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0 (https://intercom.help/kognity)

Teacher view

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The big picture

? Guiding question(s)

- What features of ecosystems allow stability over unlimited time periods?
- What changes caused by humans threaten the stability of ecosystems?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

There are ecosystems all over the world providing habitats to many organisms. Most ecosystems have shown continuity over long periods of time. There is evidence for some ecosystems persisting for millions of years.

Student view

- Tropical rainforests are the oldest and most diverse ecosystems on Earth. They have been around for millions of years and are home to an incredible

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variety of plant and animal life.

- The Great Barrier Reef (**Figure 1**) is the largest coral reef system in the world. It is home to over 1500 species of fish, 400 species of coral and 130 species of sharks and rays. The Great Barrier Reef has been around for over 20 million years and is one of the most stable ecosystems on Earth.

The abiotic and biotic factors that form and affect these ecosystems are not static. How have these ecosystems been able to survive for so long, despite the many changes that have occurred on Earth over time?

Figure 1. The Great Barrier Reef.

Credit: Reinghard Dirscherl, Getty Images

Prior learning

Before you study this subtopic make sure that you understand the following:

- The definition of biodiversity (see section A4.2.1—2 (/study/app/bio/sid-422-cid-755105/book/title-to-come-id-43810/)) and the causes of the current biodiversity crisis (see section A4.2.5—6 (/study/app/bio/sid-422-

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cid-755105/book/evidence-and-causes-of-the-biodiversity-crisis-id-44391/)).

- The abiotic variables affecting species distribution and range of tolerance of a limiting factor (see section B4.1.3—4 (/study/app/bio/sid-422-cid-755105/book/limitations-of-adaptations-and-range-of-tolerance-id-44705/)).
- Ecosystems as open systems (see section C4.2.1—4 (/study/app/bio/sid-422-cid-755105/book/flow-of-energy-and-matter-id-46631/)).

Practical skills

Once you have completed this subtopic, you can gain modelling skills by going to Practical 5: Observing a sustainable ecosystem using a mesocosm (/study/app/bio/sid-422-cid-755105/book/observing-a-sustainable-ecosystem-id-46696/).

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Stability of ecosystems

Learning outcomes

By the end of this section you should be able to:

- Define ‘ecosystem stability’, including some examples of stable ecosystems.
- Outline the factors that affect stability and explain tipping points, using deforestation of the Amazon rainforest as an example.

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The Amazon rainforest is the world's richest and most diverse biological reservoir. The age of the Amazon is a matter of debate among scientists, but evidence suggests that it is around 80 million years old. This makes it one of the oldest and most complex ecosystems on Earth. **Video 1** explores the Amazon's extreme diversity.

Video 1. The diversity of the Amazon rainforest.

Tropical rainforests face many challenges, such as climate change, plate tectonics, ice ages and the arrival of humans. How have they survived for so long?

Study skills

As a new term introduced in the syllabus, 'stability' is an important concept of Theme D: Continuity and change. You should be able to define stability with clear statements.

The stability of an ecosystem is the ability to maintain its structure and function over time, despite changes or disturbances. A stable ecosystem is able to resist changes that may disrupt its steady state. If a change or disturbance affects the structure or function of an ecosystem, a stable ecosystem should be able to restore itself back to the original state.

The Earth is a dynamic planet, and it is constantly changing. Earth is estimated to be 4.5 billion years old, and early life forms may have appeared over 3.5 billion years ago. Earth has been shaped – and is still being shaped – by many forces, which results in diverse conditions and landscapes. Despite Earth's dynamic nature, many ecosystems have shown continuity over long time periods.

Throughout the Earth's history, many species have evolved together and established complex relationships both with other species and with their surroundings. These relationships contribute to the stability of ecosystems and the continuity of ecological functions. The accumulation of diversity also increases the overall stability of ecosystems, as the loss of a particular species is less likely to cause a significant disruption.

Examples of stable ecosystems

Tropical rainforests

Mature tropical rainforests, such as the Amazon, Congo and Southeast Asian rainforests, have high biodiversity with complex food webs. The abundance and distribution of species are relatively constant over time. Despite being subject to disturbances such as natural disasters, rainforest ecosystems can recover due to their complex interactions.

Figure 1 shows the distribution of tropical rainforests around the world.

