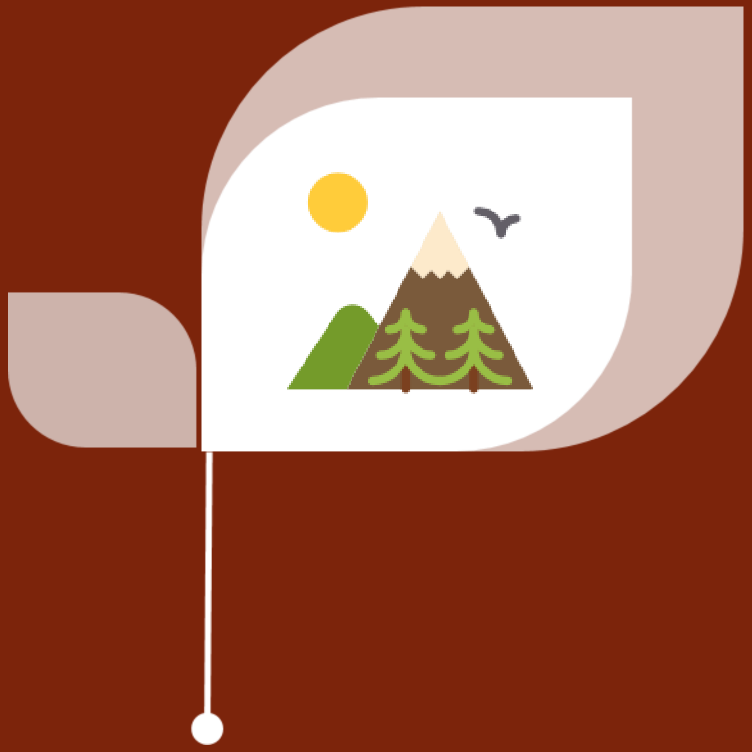


Chapter 8
Ecosystems

“An Ecosystem is greater than the sum of its parts”

Eugene P. Odum (the father of modern ecology)

Overview

Ecosystems function as complex entities where the whole is greater than the sum of its parts.

Ecosystems provide humans with a vast range of services that we could never provide for ourselves- indeed we depend on healthy ecosystems for our very survival. The interactions of species and populations within an ecosytem, the levels of biodiversity, the quality and abundance of abiotic components, are all critical factors to understanding how ecosystems function and change over time.

However, our actions are threatening ecosystem health and integrity across the planet with potentially catastophic consequences.

This chapter explores the basics of ecosytem structure and processes, looks at ecosystems in context across the globe and describes ecosystem services and health.

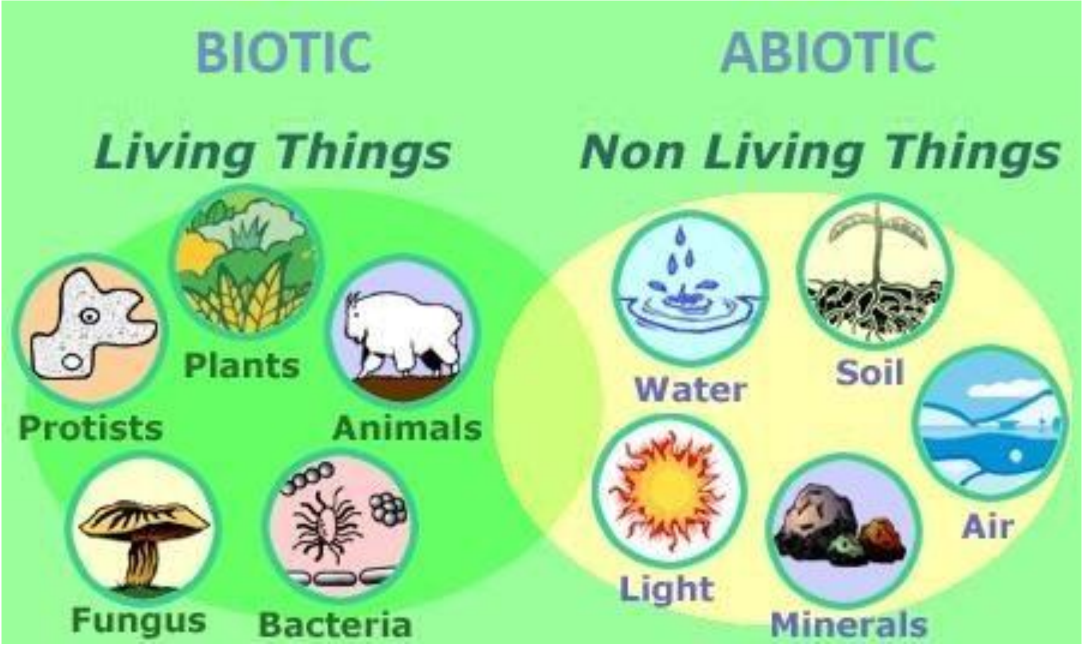
Contents

8.1

Energy flow and trophic levels

Ecosystem revision

The environment in which organisms live is made up of living and non-living parts. The community of **biotic** things in an area, interacting with each other and with the **abiotic** parts, is known as an **ecosystem.** Ecosystems maintain themselves by cycling **energy** and **nutrients.** The energy flow through an ecosystem is often described in terms of a food chain.

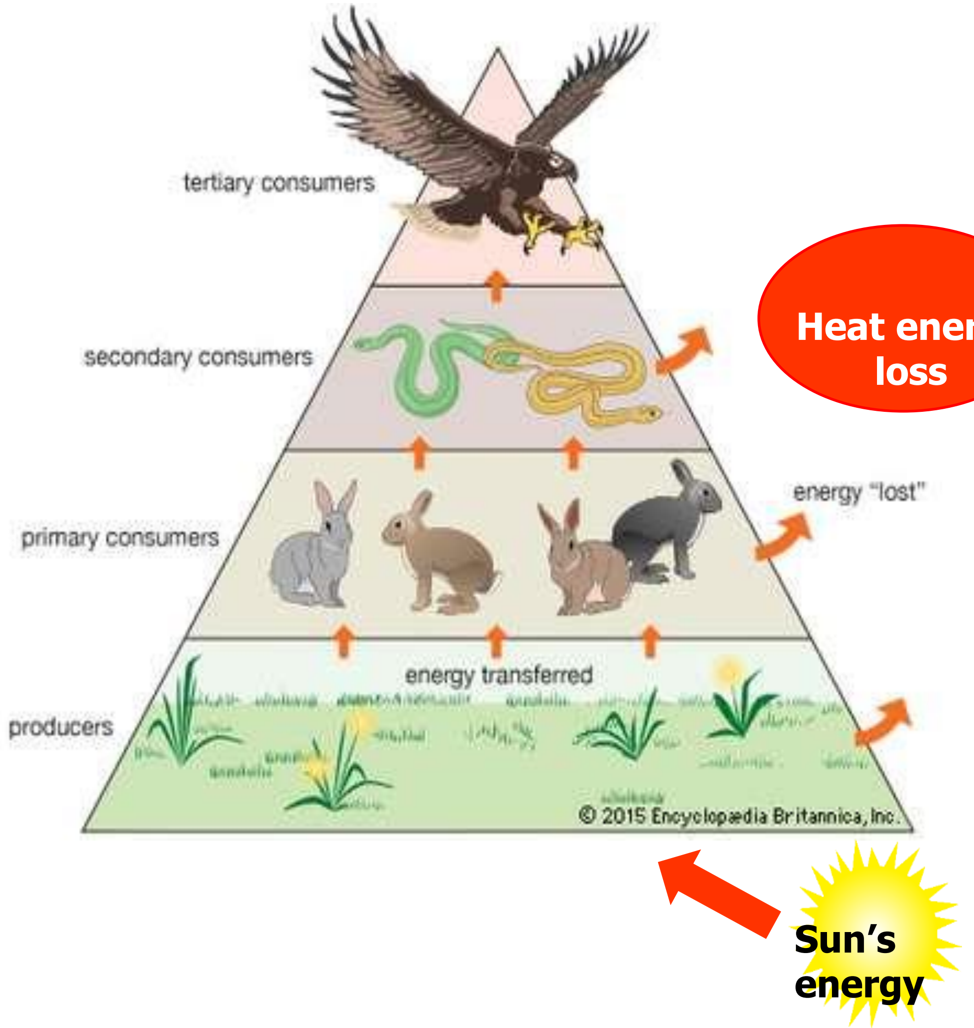


Trophic levels

The food chain can be thought of as a pyramid.

The base of the food chain is the first **trophic level,** comprised of **primary producers,** which are organisms that make their own food.

Plants and algae do this via photosynthesis sourcing the sun's energy; bacteria do this via chemosynthesis sourcing energy from chemical reactions. Primary producers feed everything else in the ecosystem.



Trophic levels

Consumers make up the other trophic levels of the energy pyramid.

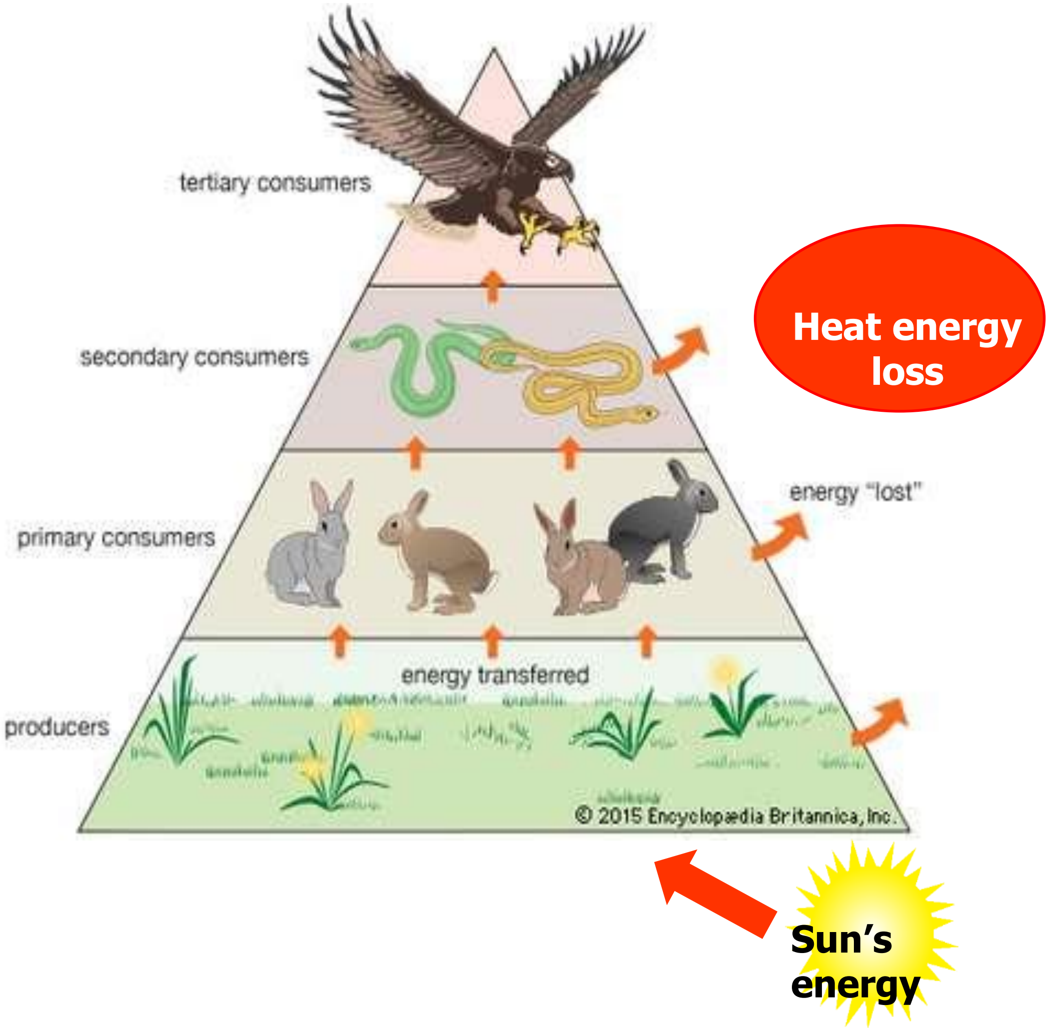
Consumers receive energy by eating other organisms.

