regulating and reducing pollutants at the point of emission through government regulation or taxation

- use of scrubbers or catalytic converters to clean the exhaust of primary pollutants from coal-burning power plants and car exhausts.
- regulating fuel quality by governments

Clean-up and restoration of damaged systems

- reforestation, regreening, and conservation of areas to sequester carbon dioxide.
- artificial sequestering
- spreading ground limestone in acidified lakes or recolonization of damaged systems — but the scope of these measures is limited.

7.2 Energy production

Most of our effect on the atmosphere is due to emissions from energy production. Energy, particularly in the form of electricity, is what drives our world. It is worth remembering that all our energy sources are derived from solar energy. Some are a direct utilisation, others are a store. For the majority of human civilisation wood (a store) was our main energy source. Now, we generate energy from a variety of sources that vary in their sustainability, availability and cost.

Sustainability	Cost	Availability
Non Renewable: fossil fuels (provide 80% of our energy)		
Coal		
High realise of carbon dioxide and sulphur dioxide (leading to acid rain). Extraction often in large opencast mines.	Cheap.	Found globally but is estimated to run out in 150–250 years (based on current use). Do to its weight, it is consumed near to where it is produced and does not require processing.
Oil		
Release of carbon dioxide. Oil spills from transport can devastate habitats.	Cheap but become increasingly more expensive as wells start to run dry.	Concentrated in the Middle east (2/3rds), Russia and North America but is estimated to run out in 50–100 years (based on current use) Could be in the next 30 years. Can be transported/piped.
Natural gas		
Often found with oil extraction, it has been considered the cleanest of the fossil fuels (although this is debated). Releases carbon dioxide.	Cheap.	Found globally but is estimated to run out in 70–80 years (based on current use) Can be transported/piped.

Shale gas		
No worse than natural gas in terms of emissions but requires hydraulic fracking which can pollute groundwater and soil, and in extreme cases trigger earthquake.	Cheap.	Shale gas is found across the globe, with one fifth concentrated in China.
Tar sands		
Very dirty source of oil which requires a lot of refinement so is only economically viable when oil prices are high. Its extraction destroys large swaths of habitat. It requires a lot of energy and water.	Expensive.	
Non Renewable: grey area		
Nuclear		
No Carbon dioxide emissions but produces radioactive waste which has to be securely stored for 1000s of years.		Can be used anywhere due to the high energy in its fuel. 1 kg go uranium contains 20000 the energy of 1 kg of coal. Reserves are found mainly in Australia and Canada. estimated to run out in 70–80 years.
Waste to energy		
Still released carbon dioxide but can be considered a better alternative to landfill.		
Renewable		
Wind		
Can be considered ugly and noisy. Can be a problem for some bird species particularly during migration.	Medium cost.	Possible everywhere but best in areas with consisted strong wind. Often best locations are far from populations, requiring lots of power lines.
Solar		
The extraction of some of the materials in the panels is questionable.	Starting to compete with oil for price.	Possible everywhere but best in sunny areas.
Wave / Tidal		
May impact wildlife, and effect tidal flows.	High installation cost and hard to scale up.	Limited to areas with high tidal range/ powerful wave action.

Biomass		
Carbon neutral but requires a lot of land. Does release carbon due to fertilisers and the transport of the crop. Has disadvantages of monoculture agriculture. Has to be refined for best results. Can displace food crops and even worst rainforest and wetlands.	Cheap.	Possible everywhere.

Geothermal		
Can also produce dangerous gasses which have to be safely disposed of.	High initial cost.	Limited to a few places with ideal plate tectonics (e.g., Iceland)

Hydro		
Can flood large areas, displacing habitats. Can effect environments downstream.	High initial cost but cheap and plentiful on going electricity.	

7.3 Energy choice and security

The energy choices adopted by a society may be influenced by availability, sustainability, scientific and technological developments, cultural attitudes, and political, economic, and environmental factors. These in turn affect energy security and independence. Fossil fuels are dominant due to their availability, cheap cost and ease of producing energy. It is only with the growing social realisation of their negative impacts on the planet that we have begun to change. Similar social movements have for good or bad halted growth in nuclear energy over radiation concerns.