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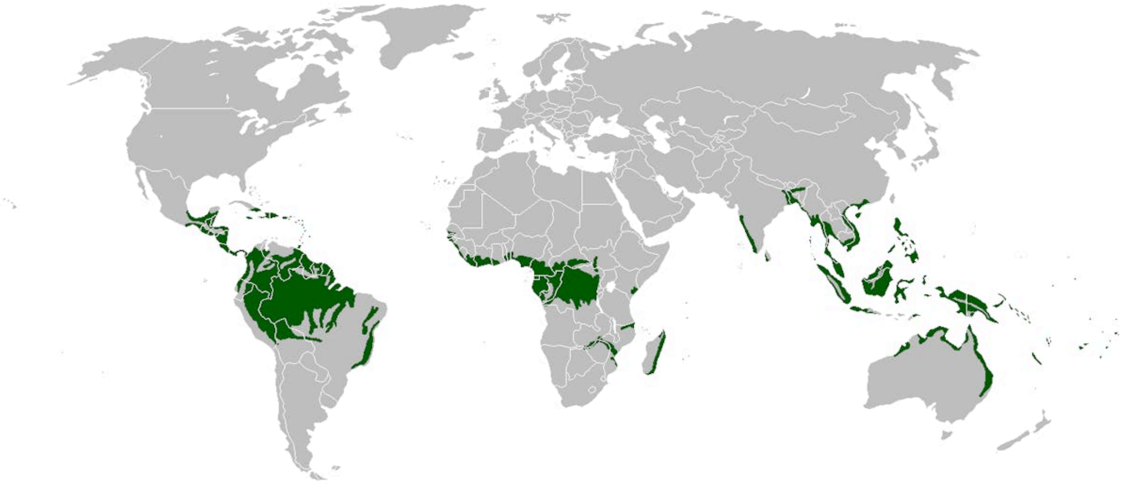

Figure 1. The distribution of tropical rainforests.

More information for figure 1

The image is a world map highlighting the distribution of tropical rainforests in various regions. Key areas where tropical rainforests are prominently found are shaded in green. These regions include Central and South America, particularly the Amazon basin; Central Africa, spanning across countries such as the Democratic Republic of the Congo; and regions in Southeast Asia, including parts of Indonesia and Malaysia. The green areas are depicted over a gray-scale map, providing a clear contrast to show where these biodiverse environments are located globally. The map illustrates the limited but widespread areas occupied by tropical rainforests, emphasizing their concentration in equatorial regions.

[Generated by AI]

Tropical rainforests are areas of high biodiversity. Biologists estimate that tropical rainforests contain about 50% of the world's terrestrial plant and animal species, yet they encompass only about 6% of the world's land area.

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The recovery from a disturbance in rainforests is a slow process. Rainforest ecosystems are complex and diverse ecosystems. The complexity of the structure and relationships supports the stability of these ecosystems and allows them to recover from disturbances.

Coral reefs

Coral reefs are one of the most diverse and productive ecosystems on the planet. They can be found in a range of habitats, where they offer a home and food source to a vast variety of creatures, as well as many other ecological benefits and services. Despite their importance, coral reefs are threatened by human activities such as pollution and climate change.

Coral reefs are sometimes referred to as the ‘rainforests of the sea’ due to their high biological diversity. About 25% of the ocean's fish depend on coral reefs.

Coral reefs have existed for over 200 million years. Despite being threatened by human activities, some remain stable and continue to support diverse marine life.

Boreal forests

Boreal forests, also known as taiga, are found in the subarctic regions of the world, such as Canada, Russia and Scandinavia. These forests are characterised by coniferous trees, such as spruce, pine and fir. Boreal forests have existed for over 10 000 years and are home to a variety of wildlife.

Boreal forests are able to withstand a wide range of environmental conditions, including long, cold winters and short, warm summers. They are also home to a diverse range of plants and animals, which helps to maintain the balance of the ecosystem.

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Sonoran Desert

The Sonoran Desert of North America covers an area of 260 000 km^2 and is the hottest desert in the Americas. Despite the harsh conditions, the Sonoran Desert supports many different life forms, including saguaro cactus, the colourful Gila monster and the iconic bobcat (**Figure 2**).

Credit: Alan Majchrowicz, Getty Images

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Credit: Peter Finch, Getty Images

Credit: Joe McDonald, Getty Images

Figure 2. (Top) saguaro cactus (*Carnegiea gigantea*); (middle) Gila monster (*Heloderma suspectum*); (bottom) bobcat (*Lynx rufus*).

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The Sonoran Desert's bi-seasonal rainfall pattern supports more plant species than any other desert. The cacti of the desert provide food and habitat to many desert invertebrates and vertebrates. Over 2000 native plant species are estimated to be found in the ecosystem, supporting over 350 bird species, 20 amphibian species, over 100 reptile species, 30 native fish species and over 1000 native bee species. The Sonoran Desert area is also a vital habitat for the population of jaguars living within the United States.

Ecosystem stability is important to all forms of life because it ensures the continuity of ecosystems. It also supports the long-term survival of the species within the ecosystem, including humans.

Factors affecting stability of ecosystems

An ecosystem requires both resistance and resilience to maintain its stability over time. Resistance is the ability of an ecosystem to remain stable in the face of disturbances, whereas resilience is the ability to recover after a disturbance.