There are different kinds of consumers that occupy different trophic levels.

Primary consumers eat plants, and include herbivores, granivores and parasitic plants.

Secondary consumers eat primary consumers and are otherwise known as carnivores**.**

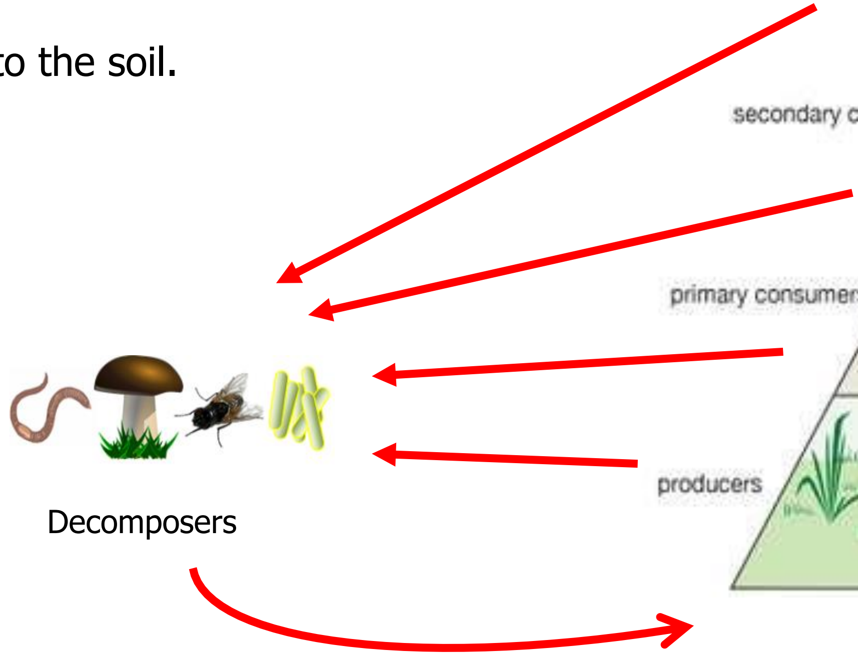
Those that eat both primary consumers *and* primary producers are omnivores. At the « top » of the food chain are **apex predators**, which are either tertiary consumers (that eat secondary consumers) or quaternary consumers (that eat tertiary consumers). Trophic levels rarely extend beyond this.

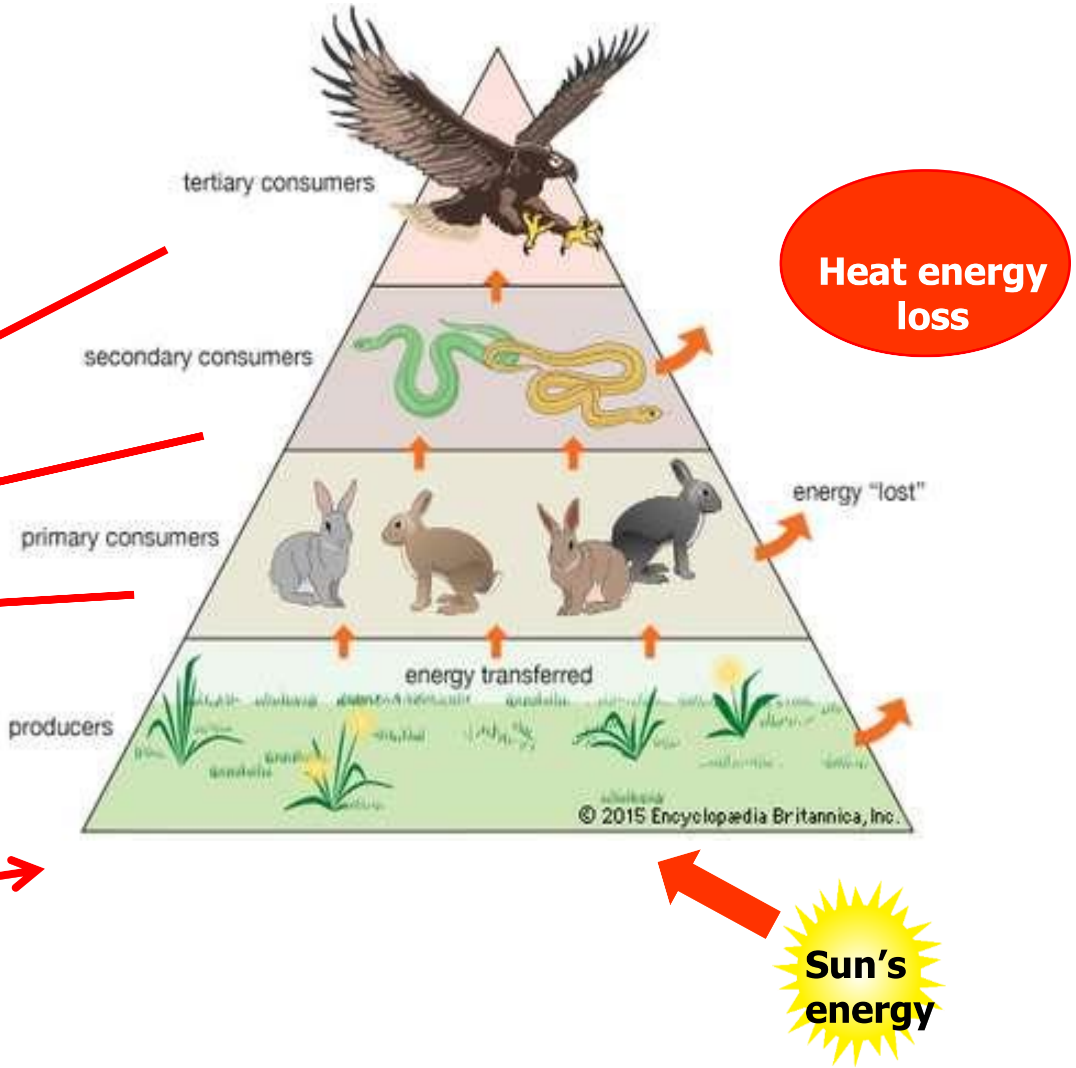


Trophic levels

When animals or plants die, they are eaten by **decomposers** (e.g. fungi, termites, soil bacteria, flies, beetles, worms).

Nutrients are returned to the soil.



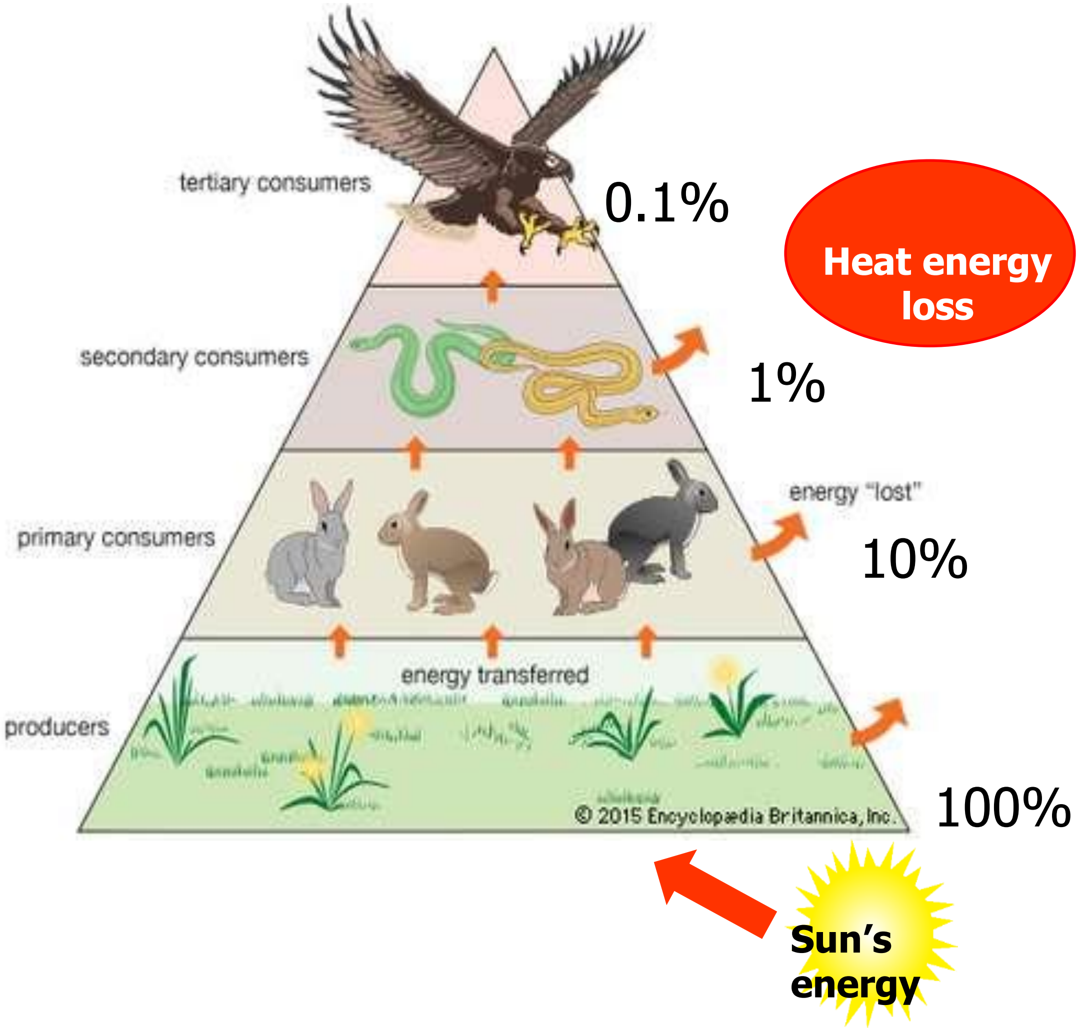


Trophic levels

Primary producers are otherwise known as **autotrophs.** Autotroph literally means 'self' (auto) 'nourishment' (troph).