Due to the necessity of energy, especially for economic growth, securing a reliable and cost effective source is a dominant factor for national governments in their choice. **Energy security** depends on an adequate, reliable and affordable supply of energy that provides a degree of independence from other countries. This motivates many governments to search for energy sources that are produced completely in their country, even if not the cheapest or most environmental friendly. Despite it's questionable environmental credentials, shale gas gives the USA energy security.

These issues are amplified by the inequitable availability and uneven distributions of energy sources. Energy rich nations can use their energy exports as a political tool but it can also make them a target. For example a dispute between Russia and Ukraine over an unpaid bill for gas lead to large pipelines that also supplied Europe being cut off. Equally much of the conflict and focus on the middle east is over securing oil supply. Further madness is the rush for the arctic, where several nations are staking a claim on the oil reserves that will become exploitable as climate change melts the ice.

These threats can be reduced through:

- Improvements in energy efficiencies and energy conservation limiting growth in energy demand.
- Having several sources of energy.
- Investing in renewables which are less location dependent.
- Better cooperation between nations. For example the European energy grid.

CLIMATE CHANGE AND SUSTAINABILITY

8

8.1 Climate change

Climate describes how the atmosphere behaves over relatively long periods of time. Climate change has been a normal feature of the Earth's history, driven by changes in the percentage of greenhouse gases (e.g., carbon dioxide, methane, CFCs and water vapour) in the atmosphere. In a broad sense, climate change shows how interconnected global systems are. Changes in one system can lead to changes in another.

Man-made climate change

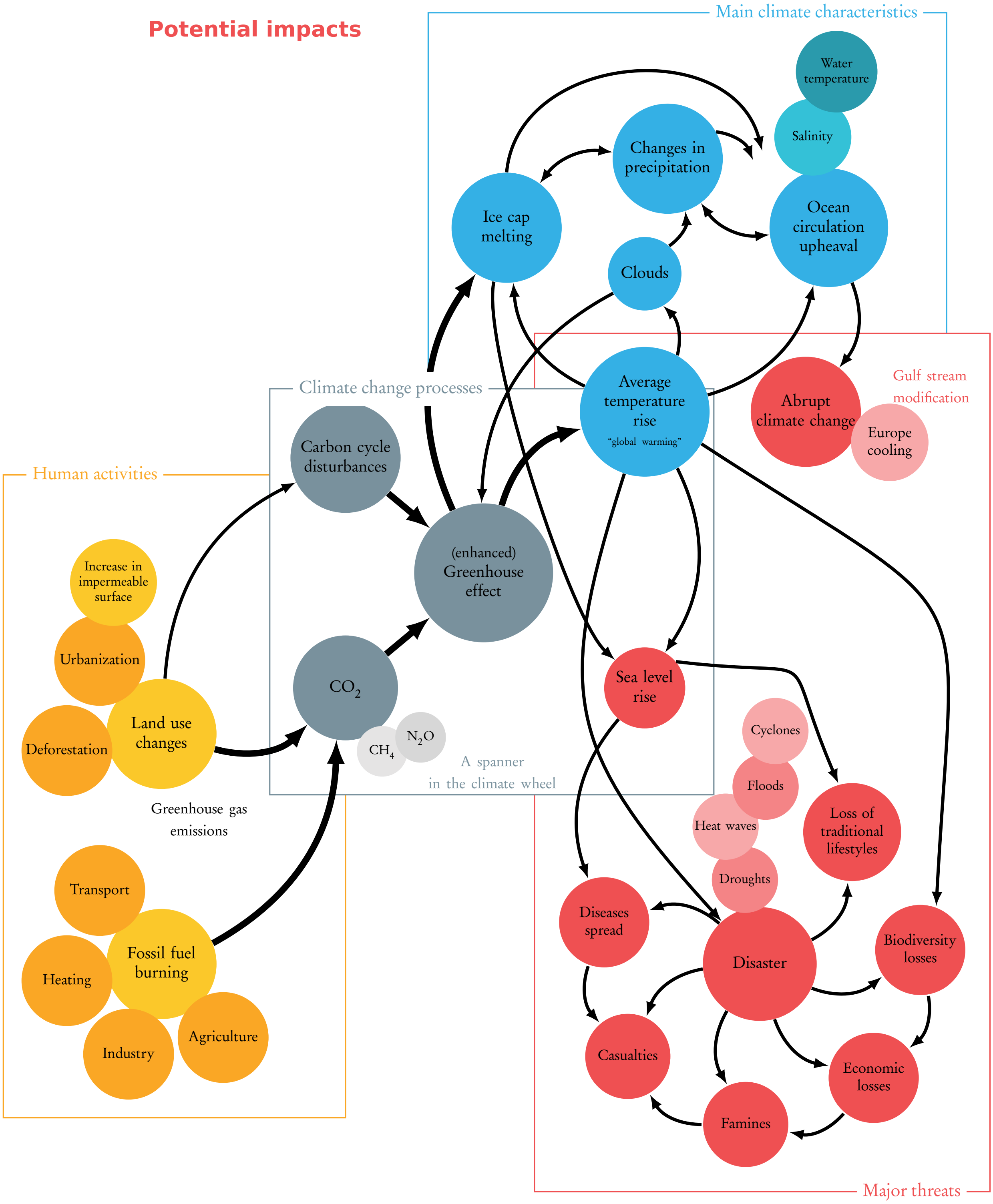
There has been a significant debate about how much human activity has contributed to recent climate change. The burning of fossil fuels and industrial agriculture emit enormous amounts of greenhouse gases into the atmosphere. Furthermore deforestation is reducing the uptake of carbon dioxide into the world's forests. Many question if this activity is large enough to have an effect. Although there is a degree of uncertainty with climate models due to their complexity, most scientists now agree that we are the cause of recent climate change. Most climate-change-deniers have pointed to unusual weather events as evidence that climate change is not happening. For example Donald Trump commenting on large amounts of snowfall. REMEMBER: Weather describes the conditions in the atmosphere over a short period of time and is therefore not an indicator of climate change. Furthermore many of the negative and positive feedback mechanisms associated with climate change involve very long time lags and so can be difficult to identify.