Several factors contribute to the stability of an ecosystem, including supply of energy, recycling of nutrients, genetic diversity and climatic variables remaining within tolerance levels.

Supply of energy

The supply of energy to ecosystems is one of the most important factors that supports ecosystem stability. Energy is needed for all life processes. Without a steady supply of energy, ecosystems would quickly collapse.

The Sun is the ultimate source of energy for the processes on Earth, but not all organisms are able to use solar energy. During the one-way flow of energy through an ecosystem, producers transform the Sun's energy to produce food, and consumers use plants or other consumers to obtain energy.

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The diversity of producers is a major factor that controls the supply of energy to food webs. An ecosystem with a higher diversity of producers will likely be more resistant to changes in biotic and abiotic factors. A stable ecosystem also requires a balanced energy flow to ensure that no one species becomes too dominant or too scarce.

Making connections

Review section C1.3.1—3 (/study/app/bio/sid-422-cid-755105/book/photosynthesis-id-46517/) to understand how light energy is transformed to chemical energy in photosynthesis.

Read through section C4.2.1—4 (/study/app/bio/sid-422-cid-755105/book/flow-of-energy-and-matter-id-46631/) to learn more about energy flow in ecosystems and how sunlight acts as the principal source of energy in most ecosystems.

Recycling of nutrients

Nutrient recycling is the process by which nutrients are cycled between the environment and organisms. Examples of important nutrients include carbon, nitrogen and phosphorus. Recycling of nutrients is essential for the long-term health of ecosystems. By efficiently recycling nutrients, ecosystems can maintain nutrient availability, supporting the productivity of populations. Nutrient recycling helps to maintain the diversity of an ecosystem.

For example, carbon (in the form of carbon dioxide, CO_2) is absorbed by plants to be used in photosynthesis to produce glucose. The glucose is used by plants and other organisms for energy, and carbon is released back to the atmosphere.

Making connections

Nutrient cycling in ecosystems is explained further in subtopic C4.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43545/). See sections C4.2.17—19 (/study/app/bio/sid-422-cid-755105/book/the-

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carbon-cycle-id-46636/) for more on the carbon cycle, and section C4.2.1—4 (/study/app/bio/sid-422-cid-755105/book/flow-of-energy-and-matter-id-46631/) for more on recycling of other chemical elements.

Depletion of nutrients can disrupt the functioning and stability of ecosystems. Recycling nutrients allows for the redistribution and regulation of nutrients. Rather than losing nutrients through leaching or runoff, capturing and retaining nutrients within the ecosystem minimises nutrient losses.

Biodiversity

A highly diverse ecosystem is more likely to be stable because it can better resist disturbances. Biodiversity can be identified in different forms, including species diversity, habitat diversity and genetic diversity (see section A4.2.1–2 (/study/app/bio/sid-422-cid-755105/book/title-to-come-id-43810/)).

Species diversity ensures that there are enough different species to fulfil various ecological roles, which creates a more resilient ecosystem. Having multiple species that perform similar roles provides alternative pathways of flow in ecosystems. If one species is impacted by a disturbance or environmental change, other species can step in and fulfil the same ecological function. For example, the parrotfish, surgeonfish and rabbitfish of coral reefs are all herbivorous fish that control algal growth. They all graze on various types of algae and prevent the establishment of dominant algal species that could negatively impact coral health. If the population of one species decreases, other fish populations continue to control algal growth.

Habitat diversity refers to diversity within a specific geographic area. In general, the variety of distinct habitats found in an ecosystem or biome results in more species diversity, which will result in more and diverse interactions. Wetlands, for example, include diverse habitats such as marshes, swamps and bogs. These waterlogged areas support a wide range of species. The varying water depths, vegetation types and soil conditions contribute to the richness of species within wetland ecosystems.

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Genetic diversity allows populations to possess a wide range of genetic traits and variations (see section D4.1.9–11 (/study/app/bio/sid-422-cid-755105/book/gene-pools-and-changes-in-their-composition-hl-id-43804/)). Species with different traits respond differently to environmental changes. In genetically diverse populations, there is a higher probability of genetic variations that increase individual fitness, reproductive success and overall population health. Genetically diverse ecosystems have greater capacity to recover from disturbances due to the presence of species with various strategies, tolerances and responses to changing conditions.

Climatic factors

Physical factors such as climate, topography and water availability can greatly affect the stability of an ecosystem. Ecosystems that experience extreme physical changes or are subject to extreme weather events are less likely to be stable.

Climatic conditions play a significant role in shaping the stability of ecosystems. These determine the geographic distribution of species and the composition of ecosystems.