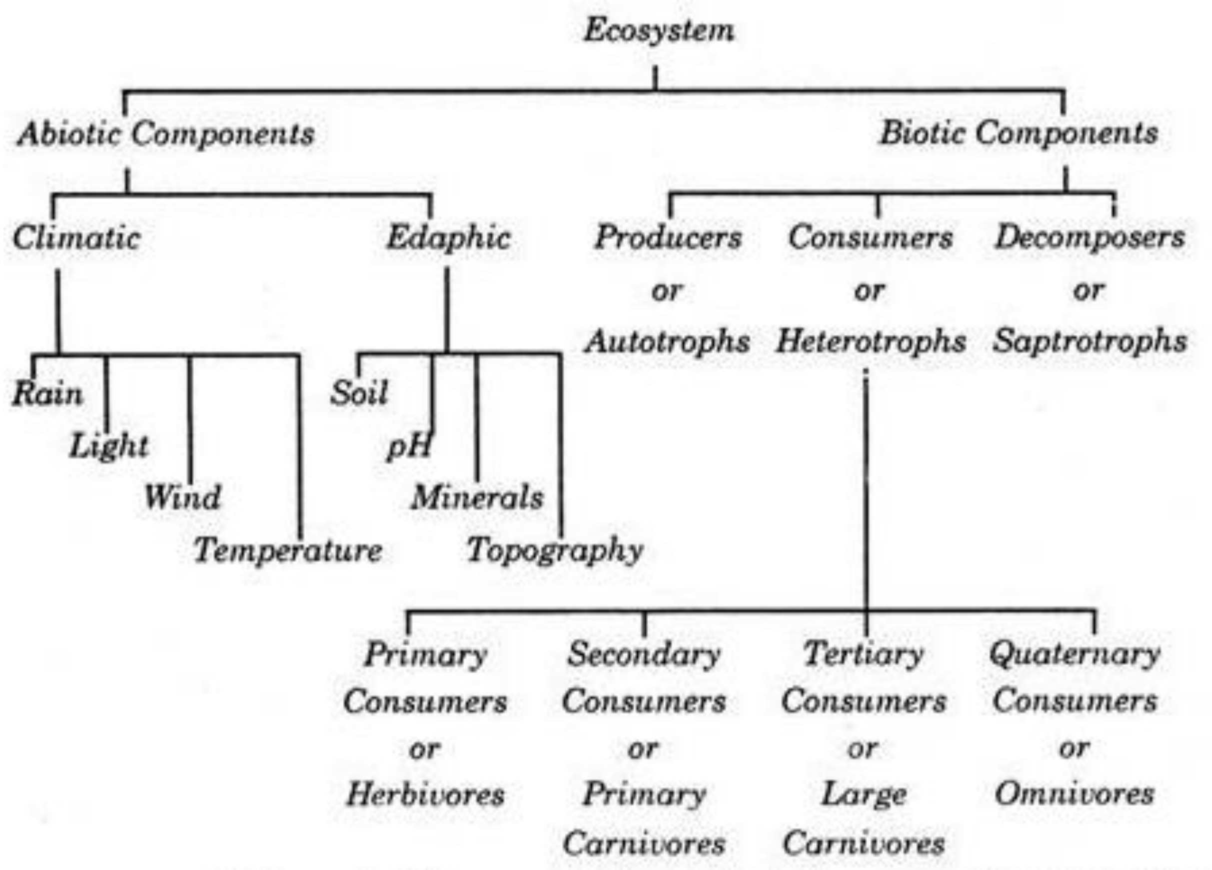
Consumers and decomposers are known as **heterotrophs:** 'other' (hetero) 'nourishment' (troph).

As energy is transferred up through each **trophic level**, most is lost along the way. Only about 10% is transferred, whereas 90% is lost through respiration, defecation and other processes. This means that only 0.1% of the original energy created by producers at the first trophic level is available for tertiary consumers.



Ecosystem Structure

The different components of an ecosystem can be summarised in this diagram:



 http://www.yourarticlelibrary.com/environment/ecosystem/ecosystems-concept-structure-and-functions-of-ecosystems-with-diagram/28211

8.2

Ecosystems in context

Examples of ecosystems

Many different kinds of ecosystem are recognised, grouped under broad categories such as forest ecosystems, grassland (or open) ecosystems, tundras, deserts, freshwater ecosystems, marine ecosystems and coastal ecosystems.

Forest Ecosystems

Forests cover about 30% of the world's land area and host more than half of the world's land-based plant and animal species. Forest ecosystems vary widely, reflecting different climates, altitudes, and soil types. In fact, there is no one recognised definition of "forest" – they are classified in many different ways using factors such as tree or ground cover, height, land use, legal status etc. Governments, decision-makers and scientists tend to use the definition that best suits their needs.

Forests accumulate large amounts of standing biomass, an important proportion of which is underground. The world's forests remove an estimated 2.1 billion tonnes of CO_2 from the atmosphere annually. This plays a fundamental role in balancing the world's carbon cycle and helping to combat climate change.

Mangrove forest

Plantation forest

Temperate deciduous forest

Tropical rainforest

Subalpine forest

Forest Ecosystems

In addition to playing a critical role in the planet's carbon balance, forests are home to 80% of the world's terrestrial biodiversity: the most biologically diverse and complex forests being tropical rainforests.

Forests provide essential ecosystem services to humans. For example, a quarter of all modern medicines come from tropical forest plants, including two-thirds of all cancer-fighting drugs.

Almost 900 million people, mostly in developing countries, are involved in woodfuel and charcoal production. Woodfuel provides 40 percent of today's global renewable energy supply – as much as solar, hydroelectric and wind power combined.

However, it is estimated the world is witnessing an average net loss of about 13 million ha per year (about 0.18% net loss annually). The Amazon has lost at least 17% of its forest cover in the last 50 years, and the island of Sumatra has lost 85% of its forests: primarily due to conversion for oil palm plantations.

Open ecosystems

Open ecosystems are not dominated by tree cover. They have an understory that is dominated by grasses, but may contain many other kinds of plant life. They include tropical and subtropical savannahs, temperate prairies, meadows and steppes, and are among the largest ecosystems in the world: 52.5 million km^2, or 40.5 % of the earth's terrestrial area are covered by open ecosystems. They occur on every continent except Antarctica and can host extraordinary levels of biodiversity and support diverse animal communities.

For example the "Fynbos" shrubland of the Cape Floristic Region has around 9000 plant species, 6200 of which are endemic. The North American Coastal Plain has more than 1500 endemic plants, but was only recognised as a biodiversity hotspot in 2000!

Open ecosystems also have the capacity to support large populations of megafauna and large herbivores, many of which are now extinct (see Section 9.2).

Tropical Savannah

Chaparral shrubland

Temperate grassland

Heathland

Eurasian Steppes

Open ecosystems

Despite their expansiveness and importance to biodiversity, these ecosystems have not been awarded as much interest in terms of protection and research, compared to forests. This is because the prevailing 20th century view generally held that many grasslands were anthropogenic, caused by livestock, deforestation and human fires. We now know this to be untrue.

While some grasslands are certainly anthropogenic in origin, many are not. Natural fires have been burning for more than 400 million years (long before hominoids evolved), and large vertebrate herbivores (grazers) have been around for more than 300 million years. Grasslands and savannahs are ancient, natural ecosystems.

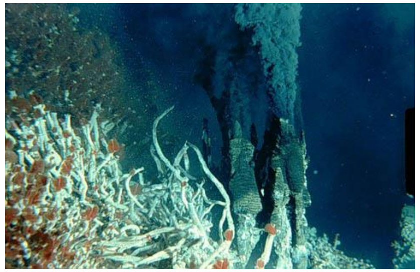
It is now known that fire and herbivory (particularly fire) are factors that play an important role in maintaining open ecosystems and biodiversity.

Recently, the bias towards forests as a more ‘important’ ecosystem than grasslands has taken another turn, as an emerging conflict of interests between **carbon** and **biodiversity** targets develops. Large-scale afforestation programs plan to convert large areas of open ecosystem to forest (or plantation) in order to capture more atmospheric CO_2. However, critics argue that if not thought out properly, this risks destroying some of the planet’s ancient natural ecosystems and the biodiversity that comes with it.

Marine ecosystems

Marine ecosystems cover more than 70% of the world's surface and account for more than 97% of the earth's water supply. Incredibly diverse, they include coastal and near-shore systems such as salt marshes, mudflats, estuaries, mangroves, rocky intertidal systems, lagoons, sandy beaches, coral reefs. Offshore, they include surface ocean, pelagic ocean, deep sea, oceanic hydrothermal vents, and the ocean floor.

Almost half the known species on earth live in marine ecosystems, and oceans play a critical role in regulating the earth's climate. Phytoplankton account for about 50% of global primary production, producing between 50% -86% of the planet's oxygen, and absorbing about 10 Gigatons of carbon per year through photosynthetic activity. Oceans also absorb much of the sun's heat, particularly around the equator, which is distributed around the planet by ocean currents. Ocean water evaporation creates rain, thunderstorms and hurricanes and is transported to land by trade winds.



Hydrothermal vents

Pelagic zone

Mudflats

Rocky intertidal zone

Salt marsh

8.3 Biomass and productivity

Biomass

In ecology, biomass refers to the total weight of organisms in a given area. Biomass can be measured in different ways, depending on the situation.