The atmosphere and oceans

The main driver of weather and climate is the circulation of water and heat between the atmosphere and the oceans. The interchange of water happens by evaporation of ocean water into the atmosphere and returns through the subsequent rainfall. The interchange of heat happens at the sea surface. Here, a warmer ocean can warm the atmosphere or a warmer atmosphere, the ocean. Each of the systems further distribute this heat and water through oceanic currents (see Chapter 6) and atmospheric currents (see Chapter 1). Therefore water and heat will not necessarily interchange back where it came from.

Current climate change is increasing the mean global air temperature due to the greenhouse effect. This will lead to an increase in the sea surface temperature. Because the ocean is far more dense than the atmosphere, this temperature change is smaller and with a significant time lag. The increase in oceanic temperature will likely lead to increased frequency and intensity of extreme weather events due to increased evaporation. Another likely effect is a rise in sea level as the warmer oceans melt the ice caps.

Potential impacts



Climate change is likely to impact all our global systems. The potential impacts will vary from one location to another and may be perceived as either adverse or beneficial. Some changes may balance themselves out (negative feedback), for example increased evaporation is balanced by increased precipitation. Others, more worryingly, could become steadily worse (positive feedback). An example is: polar ice melting reduces the albedo effect, increasing temperatures and melting more ice.

ACADEMY

Below are some of the potential impacts, of which many are already being observed. As with the systems in the previous chapters, these impacts are interlinked. Even if we stopped emitting all greenhouse gases today, we would still experience these impacts due to the planetary lag time.

- changed weather patterns – reduced or increased amounts of precipitation.
- ocean acidification as the oceans absorb more carbon dioxide from the atmosphere
- Biomes shifting due to changes in temperature and precipitation
- loss of biodiversity and ecosystems as species cannot adapt to the shifting of biomes
- change in location of crop growing areas, agriculture may shift towards the poles
- Polar ice melts
- rising sea levels lead to coastal inundation
- increased drought and possible water shortages
- spreading of tropical diseases

Mitigation and adaptation

In order to prevent catastrophic climate change, we must mitigate and adapt.

Mitigation attempts to reduce the causes of climate change through the reduction and/or stabilization of greenhouse gas (GHG) emissions and their removal from the atmosphere.

Mitigation strategies to reduce GHGs in general may include:

- reduction of energy consumption – requires large societal changes.
- carbon taxes / carbon credits – by putting a price on emissions, cleaner alternatives are encouraged.
- reduction of emissions of nitrogen oxides and methane from agriculture
- use of alternatives to fossil fuel such as wind, solar and hydropower.