Different species have specific climatic requirements and tolerances. For example, while polar bears and emperor penguins are adapted for cold temperatures and sea ice, koalas are adapted to the high temperatures of Australia. Similarly, bromeliads are a diverse group of plants found primarily in tropical and subtropical regions. They have specific requirements for high humidity, filtered sunlight and well-drained environments. But Joshua trees (yuccas) are iconic plant species found in the arid regions of the southwestern United States, particularly in the Mojave Desert. They have specific requirements for low precipitation, well-drained sandy soils and high temperatures.

Changes in climatic conditions can lead to shifts in species ranges and alter the composition of ecosystems. If climatic conditions become unsuitable for certain species, it can disrupt the balance and stability of ecological communities.

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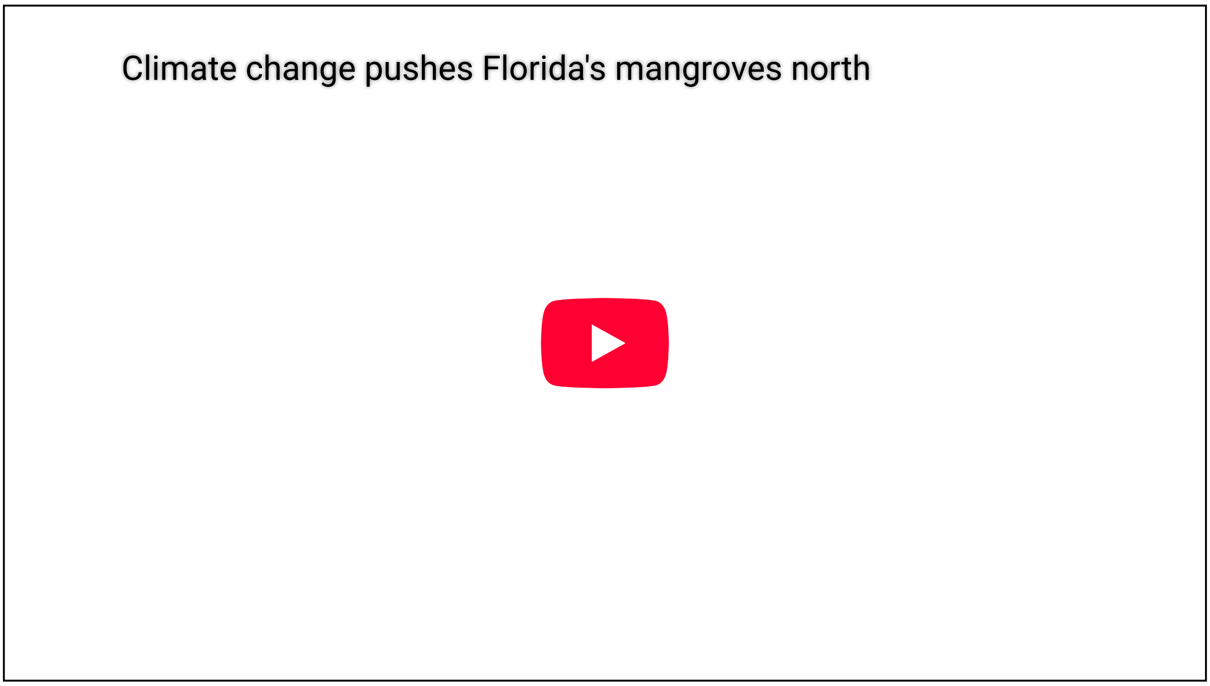
Video 2 shows the example of marsh grasses being replaced by mangrove forests as a result of warmer winters.



Video 2. Marsh grasses are replaced by mangrove forests due to warmer winters.

Temperature and precipitation influence ecosystem productivity and nutrient cycling. Temperature affects the rate of biochemical reactions, plant growth and nutrient availability. Precipitation patterns determine water availability, which is essential for plant growth and nutrient transport. Changes in climatic conditions, such as increased temperatures or altered precipitation patterns, can impact the productivity of ecosystems and nutrient cycling processes, potentially leading to instability.

Making connections

To read more about the range of tolerance and limiting factors, see sections B4.1.3—4 (/study/app/bio/sid-422-cid-755105/book/limitations-of-adaptations-and-range-of-tolerance-id-44705/) and B4.1.6—7 (/study/app/bio/sid-422-cid-755105/book/determinants-of-biome-distribution-id-44396/).

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Tipping points

Ecosystems with high stability maintain their structure and function over time, despite changes or disturbances – but only within limits.

The critical threshold of a change that results in a significant and often irreversible change in an ecosystem's structure, function or composition is called a tipping point. Once the tipping point is reached, the ecosystem undergoes a profound transformation, often leading to the loss of biodiversity, collapse of populations or degradation of ecosystem services.

Tipping points are often associated with hidden dynamics, where small changes can accumulate and trigger larger effects. The concept emphasises the importance of understanding and managing systems to prevent or mitigate irreversible changes.