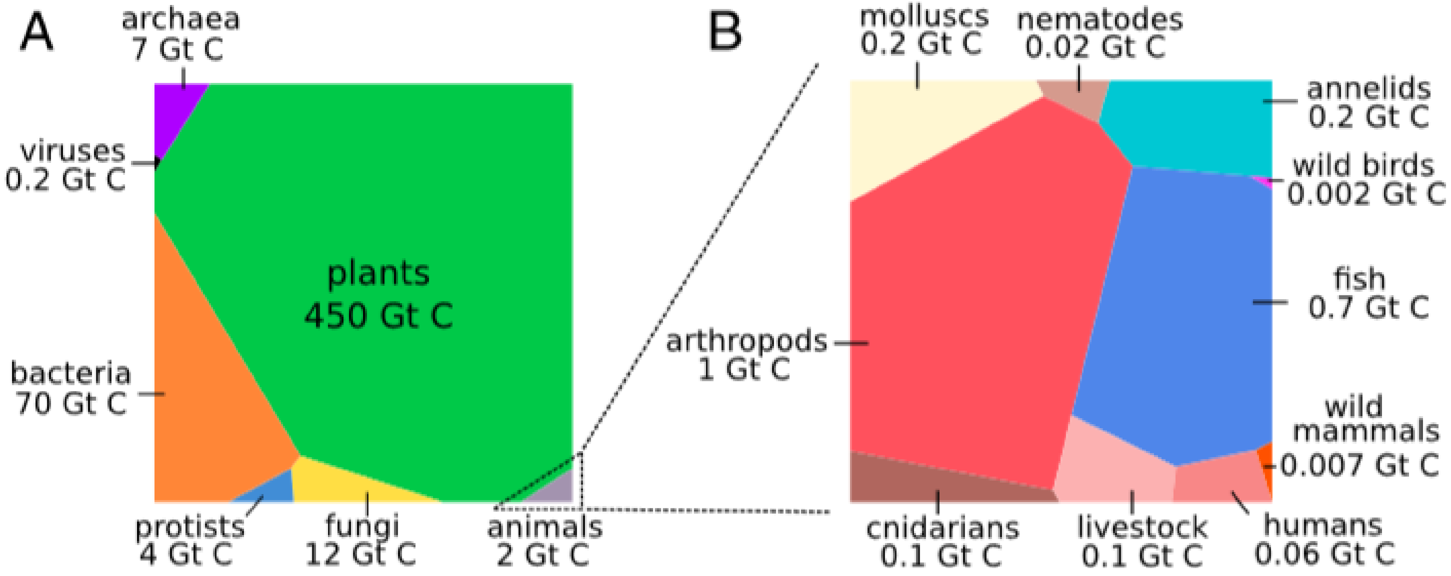
In the scientific literature you may come across **wet biomass**, **dry biomass** or **carbon biomass.**

Wet biomass is the mass of organic matter plus contained water. It is often used in fields such as fisheries management. Dry biomass is the mass of organic matter after drying, and is commonly used in forest ecology. Carbon biomass is the proportion of dry weight that is contributed to carbon, and is usually calculated as 0.47 x dry biomass.

In energy production, biomass refers to the organic material that comes from plants and animals, and as such is a renewable source of energy. It contains stored energy from the sun. When biomass is burned, the chemical energy in biomass is released as heat. e.g: as wood, agricultural crops or animal manure and human sewage

Biomass

Scientists have made attempts to measure the total biomass on earth: it is currently estimated at about 550–560 billion tonnes of carbon. We live in a green world: about 80% of the world's biomass is plants. Animals make up only 0.4% of total biomass. Despite there being 7 billion of us, humans are only 0.01% biomass- however this is still 10 x more than all wild animals, which make up just 0.001%. Fungi outweigh all animal biomass, making up 2.2%.

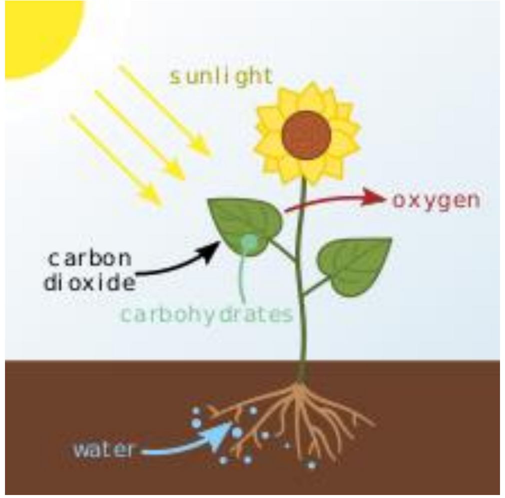


Bar-On et al., 2018. The Biomass Distribution on Earth. PNAS, 115: 6506-6511

Productivity

Remember that plants (primary producers, or autotrophs) use the sun's energy to make chemical energy (organic matter: carbohydrates). This is done through photosynthesis. The energy assimilated by plants is stored as carbon compounds in plant tissues.

$$CO_2 + H_2O \xrightarrow{\textit{light}} \text{Carbohydrates} + O_2$$



Productivity

Productivity is the rate at which energy is added to the bodies of organisms in the form of biomass.

Primary production is the chemical energy plants generate in organic compounds through photosynthesis. The total amount of chemical energy created as biomass is called **Gross Primary Productivity,** or **GPP.** Plants use some of this energy to breathe **(respiration)**. The amount of energy that is left for plant growth after respiration is called **Net Primary Productivity,** or **NPP.**

So, Net Primary Productivity is the difference between Gross Primary Productivity and Respiration:

NPP = GPP – Respiration.

Productivity is measured in units of carbon.

On land, almost all primary production is done by vascular plants. In the sea, almost all primary production is done by phytoplankton.

Productivity

The carbon used for ecosystem growth (net primary production, NPP) is eventually transferred to the soil in litter fall, root turnover and death of individual plants. In addition, trees notably allocate carbon to the root systems for root growth and root maintenance. Carbon is also added to the forest floor from leaching of dissolved organic matter from the canopy.

The total flux of carbon dioxide from the soil to the atmosphere is known as soil respiration. Soil respiration is a key ecosystem process.

Soil respiration originates from the respiration of plant roots, the rhizosphere, microbes and soil fauna.

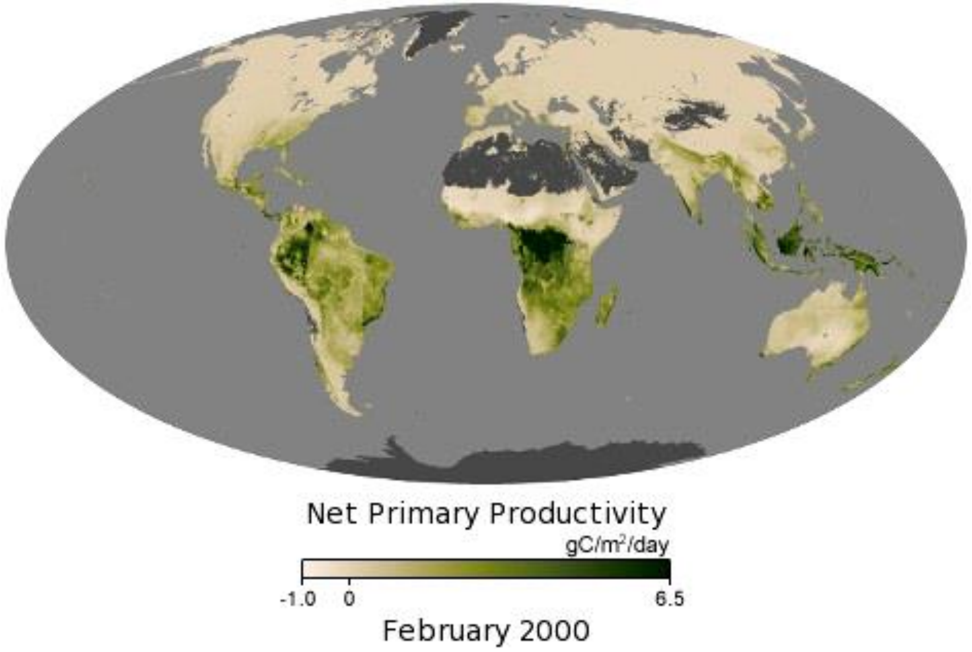
Heterotrophic respiration occurs when soil animals and soil micro-organisms consume dead organic matter in the soil (the soil organic matter is decomposed).

Autotrophic respiration occurs from the respiration of plant roots and is another major source of CO_2.

The share of the root respiration is roughly similar to that of heterotrophic respiration. Some studies have shown that the annual CO_2 flux from the soil corresponds to about 50-60% of the annual carbon uptake (gross primary production, GPP) of a forest ecosystem.

Productivity

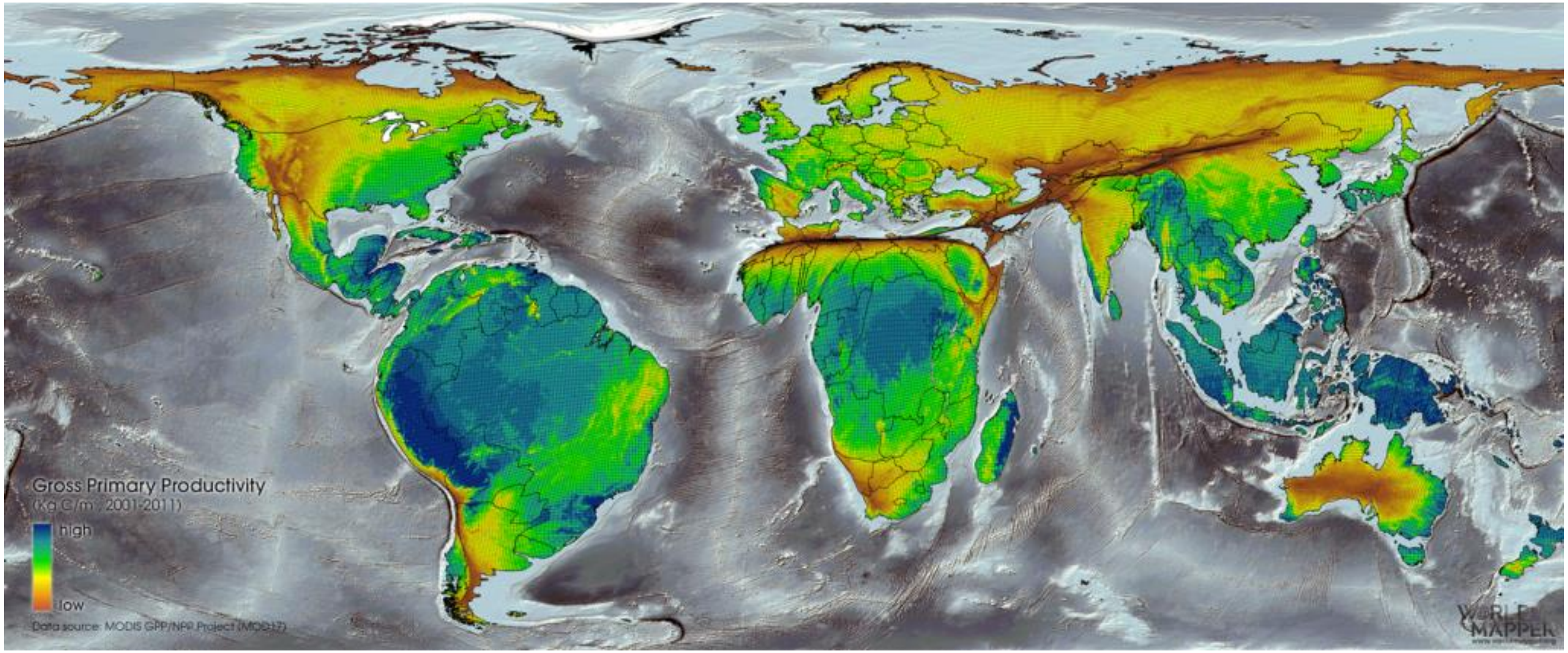
NPP is directly influenced by an environment's abiotic factors, which include **temperature** and **moisture**. Productivity generally rises with temperature up to about 30°C, after which it declines, and is positively correlated with moisture. On land primary productivity is highest in warm, wet zones in the tropics and lowest in desert scrub ecosystems. This video shows the seasonal changes in NPP across the planet, showing how productivity in temperate regions changes dramatically between summer and winter. Click on the map to play it.