Mitigation strategies for carbon dioxide removal (CDR techniques) include:

- protecting and enhancing carbon sinks through land management.
- Reduction of Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD programme)
- using biomass as fuel source
- using carbon capture and storage (CCS)
- enhancing carbon dioxide absorption by the oceans through either fertilizing oceans with nitrogen, phosphorus, iron (N/P/Fe) to encourage the biological pump, or increasing upwellings to release nutrients to the surface.

Geo-engineering is a technological solution to reduce the amount of solar radiation reaching the Earth's surface. Proposals include cloud seeding, space mirrors and dispersal of sulfur dioxide (see previous chapter for why this is a terrible idea). These "solutions" are very expensive and likely to have other negative effects. They should therefore be seen as a last resort.

Adaptation attempts to manage the impacts of climate change by reducing adverse affects and maximizing any positive effects. This is necessary as, even with a large reduction in GHGs, historic emissions will still have an effect on the current climate.

Examples of adaptations include:

- flood defences to protect against sea level rises;
- monitoring and control (vaccination programmes) of spreading tropical diseases;
- rainwater harvesting and desalination plants to provide water in drought regions;
- planting of crops in previously unsuitable climates to meet the gap in global food supply;
- adaptation of buildings and cities to their changing climate.

International cooperation

Climate change is a global challenge that requires a global solution. There is a need for international cooperation to effectively mitigate against climate change. Furthermore it is predicted that areas that are less responsible for GHG emissions (LEDCs) will experience the worst effects. Is it not right that those who emitted the most (MEDCs) should provide economic and technological support.

There are several international efforts and conferences to address both mitigation and adaptation strategies. These have had varying levels of success but have shown progress over time.

1992 – Rio Earth Summit Countries developed a framework to address climate change and stabilize greenhouse gas concentrations. The United Nations Framework Convention on Climate Change (UNFCCC) went into effect 1994 but failed to slow down greenhouse gas emissions. It had little effect as there were no binding limits or enforcement.

1997 – Kyoto Protocol An extension of the UNFCCC to commit developed countries to reducing GHG emissions from their 1990 levels. It encouraged the use of alternative energy sources but also allowed for carbon trading. The USA and Canada withdrew from the protocol. Furthermore China and India are not included.

2015 – Paris Agreement A stricter treaty committing all countries to limit global temperature rise to 1.5 °C. Although there are no binding mechanisms, countries must be transparent with their emissions to allow for continued monitoring.

Intergovernmental Panel on Climate Change (IPCC) Set up by WHO and UNEP, the panel provides reports, assessing the science related to climate change. The latest report in 2018 highlighted the negative impacts of global temperature rise over 1.5 °C.

National Adaptation Programmes of Action (NAPAs) National reports from LEDCs to the UNFCCC, which focus on urgent and immediate needs to adapt to climate change. The country provides a prioritized list of activities to best cope with the impacts of climate change. Once submitted the country is eligible for funding through the Least Developed Countries Fund.

8.2 Sustainability

We have started to become aware of the various impacts we can have as a species on our planet. We have covered many of these in the previous chapters. By thinking about these possible impacts before we act is thinking sustainably. This thinking can be applied to all systems. **Sustainable development** meets the needs of the present without compromising the ability of future generations to meet their own needs. Applied to resources this means that they can be naturally replaced at the rate at which they are used and there is full recovery of the ecosystems affected by their extraction and use.

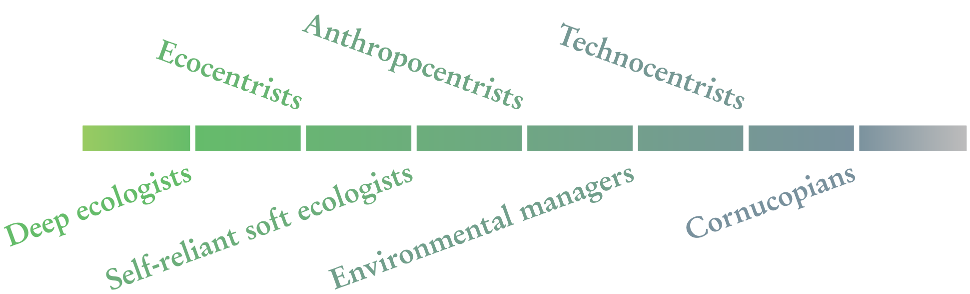
Environmental value systems

"Sustainable" can be a vague term as it means different things to different people according to their Environmental value system. An EVS is an individual's worldview or paradigm that shapes the way they perceive and evaluate environmental issues. They are a combination of the following:

Ecocentrists
: An ecocentric viewpoint integrates social, spiritual and environmental dimensions into a holistic ideal. It puts ecology and nature as central to humanity and emphasizes a less materialistic approach to life with greater self-sufficiency of societies. An ecocentric viewpoint prioritizes biorights, emphasizes the importance of education and encourages self-restraint in human behaviour.

Anthropocentrists
: Humans must sustainably manage the global system. This might be through the use of taxes, environmental regulation and legislation. Debate would be encouraged to reach a consensual, pragmatic approach to solving environmental problems.

Technocentrists
: Optimistic view that technological developments can provide solutions to environmental problems. Scientific research is encouraged in order to form policies and to understand how systems can be controlled, manipulated or changed to solve resource depletion. A pro-growth agenda is deemed necessary for society's improvement.



Some examples EVSs:

Deep ecologists *The earth is not just for us*
Intrinsic importance of nature and its rights. Biorights – the right of endangered species or unique landscapes to remain unmolested.

Self-reliant soft ecologists *We should only use what we need*
Emphasis on smallness of scale and hence community identity in settlement, work, and leisure. Importance of participation in community affairs, and of guarantees of the rights of minority interests. Participation seen as both a continuing education and a political function.

Environmental managers *Humans are the stewards of the earth*
Belief that we should manage the environment to allow for sustainable resource use through legislation, taxes and compensation for affected societies/ecosystems.

Cornucopians *There are infinite resources for us to use*
By using technology and inventiveness we can solve any problem, including the environmental one. Have a strong taith that scientific and technological expertise provides the basic foundation for advice on matters pertaining to economic growth, and public health and safety.

EVS are not fixed. They are continually shaped by cultural, religious, economic, socio-political contexts, education, experience, media, historical events, technological developments.

For example, our general attitude to our planet has changed dramatically in the last 50 years. Our awareness of our impact on the planet has created the environmental movement.

Some significant events are shown in the time line below.

1962 — **Rachel Carson's book Silent Spring** highlighted the effect of our increased chemical use on the environment and how they can be passed up the food chain to us.

1984 — **Bhopal Disaster 1984.** Pesticide plant released 42 tonnes of methyl isocyanate (MIC) gas, immediately killing nearly 3,000 people and ultimately causing at least 15,000–22,000 total deaths.

1986 — **Chernobyl disaster.** The worlds worst nuclear disaster sent radiation across Ukraine, Belarus and Russia. The 2600 km^2 site around the reactor is still unsafe.

1992 — **Earth Summit in Rio.**

1997 — **Kyoto Protocol.**

2006 — **An Inconvenient Truth.** Davis Guggenheim's documentary with Al Gore helped to make global warming widely known.

2010 — **Deepwater horizon oil spill in the gulf of Mexico.** The largest oil spill in history, it released an estimated 4.9 million barrels.

2011 — **Fukushima Daiihi nuclear disaster, Japan**, lead to many countries rethinking their future use of nuclear power.

2012 — **UN conference on Sustainable developement (Rio+20).**

2015 — **Paris Climate agreement.**

Sustainability tools

We can use certain tools to assess sustainability.

Environmental indicators

Factors such as biodiversity, pollution, population, or climate may be used quantitatively as environmental indicators of sustainability. These factors can be applied on a range of scales from local to global. The Millennium Ecosystem Assessment (initiated in 2001) gave a scientific appraisal of the condition and trends in the world's ecosystems and the services they provide using environmental indicators, as well as the scientific basis for action to conserve and use them sustainably.

Environmental Impact Assessments (EIAs)

Environmental Impact Assessments (EIAs) provide decision-makers with information in order to consider the environmental impact of a development project by incorporating baseline studies before the project is undertaken. It is a globally adopted framework based on the USA's National Environmental Policy act (1969). EIAs, first, assess the environmental, social, and economic impacts (both positive and negative) of the project. A baseline study is taken of the proposed site and then the possible impacts are modelled against this. Second, predictions on the scale of these potential impacts are made. Third, mitigation strategies are suggested to limit the negative impacts. They include a non-technical summary so that the assessment can be understood by all. They are usually followed by an audit and continued monitoring.