Deforestation of the Amazon rainforest is a well-known example of a possible tipping point in ecosystem stability. Deforestation is the permanent removal or clearing of forests or wooded areas, usually to convert land for agricultural, industrial or urban purposes (**Figure 3**).

Figure 3. Deforestation in a forest.

Credit: Nora Carol Photography, Getty Images

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Generally, after a small amount of tree removal, the remaining trees and vegetation in the surrounding forest can support the recovery of the cleared area. The rate of natural recovery depends on many factors and can take several years. The resulting forest may differ in community composition and structure compared with the original ecosystem.

When deforestation occurs at a higher rate, it can push the forest past a critical point, where the forest's ability to regenerate and maintain its ecological functions is compromised.

Deforestation in the Amazon is one of the biggest ecological crises of our time, and many believe that the threshold for natural recovery has passed. Tropical rainforests play a critical role in both local and global ecosystems. They provide habitat for wildlife, sequester carbon dioxide from the atmosphere, protect biodiversity and provide valuable resources for nearby communities.

Trees absorb water from the ground with their roots and release water from their leaves as water vapour. This process is called transpiration. With one or two trees, this process may have no effect on local ecosystems, or have a very limited effect. On the other hand, when enough trees are concentrated in a large area, trees can absorb a large amount of water from the soil and release much vapour to the atmosphere via transpiration. The water vapour from the rainforests can form clouds.

Both absorption of water from soil and release of water vapour affect the water cycle. The dense vegetation slows the movement of water on the surface of soil. Due to the slow movement, runoff is avoided, and more water is absorbed by soil. The water is absorbed by the trees and released back to the atmosphere.

The water vapour released via transpiration increases the moisture in the atmosphere. The increased moisture contributes to the formation of clouds and precipitation in the surrounding areas. The name of these forests is directly related

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to the high rainfall available throughout the year, which is created by their function. As forests, they create their own rain. More precipitation will allow more trees to grow, and more trees will produce more precipitation (positive feedback).

Transpiration in major tropical rainforests such as the Amazon does not only affect local conditions but also has significant effects on global precipitation patterns. The Amazon rainforest produces around 20 billion tons of water in transpiration per day, and can create rainfall hundreds of miles away.

Watch **Video 3** to see how the Amazon rainforest creates clouds.

Video 3. The transpiration of Amazonian trees releases a large quantity of moisture into the air.

More information for video 3

The video visually demonstrates how the Amazon's transpiration drives cloud formation and rainfall. The video is filmed at the Wayqecha Biological Station in Peru and captures clouds generated by Amazonian transpiration surging through the valleys of the lush rainforest, resembling a tsunami. These rain clouds form from moisture released by the Amazonian trees, which condense into rain when forced upward by mountain slopes.

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Creativity, activity, service

Strand: Service
Learning outcomes:

- Demonstrate engagement with issues of global significance
- Recognise and consider the ethics of choices and actions

The rainforests are unmatched in biodiversity, with millions of plant and animal species. According to the Food and Agriculture Organization (FAO) of the UN, approximately 10 million hectares of global forests are lost every year. Forests are treasures of the whole communities inhabiting the Earth, independent from their locations.

- Visit https://www.wwf.org.uk/where-we-work/amazon (https://www.wwf.org.uk/where-we-work/amazon) to learn more about the Amazon.
- Identify the local and national opportunities that you can contribute to, using 'support' section of WWF on the Amazon.
- Identify a service activity you can contribute to individually, or you can spread this to the whole school community.

During transpiration, the released water absorbs heat from the surrounding environment and cools the surroundings. This cooling effect helps to regulate temperatures within the rainforest and can have broader impacts on regional climate patterns.

The power of rainforests comes from the size of the area they cover, thus the number of plants transpiring during the day. As plants are cut, the deforestation decreases both the number of plants and the area covered by the vegetation. At some point, the area of the forest will not be enough to maintain this globally important process, and the ecosystem may transform from a rainforest to ordinary forest or even a savannah.

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The point where the area of a rainforest is not enough to maintain its functions is defined as the minimum area of rainforests or the tipping point. The minimum area of a rainforest to maintain its services is not clear.

International Mindedness

The Amazon is a unique biome that is shared by eight countries — Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana and Suriname — and French Guiana. It provides goods and services to indigenous communities living near and far. It's a highly biodiverse ecosystem, home to untold species of plants and animals.

The Amazon's waters and forests are a crucial resource for South America's economic development. As much as 70% of the South American continent's Gross Domestic Product (GDP) is produced in areas that receive water from the Amazon. More than 40 million people, including over 500 indigenous and ethnic groups, live in the Amazon and depend on nature for agriculture, clothing and traditional medicines.

Ironically, as rainforests disappear, science shows that the health of rainforests is critically tied to the health of the rest of the world. Tropical rainforests are a major carbon sink, and without them the greenhouse effect would likely be even more pronounced, and climate change may possibly get even worse in the future.