https://earthobservatory.nasa.gov/global-maps/MOD17A2_M_PSN

Productivity

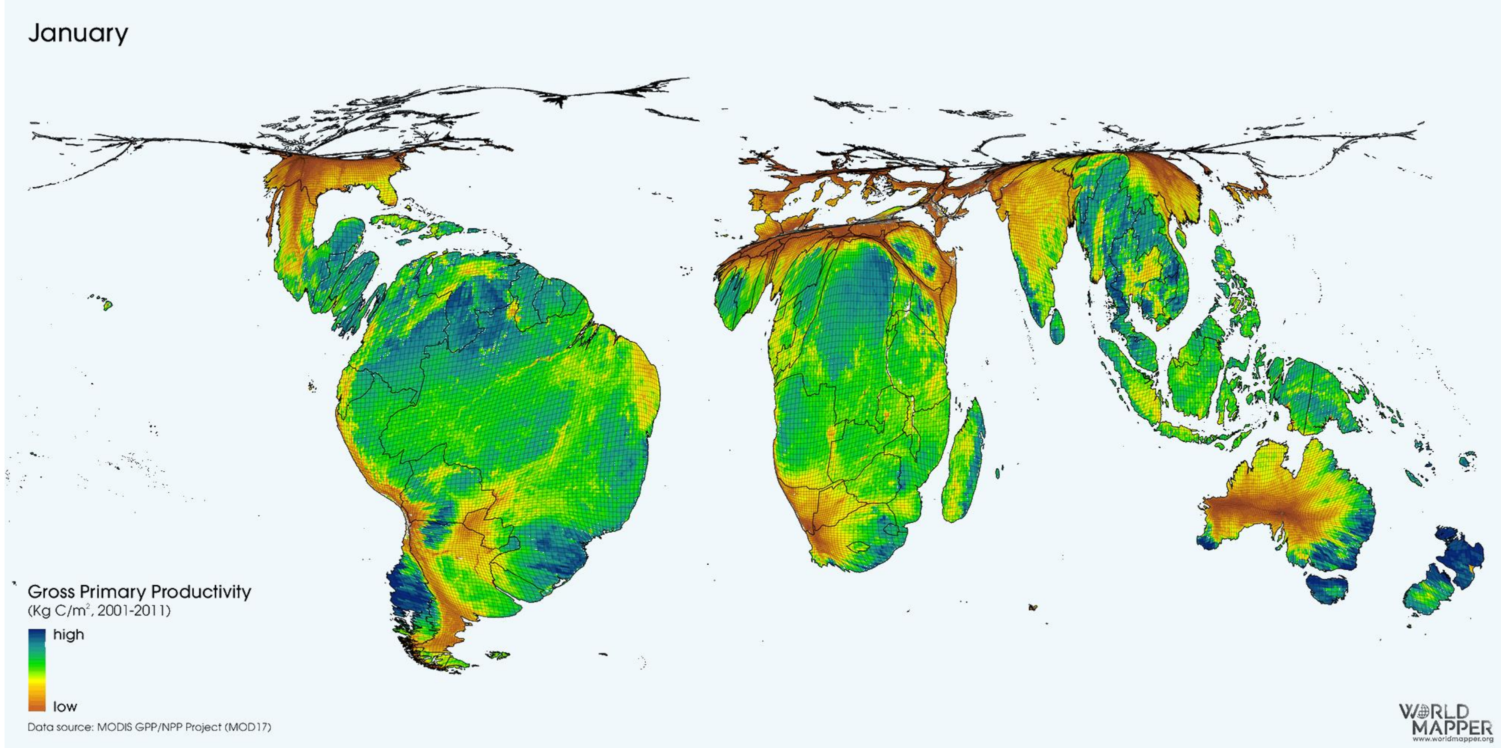
In this map, the world's land surface is resized according to its overall (annual) relative contribution to productivity: here the outsized importance of South American and African tropical forests in creating biomass (Gross Primary Productivity) can be clearly seen.



https://worldmapper.org/natures-heartbeat/

Productivity

When the same map is plotted month by month, you can see the world's 'heartbeat' as the changing seasons determine the variability of energy production throughout the year.



 https://worldmapper.org/natures-heartbeat/

8.4

Nutrient cycling

Nutrient cycling

Nutrient cycling is one of the most important processes that occur in an ecosystem. It involves the movement, exhange and recycling of nutrients in the environment.

Nutrient cycles involve both biotic and abiotic components, and involve biological, geological, and chemical processes. They are also known as **biogeochemical cycles.**

The most important nutrient cycles are the carbon cycle, oxygen cycle, water cycle, phosphorus cycle, sulfur cycle and nitrogen cycle.

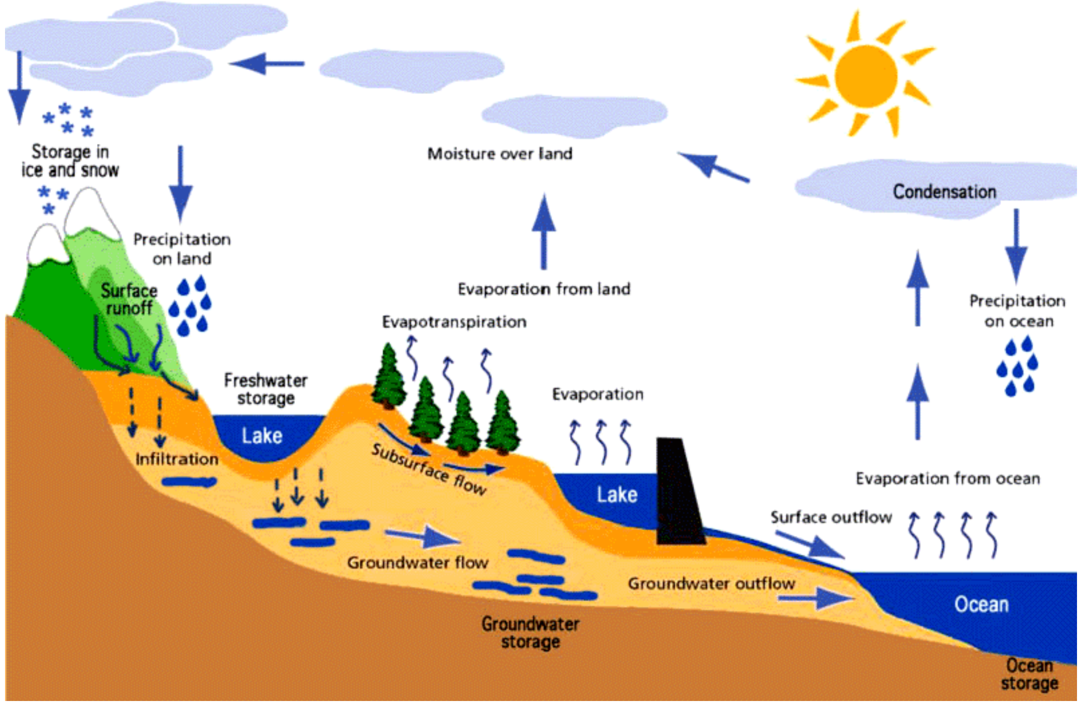
The hydrological cycle

Water is the most important abiotic component of any ecosystem- all living organisms need water to grow and survive. The ability to conserve water or get rid of excess water are some major adaptations we see in organisms.

In an ecosystem, water cycles through the atmosphere, soil, rivers, lakes, and oceans. This process is known as the water, or **hydrological cycle**. Some water is stored deep in the earth. The amount and timing of water cycling influences the types of life-forms that can thrive in different habitats.

The hydrological cycle

This begins with the **evaporation** of water from the surface of the ocean. Moist air is lifted, cools and water vapour **condenses** to form clouds. Moisture is transported around globe until it returns to the surface as precipitation. Some water evaporates back into the atmosphere. Some penetrates the surface to become groundwater. Groundwater seeps into oceans, rivers and streams, or is released back into the atmosphere through transpiration. Water remaining on earth's surface is runoff, which empties into lakes, rivers and streams and is carried back to the oceans.

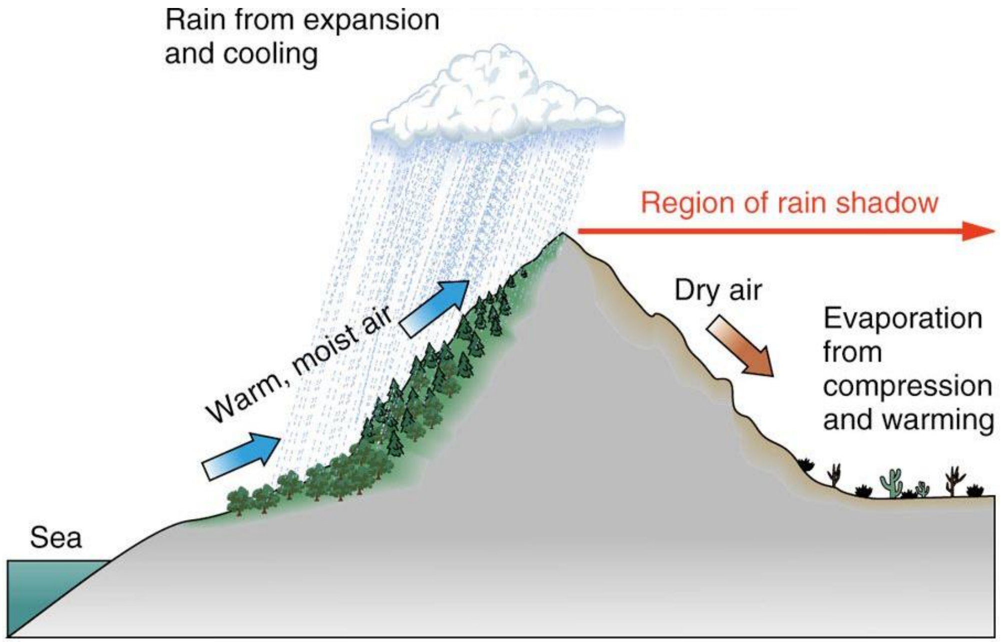


Topography

Topography has a big effect on hydrological cycles. Topography describes the shape and physical features of a landscape: the "lay of the land". It includes land elevation, slope and terrain (flat, rolling, hilly, etc.) Topography has a powerful effect on the distribution of rainfall, local climate, and the organisms and ecosystems that can survive in an area.