Each country or region has different guidance on the use of EIAs. They are commonly used in planning large (intrusive) developments such as quarrying, infrastructure and large-scale housing. There is also no standard way of carrying out an assessment, which makes them hard to compare from country to county. Furthermore it is not necessarily a requirement to implement an EIA's proposals and many socio-economic factors may influence the decisions made. Other criticisms of EIAs include the lack of a standard practice or training for practitioners, the lack of a clear definition of system boundaries and the lack of inclusion of indirect impacts.

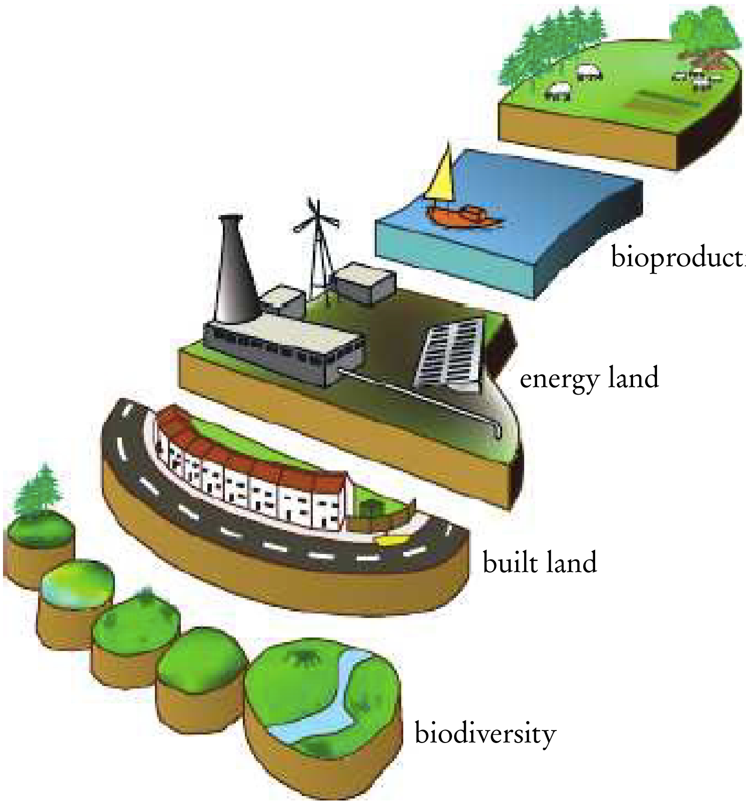
Carrying capacity

Carrying capacity is the maximum number of a species or 'load' that can be sustainably supported by a given area.

Human carrying capacity is difficult to quantify compared to other species, because our resource use is more complicated. We use a larger range of resources and can substitute and import lacking resources. Technological developments allow use to use resources more efficiently and exploit new resources. Furthermore our resource use is not just based on individual needs but desires. It has been thought that degradation of the environment together with the use of finite resources would limit human population growth. However technological developments have allowed us to continue to grow for now. Perhaps it is a better strategy to examine how much land we each require, rather than how many that land can sustain.

Ecological footprints

An ecological footprint is a model that makes it possible to determine whether human populations are living within the carrying capacity of their environment. It is the area of land and water required to support a defined human population at a given standard of living. The measure takes into account of the area required to provide all the resources needed by the population, and the assimilation of all wastes. These factors are influenced by lifestyle choices (environmental value systems). A full calculation would include:



Bioproductive land – for food, materials and waste
Bioproductive sea – for food and waste.
Energy Land – area require to produce energy requirement with renewable energy (even if using non-renewable energy)
Built land – roads and buildings
Biodiversity land – land required to support all of the non-human species
Non-productive land – land that we cannot use (e.g., deserts).

The assessment can be visually represented and easily understood. Ecological footprints can be used to compare the differing environmental impact of countries and people. If the ecological footprint of a human population is greater than the land area available to the population, this indicates that the population is unsustainable and exceeds the carrying capacity of that area. If the world was evenly divided we would each have 1.8 hectares. In most MEDC, people are using 5 hectares or more.