Interactive 1 (https://earthengine.google.com/timelapse/) demonstrates the extent of deforestation in the Amazon over the past forty years. Use the left sidebar menu to scroll to the bottom. There you will find the time-lapse of deforestation in Rondonia, Brazil.

It is estimated that over 20% of global rainforests have already been destroyed due to land clearing for agricultural production, logging, mining and other human activities. In addition to its devastation of the natural environment, deforestation also contributes significantly to changing climates by releasing tonnes of carbon dioxide into the atmosphere.

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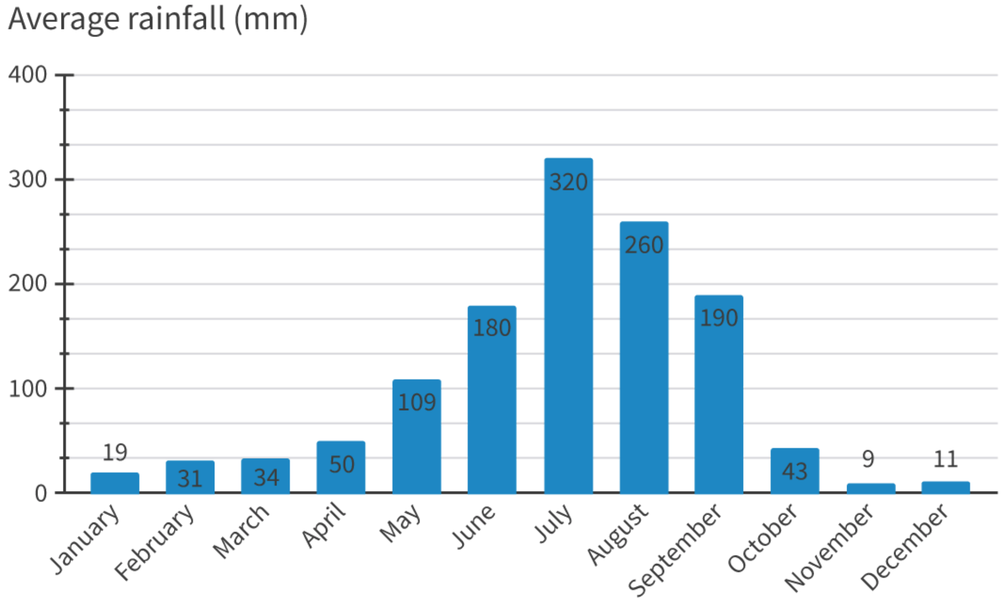
Worked example 1



More information

The bar chart represents Nepal's average monthly rainfall in millimeters, derived from observed historical data between 1991 and 2020. The X-axis lists the months from January to December. The Y-axis indicates the average rainfall in millimeters, with a scale from 0 to 400 mm.

The bars for each month show the following average rainfall: - January: 19 mm - February: 31 mm - March: 34 mm - April: 50 mm - May: 109 mm - June: 180 mm - July: 320 mm - August: 260 mm - September: 190 mm - October: 43 mm - November: 9 mm - December: 11 mm

The trend shows peak rainfall in July, followed by a decline in the following months, with the lowest levels in November and December.

[Generated by AI]

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The above chart shows Nepal's average rainfall derived from observed historical data between 1991 and 2020.

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Determine the months with highest and lowest rainfall during the year and calculate the percent change.

Solution steps	Calculations
Step 1: determine the month with highest rainfall	The highest bar with the greatest value (320 mm) is July.
Step 2: determine the month with lowest rainfall	The lowest bar with the smallest value (9 mm) is Novembe
Step 3: calculate the percent change	$\% \text{ change} = \frac{\text{final value} - \text{initial value}}{\text{initial value}} \times 10$ % change $= \frac{\text{lowest rainfall value} - \text{highest rainfall value}}{\text{highest rainfall value}}$ $\% \text{ change} = \frac{9 \text{ mm} - 320 \text{ mm}}{320 \text{ mm}} \times 100$ $\% \text{ change} = \frac{-311 \text{ mm}}{320 \text{ mm}} \times 100$ % change = —97.2
Step 4: interpret your answer	Since the change is (−) negative, it implies a decrease, wh stated as: From July to November, a 97.2% decrease is observed.

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Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 15 minutes
- **Activity type:** Individual activity

Look at the data in **Table 1** and answer the questions that follow.

Table 1. Deforested area (in km^2 per year) of Amazon rainforest in Rondonia
2015.

Year	Deforested area (km^2 per
1985	3 479
1990	73 776
1995	134 328
2000	211 815
2005	269 815
2010	349 159
2015	405 071

Data source: https://time.com/amazon-rainforest-disappearing
(https://time.com/amazon-rainforest-disappearing).