Rain Shadow Effect

The effect of topography on local climate can be seen in mountain systems- here a phenomenon known as the rain shadow effect occurs. Warm, moist air rises upwards on one side of a mountain accompanied by prevailing winds. As warm air is pushed upwards it begins to cool: cool air holds less moisture than warm air, so as the cool air condenses, it forms rain on the windward and top side of the mountain. The cool, dry air passes over the top of the mountain, once on the other side it begins to fall, and because cool air holds more moisture than warm air, it absorbs moisture as it descends. This results in different **abiotic** environments on either side of the mountain, which in turn affects which organisms can survive. Different ecosystems develop and thrive on the two sides of the mountain.



The Carbon Cycle

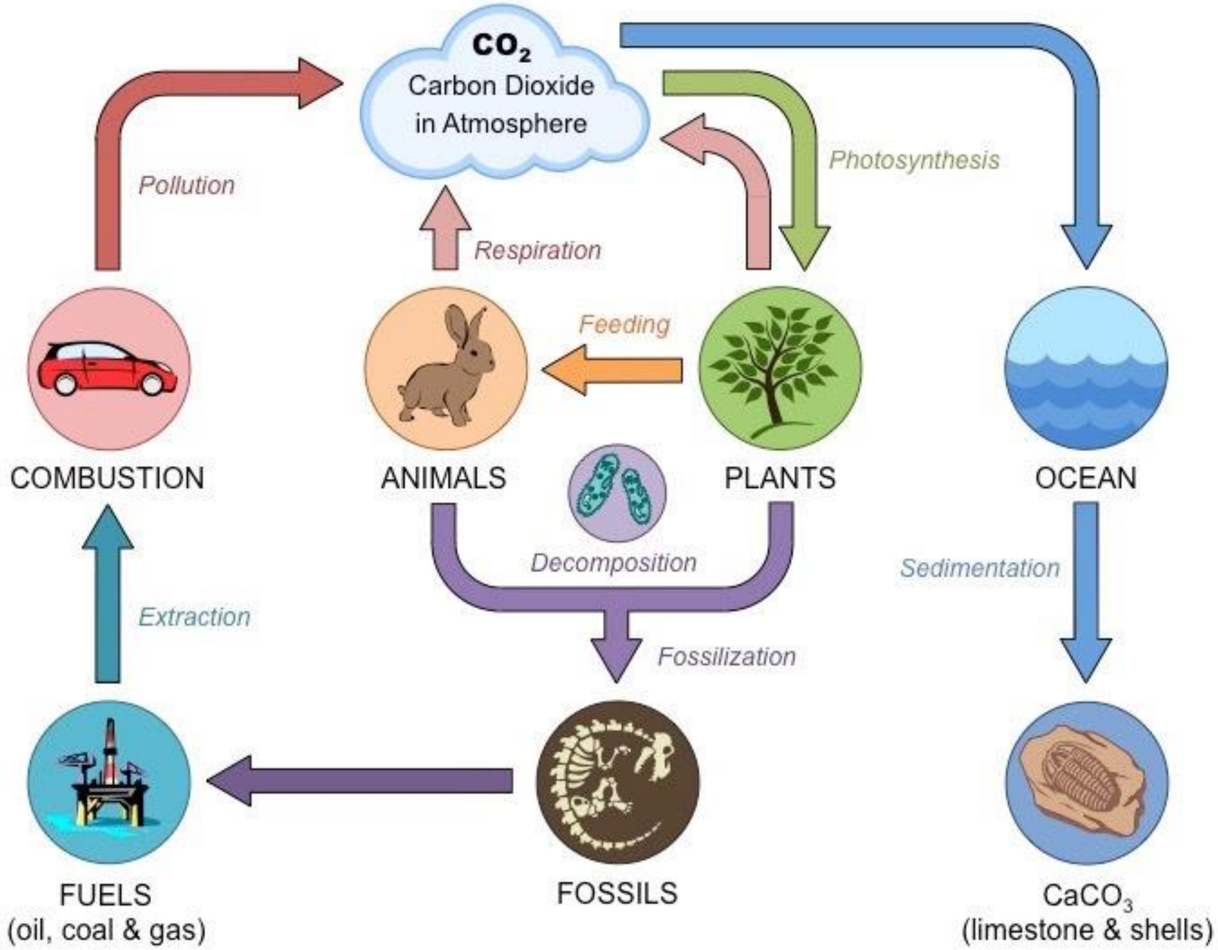
The carbon cycle is a biogeochemical cycle whereby carbon is exchanged between the four different spheres of the Earth: the atmosphere (air), the lithosphere (ground), the hydrosphere (water / oceans) and the biosphere (living things).

Carbon is exchanged between a variety of forms, including atmospheric gases, oceanic carbonates, organic materials and non-living remains.

The carbon cycle involves the following steps:

1. Carbon enters the atmosphere as CO_2 from respiration and combustion
2. CO_2 is absorbed by autotrophs to make **glucose** during photosynthesis. These producers then emit oxygen.
3. Animals feed on the plants, thus passing the carbon compounds along the food chain. Most of the carbon these animals consume is emitted as **carbon dioxide** during respiration. The animals and plants then eventually die.
4. The dead organisms (dead animals and plants) are eaten by **decomposers** in the ground. The carbon that was in their bodies is then returned to the atmosphere as carbon dioxide. In some circumstances the process of decomposition is **prevented**. The decomposed plants and animals may then be available as **fossil fuel** in the future for combustion.

The Carbon Cycle



The Nitrogen cycle

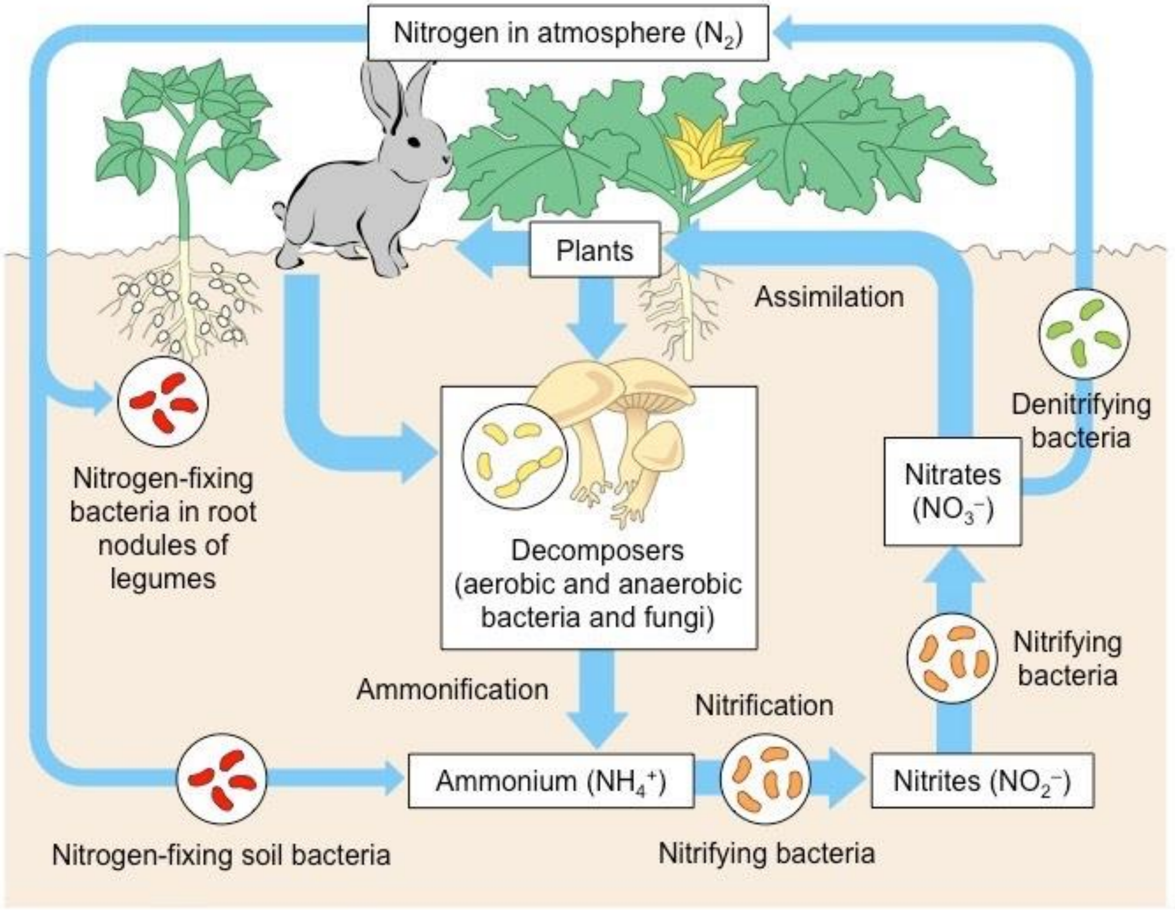
Nitrogen (N_2) is a necessary component of biological molecules, including amino acids (that form proteins) and nucleic acids (the building blocks of DNA and RNA). 78% of the atmosphere is composed of N_2, but this gas is inert and unable to be used by plants and animals.

1. **Nitrogen fixation**: Atmospheric nitrogen (N_2) is converted to ammonia (NH_3) by nitrogen-fixing bacteria in aquatic and soil environments. Ammonia (NH_3) becomes ammonium (NH_4^+) when mixed with water, and this can absorbed by plants.
2. **Ammonification**: When a plant or animal dies, saprotrophs will decompose organic materials to produce a NH_3 and NH_4^+ that are released into the soil and can be absorbed by plants.
3. **Nitrification**: ammonium ions (NH_4^+) are converted into nitrites (NO_2-) and nitrates (NO_3-) by nitrifying bacteria. NO_2- and NO_3- are a predominant source of nitrogen for plants. Oxygen is required for this.
4. **Denitrification:** in the absence of O_2 (such as waterlogged soils), denitrifying bacteria convert nitrite and nitrate to N_2, releasing N_2 back into the atmosphere.