1. Identify the year in which highest deforestation occurred.
2. Explain why there is no data given before 1985.
3. Calculate the percent change of deforestation from 1985 to 2015.

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5 section questions

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Models

D4.2.4: Modelling the effect of variables on ecosystem stability

Learning outcomes

By the end of this section you should be able to evaluate the use of models to investigate the effect of variables on ecosystem stability.

The world's largest Earth science experiment, Biosphere 2, is a terrarium research system located in Oracle, Arizona. It serves as a centre for research, outreach, teaching and lifelong learning about Earth and its living systems.

Biosphere 2's original purpose as an experimental space was tested from 1991–1993 and for several months in 1994, but both times the experiments faced issues with species dying off due to lack of oxygen and food. Despite the failures, both attempts were very important due to the insights gained on the self-organisation and dynamics of complex systems.

Can we trust models on representing reality related to relevant factors and interactions?

Modelling ecosystems

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Identifying and predicting tipping points is important for informed decision-making, policy development and sustainable management practices. It is challenging as tipping points can be highly complex and influenced by multiple

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interacting factors.

Scientists aim to simplify complex systems and phenomena by using models so that they can better understand, explain and predict the different aspects. Models are simpler representations of real-world phenomena. They can be used to represent physical objects, processes or systems, and can be either physical or mathematical. For example, a mathematical model of the Earth’s climate can be used to predict how the climate will change in the future.

Theory of Knowledge

Models can be used to achieve a variety of goals in science:

- To explain how a system or process works. For example, a model of the human heart can be used to explain how the heart pumps blood.
- To predict how a system or process will behave in the future. For example, a model of the Earth's atmosphere can be used to predict how its composition will change in the future.
- To design new systems or processes. For example, a model of a new ecosystem can be used to test different designs before it is built.
- To teach students about science. For example, a model of the solar system can be used to teach students about the planets in our solar system.

Models in science are valuable tools for hypothesis testing, theory development, data analysis and communication of scientific ideas. They provide a framework for scientists to understand and explore the natural world, make predictions and inform decision-making processes. However, it's important to note that models are simplifications of reality and may not capture all the complexities and nuances of the system. Scientists continually refine and improve models based on new evidence and insights to enhance their accuracy and usefulness.

Are models reliable tools when different models of the same phenomenon give different results?

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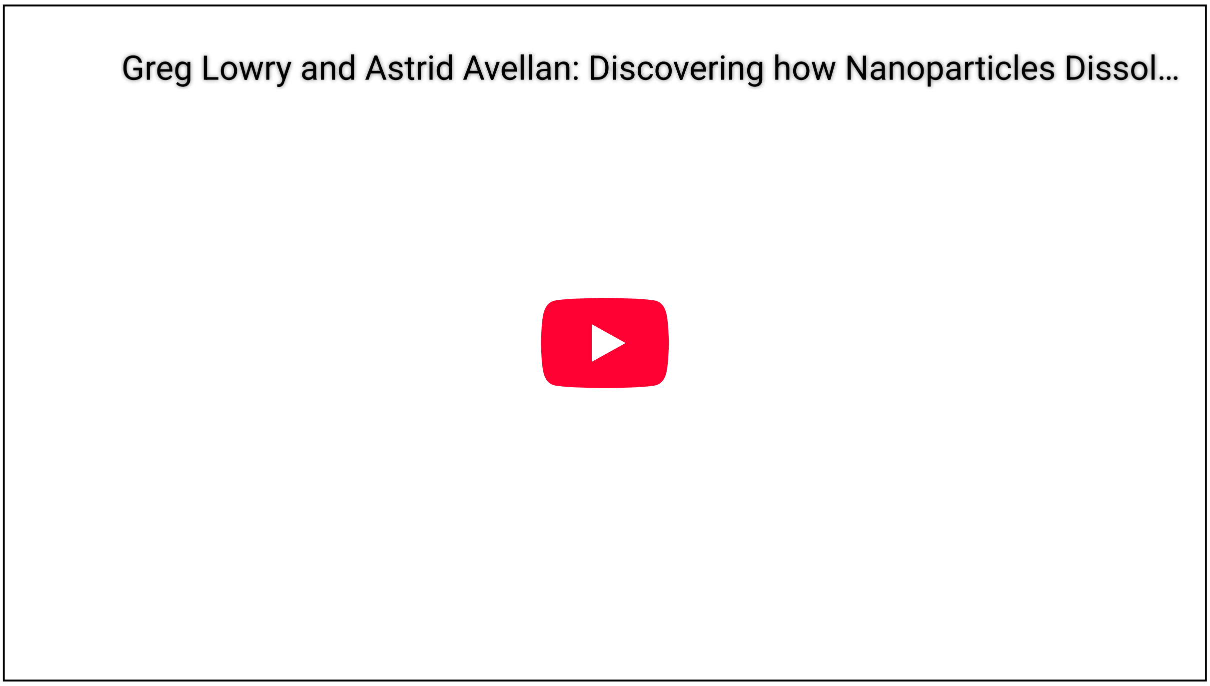
Mesocosms

The word ‘mesocosm’ comes from the Greek for medium (meso) and world (cosm). Mesocosms are used in ecological research to allow scientists to investigate a variety of issues. They are generally seen as outdoor systems but may be constructed as smaller, inside models. Scientists can create conditions that mimic possible results of climate change, see how a change in nutrient levels affects an ecosystem or investigate a pollutant’s spread through a food web. Experiments such as these can help us address questions of sustainability.