Plants obtain their nitrogen from the soil by absorbing ammonium (NH_{4-}) and nitrate through their roots. Nitrate and ammonium are used to produce organic compounds.

Nitrogen in its organic form is obtained by animals when they consume plants or animals.

The Nitrogen cycle



The Oxygen cycle

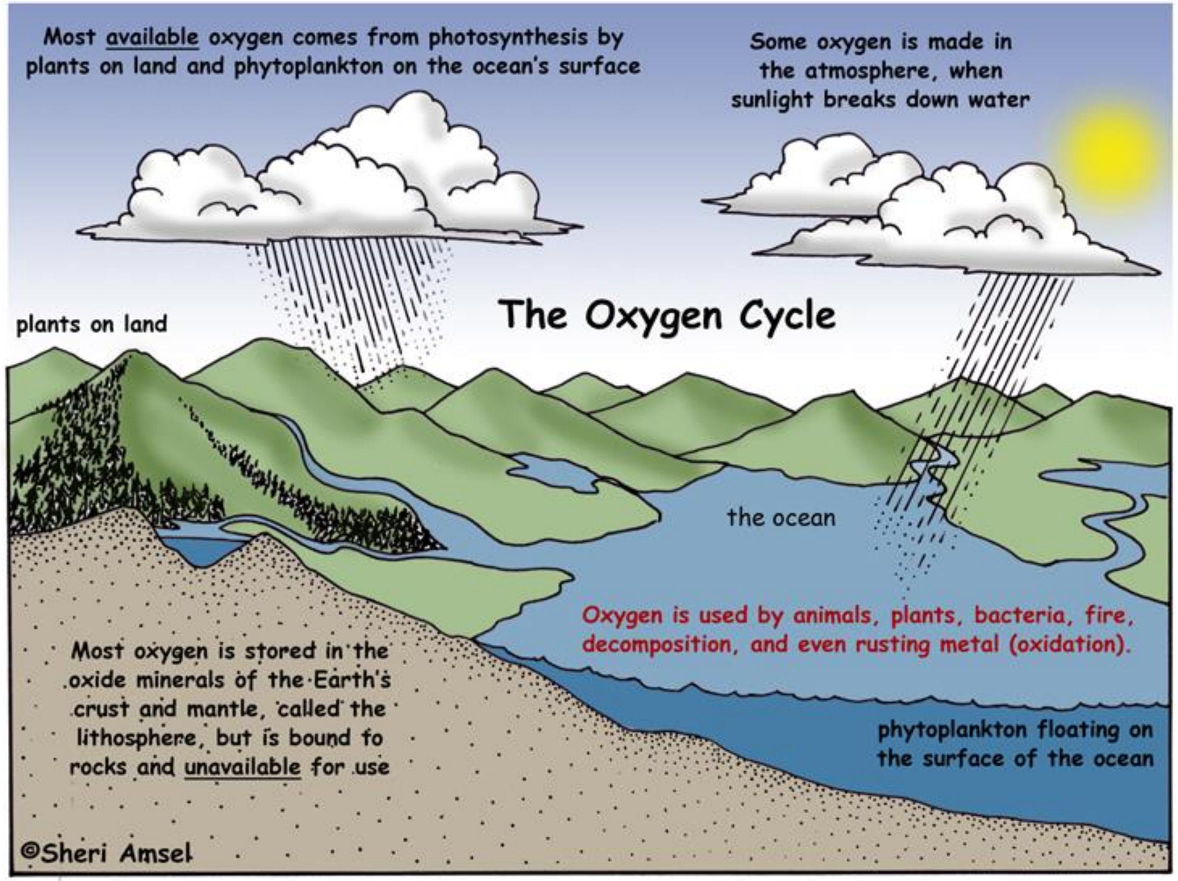
The **oxygen cycle** refers to the transitions that move **oxygen** through the four main ‘spheres’ of the Earth: the atmosphere, the biosphere, the hydrosphere and the lithosphere (the earth’s crust).

In the atmosphere Oxygen is freed by a process called **photolysis**. This is when high energy sunlight breaks apart oxygen bearing molecules to produce free oxygen. One of the most well known examples of photolysis is the ozone cycle. O_2 oxygen molecules are broken down to atomic oxygen by solar UV-radiation. This free oxygen then recombines with existing O_2 molecules to make ozone (O_3). This cycle is important because it helps to shield the Earth from the majority of harmful UV-radiation.

In the biosphere the main cycles are respiration, decay and photosynthesis. Oxygen is consumed during respiration and decay whereupon CO_2 is released. Photosynthesis is the reverse of this process, and is the main source of free oxygen: it is mainly done by plants and phytoplankton.

Most of the Earth's oxygen (about 99.5%) is stored in rocks and minerals in the lithosphere. Here oxygen is fixed in minerals such as silicates and oxides. Silicates are formed when molten rock cools and crystallises. Oxides form when a pure form of an element comes into contact with oxygen, e.g. iron rusting.

The Oxygen cycle



 https://www.thinglink.com/scene/700762414693482498

The Phosphorus cycle

Phosphorus is an essential nutrient for plants and animal growth- it's primary biological role is in the formation of nucleotides for RNA and DNA. Phosphates move quickly through plants and animals; however, the processes that move them through the soil or ocean are very slow, making the phosphorus cycle overall one of the slowest biogeochemical cycles. The phosphorous cycle occurs mainly in terrestrial and aquatic systems, with the atmosphere not playing a significant role.

It is comprised of the following steps:

1. **Weathering**: most phosphorous is found in rocks, so the first step involves the extraction of phosphorus from the rocks by weathering. Weather events, such as rain and other sources of erosion, result in phosphorus being washed into the soil.
2. **Absorption by organisms**: once in the soil, phosphorus can be absorbed by plants, fungi and micro-organisms, and can seep into local water systems.
3. **Return to the environment via decomposition**: When plants and animals die, decomposition results in the return of phosphorus back to the environment via the water or soil. Plants and animals in these environments can then use this phosphorus, and step 2 of the cycle is repeated.

8.5

Ecosystem services

Ecosystem function and services

Ecosystems provide humans with a wealth of services that we need to survive, and that we are unable of providing for ourselves. These services make the planet inhabitable by supplying and purifying the air we breathe and the water we drink. As we have seen, water, carbon, nitrogen, phosphorus, and sulphur are all major global biogeochemical cycles. Disruptions of these cycles can lead to floods, droughts, pollution, acid rain, and many other environmental problems. Soils provide critical ecosystem services, especially for sustaining ecosystems and growing food crops, but soil erosion and degradation are serious problems worldwide.

Ecosystem function and services

Higher biodiversity usually increases ecosystem efficiency and productivity, stabilizes overall ecosystem functioning, and makes ecosystems more resistant to perturbations. Mobile, connected animal species provide critical ecosystem functions and increase ecosystem resilience by connecting habitats and ecosystems through their movements. Their services include pollination, seed dispersal, nutrient deposition, pest control, and scavenging. Increasing habitat loss, climate change, settlement of wild areas, and wildlife consumption is not only precipitating devastating losses of biodiversity, but also facilitating the transition of disease from animals to humans (anthropozoonoses).

Ecosystem function and services

Thousands of plant species that are the components of ecosystems also harbour unique chemicals and pharmaceuticals that can save people's lives. However, many potentially valuable plant species are threatened with extinction and along with it traditional practices as well as knowledge of medicinal plants. For example, about 93% of wild plants used in the traditional Indian practice of Ayurvedic medicine are threatened with extinction due to overexploitation.

Kutki (*Picrorhiza kurrooa*), an antibiotic used in Ayurvedic medicine

Desert cistanche (*Cistanche deserticola*, used in Chinese medicine for over 1800 years

Himalayan Yew (*Taxus wallichiana*), used in Unani medicine for snake bites and scorpion stings, amongst other things

 https://blogs.scientificamerican.com/extinction-countdown/ayurveda-out-of-balance-93-percent-of-medicinal-plants-threatened-with-extinction/

Ecosystem function and services

The valuation of ecosystems as service-providers helps integrate them into public decision-making and aid in their protection.

Ecosystem services are usually grouped into four broad categories:

- **provisioning**, such as the production of food and water;
- **regulating**, such as the control of climate and disease;
- **supporting**, such as nutrient cycles and oxygen production;
- **cultural**, such as spiritual and recreational benefits

Provisioning Services

Provisioning services refer to the products we obtain from ecosystems.

They include food (wild meat, fish and seafood, crops, wild plants and spices); water; raw materials (timber, skins, fuel wood, organic matter, fodder, and fertilizer); genetic resources (crop improvement genes and health care); medicinal resources (e.g. pharmaceuticals, chemical models, and test organisms) and energy (hydropower, biomass fuels).

Provisioning services are vital in the human economy and have often well-developed markets and valuation systems. For example, in Gabon the timber industry is worth $250 million/year or 5% of the country's Gross Domestic Product (GDP). In Micronesia the fisheries sector is worth 10% GDP. In Rwanda the agriculture sector (tea, coffee, wheat, rice) is worth 30.9% GDP.




Regulating services

Regulating services refer to the benefits we obtain from the **regulation** of ecosystem processes.

They include carbon sequestration and climate regulation; the regulation of prey populations by predation; waste decomposition and detoxification; the purification of water and air; pollination; seed dispersal and pest and disease control.

Supporting services

Supporting services refer to the underpinning structures and processes that are necessary for the production of all other ecosystem services. They include nutrient recycling, primary production, and biodiversity.

Cultural services

Somewhat less tangible but nonetheless important, these are the non-material benefits people obtain from ecosystems and the natural world around us.

They include the cultural value of ecosystems (e.g. the use of nature in stories, folklore, paintings, national symbols, architecture, advertising, etc.); the spiritual and historical value of nature (e.g. the use of nature for religious or heritage values); the recreational value of nature (e.g. for ecotourism, sports and recreation); the scientific and education value of nature and finally the therapeutic benefits that nature can provide (feelings of wellbeing, as well as more modern concepts such as ecotherapy, social forestry and animal assisted therapy).

Ecosystem services- summary

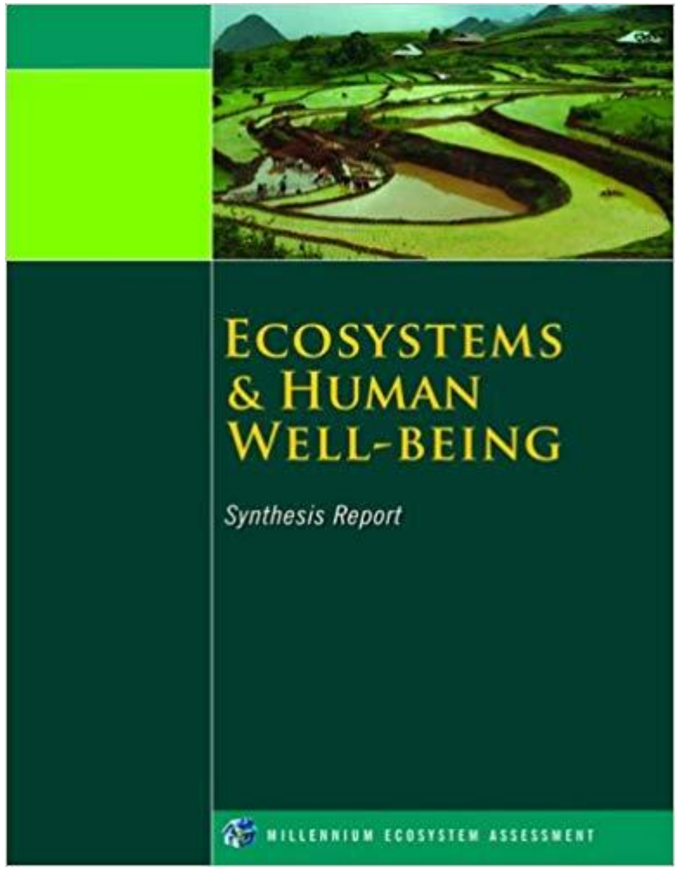
PROVISIONING SERVICES	REGULATING SERVICES	CULTURAL SERVICES
The "products" obtained from ecosystems	*Benefits obtained from the regulation of ecosystem processes*	*Nonmaterial benefits obtained from ecosystems*
Foods Fibers Ornamentals Medicines Biofuels Fresh water Genetic resources	Climate regulation Flood prevention Erosion control Pest control Pollination Seed dispersal Disease regulation	Educational Recreational Sense of place Spiritual Cognitive development Stress relief Gardening

SUPPORTING SERVICES
Services necessary for the production of all other ecosystem services
Biodiversity Nutrient recycling Primary productivity

Millennium Ecosystem Assessment

In **2005** a major global assessment of the human impact on the environment was commissioned by the United Nations (UN). This was called the Millennium Ecosystem Assessment. They identified and assessed 24 specific ecosystem services, and concluded that:

- While living standards have generally improved over the past two centuries, human activity is putting such strain on nature that we are undermining the Earth's capacity to support current and future generations.
- We are living beyond our means: recent gains in quality of life have come at considerable cost to the natural systems on which we all depend.
- If we act now, we can avoid irreversible damage to ecosystems and human well-being.
- But this will require a dramatic change in the way we think about and use natural resources.



Ecosystem valuation

Ecosystem valuation is the process by which policymakers assign a **value**—monetary or otherwise—to environmental resources or to the outputs and/or services provided by those resources.

Various valuation methods can assist the government in making sustainable management policies. Ecosystem valuation uses a range of economic methods in an attempts to capture the range of benefits and costs contained within complex natural systems. It is a complicated field, because many different factors need to be taken into consideration. However, economic valuation based on ecosystem services is very important to maintain sustainable management.

Emerging from this approach is Payments for ecosystem services (PES), sometimes dubbed 'cash for conservation'.

PES programs offer financial incentives to famers and landowners to protect their land in the interest of ensuring the provision of some "service" rendered by nature, such as clean water, habitat for wildlife, or carbon storage in forests. Conducted on a voluntary basis, the idea behind PES is, essentially, to encourage the maintenance of natural ecosystems through environmentally friendly practices that avoid damage for other users of the natural resources. In addition to preserving natural resources, this method improves rural areas and rural lifestyles.

PES is still an emerging field, and the effectiveness of PES programs is under debate and largely unquantified.

8.6

Ecosystem health

Ecosystem health

Ecosystem health refers to the overall condition of an ecosystem. Ecosystem condition can vary, as a result of many factors.

Factors that affect ecosystem health include fire, drought, extinction, invasive species, climate change, mining, over-exploitation, road construction, farming, logging and pollution.

Assessing ecosystem health is an ongoing priority for governments, scientists and managers worldwide.

How can we tell if an ecosystem is healthy?

One widely used definition states that a healthy ecosystem must be both **stable** (resilient) and **sustainable** in the provision of goods and services (ecosytem services).

Ecosystem health can measured through a combination of three elements:

1. **Condition of components** – how far the ecosystem is from a 'good' state.
2. **Function** – the extent to which ecosystems retain their natural function and so have the capacity to deliver a range of benefits.
3. **Sustainability** or **resilience** – the extent to which the health of ecosystems (and their capacity to deliver benefits) can be sustained under human and environmental pressures, including climate change.

In the same way that medical professionals use indicators (e.g. temperature, rash, coughing) to measure and monitor the status of a person's health, ecologists have developed a range of indicators to measure and monitor ecosystem health.

Condition indicators

Condition indicators tell us whether an ecosystem is in a good state. They include indicators of habitat, species and resources, such as water and carbon.

For example, the Scottish Government considers native woodland to be 'healthy' if the following 4 conditions are met:

- canopy cover 50-90%;
- percentage of canopy comprising native species at least 90%;
- herbivore impact Low or Medium;
- invasive non-native species not more than 10% cover and fewer than three invasive species present.

After conducting a national assessment, they have concluded that 46% of all native woodland area is in satisfactory overall health for biodiversity, where all condition attributes were in the desired range.

Function indicators

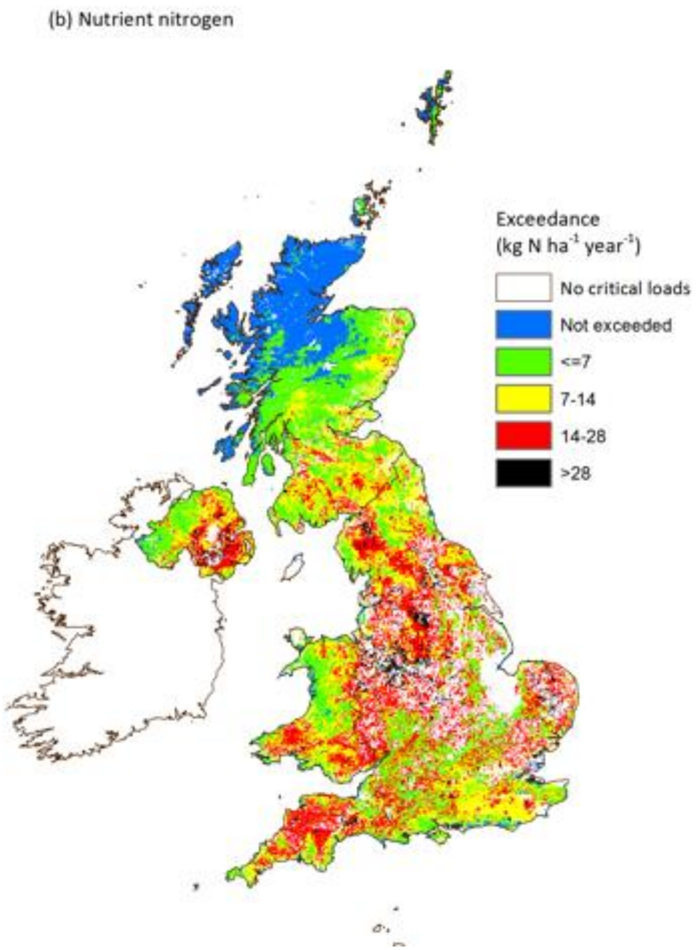
Function indicators tell us the extent to which ecosystems retain their natural function and so have the capacity to deliver a range of benefits.

(Reminder: Ecosystem functions are the processes within ecosystems that help deliver ecosystems services.)

For example: in the UK, acid and nitrogen pollution must stay below a defined threshold, above which ecosystem function is considered compromised and significant harm to habitats can occur.

Following assessments across the whole of the UK, it has been shown that large parts of the UK show acid and nitrogen pollution levels in excess of the critical threshold, whereas Scotland maintains large areas below the threshold.

Other examples include habitat connectivity.

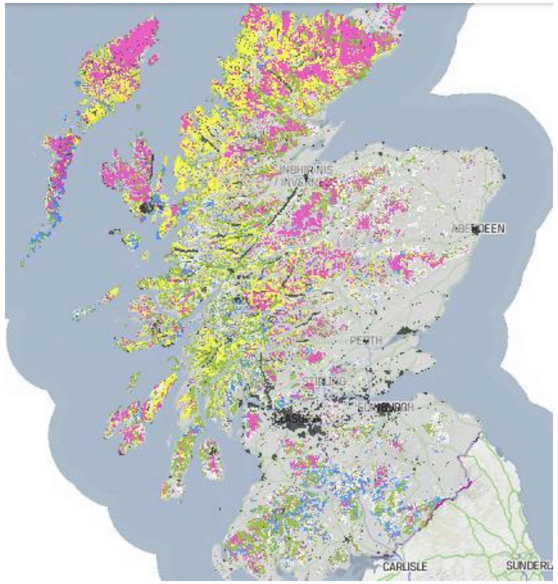


Resilience Indicators

Resilience indicators measure the extent to which the health of ecosystems can be sustained under human and environmental pressures. In turn, this relates to their capacity to continue to deliver benefits.

For example, peatland has great economic value in Scotland, both as a fuel and for whisky-making. It also acts as an important carbon sink globally. However, peatlands are under threat from burning, grazing, pollution and forestry. Peatland restoration in Scotland is restoring peatland function and protecting biodiversity.

Carbon and peat maps are being used as indicators of the extent and distribution of this important habitat.



8.7

Resources

Suggested Reading

- Weathers, K., Strayer, D., Likens, G. (2012). Fundamentals of Ecosystem Science. Academic Press.
- Lorenz, K. and Lal, R. (2010). Carbon Sequestration in Forest Ecosystems. Springer
- Everard, M. (2017). Ecosytem Services: Key Issues. Taylor & Francis Ltd.
- Jorgenses, S.E. (2009). Ecosystem Ecology. 1st Edition. Academic Press.
- Malhi, Y (2012). The productivity, metabolism and carbon cycle of tropical forest vegetation. *Journal of Ecology*. 100: 65-75. https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/j.1365-2745.2011.01916.x
- Canadell, J. and Mooney, H.A. (1999). Ecosystem metabolism and the global carbon cycle. Trends in Ecology and Evolution. 14:249.

Online Resources

- Global Forest Watch. www.globalforestwatch.org
- Millenium Ecosystem Assesment. https://www.millenniumassessment.org/en/index.html
- IPES Ecosytem Services Reference book https://www.ipbes.net/policy-support/tools-instruments/ecosystem-services-reference-book