You can learn more about how mesocosms are used experimentally in **Video 1**.



Video 1. Scientists use mesocosms that represent freshwater wetlands to explore how nanomaterials behave in very complex environments.

Mesocosms have been designed all over the world by scientists wishing to investigate their own ecosystems. They allow researchers to easily manipulate environmental variables under controlled conditions. Organisations exist to try to increase communication between these research facilities. You can access locations of aquatic mesocosms around the world here (http://mesocosm.eu/).

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Mesocosms may also be quite small. No matter their size, mesocosms help scientists to model the complex interactions that occur in natural ecosystems. This is an advantage over studying a single organism in the laboratory, where it might behave differently than it would in its natural environment.

Preparing a mesocosm to investigate the effect of variables on ecosystem stability

In Practical 5: Observing a sustainable ecosystem using a mesocosm (/study/app/bio/sid-422-cid-755105/book/observing-a-sustainable-ecosystem-id-46696/), as a model for ecosystems, you will create a simple mesocosm to investigate the effect of variables on ecosystem stability.

Mesocosms can be set up in open tanks but sealed glass vessels are preferable because entry and exit of matter can be prevented but energy transfer is still possible. Aquatic or microbial ecosystems are likely to be more successful than terrestrial ones.

The mesocosm you will study will be a closed model of an aquatic ecosystem.

- Once sealed, there will be no exchange of matter.
- Energy will be exchanged between the mesocosm and the surroundings: sunlight will enter the system through the glass and photosynthesis will occur in plants.

Then, if the initial conditions include an appropriate number of biotic and abiotic factors, the water cycle, carbon cycle and oxygen cycle will allow for continued survival in a sustainable mesocosm.

Aspect: Experiments

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Mesocosms can sometimes incorporate animals, such as snails, crustaceans or fish, along with plants. If you wish to include these organisms in your mesocosm you should discuss options with your teacher. To avoid stress on the chosen organisms, care and maintenance of your mesocosm should follow IB's animal experimentation policy.

Figure 1 shows some examples of aquatic mesocosms.

Figure 1. Aquatic mesocosms prepared in a jar.

Credit: Fahira Islamiyah, Getty Images

For a mesocosm to be comparable to real life, the components should work together in a way that simulates a real, self-sustaining ecosystem. The mesocosm should ensure that energy and nutrients are available and waste by-products of biological activity can be recycled instead of building up.

Mesocosms are an excellent research apparatus because they can be used to investigate a wide array of factors, such as:

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- pH of water
- temperature
- light intensity
- colour of light
- concentration of ions
- population size of producers
- diversity of producers
- population size of consumers
- community composition.

Methods and apparatus for mesocosms are quite variable and will depend on both the supplies available to you and the local ecosystems available to you to study.

Aspect: Observations

Scientific observation is a fundamental component of the scientific method, and one of its key objectives is to identify patterns and trends in data or phenomena. Through careful and systematic observation, scientists aim to gather information about the natural world and discern regularities or relationships between variables.

Observations can be made using senses, instruments and measurement tools, depending on the nature of the research. Scientists record and analyse these observations to identify patterns or trends that may provide insights into the underlying processes or mechanisms at work.

Try the activity below to help summarise your learning about ecosystem models and the Amazon rainforest.

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Activity

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- **IB learner profile attribute:** Communicator
- **Approaches to learning:** Communication skills — Applying interpretive techniques to different forms of media
- **Time required to complete activity:** 60 minutes
- **Activity type:** Individual activity

As you have learned, the Amazon rainforest is one of the world's most diverse biomes and it is facing severe deforestation due to human activities.

Your task is to conduct a case study on the deforestation of the Amazon and propose conservation and management strategies using models in science. This case study will allow you to apply scientific principles, use various modelling techniques and explore solutions to address deforestation and its impacts on the Amazon rainforest.

Focus on the following key areas:

- Deforestation patterns and causes:
  - Use models to analyse historical deforestation patterns in the Amazon rainforest and identify major causes, such as agriculture, logging and infrastructure development.
  - Examine the impacts of deforestation on biodiversity, carbon sequestration and local communities.
  - Predict future deforestation trends based on existing data and develop models to understand the underlying factors driving deforestation.
- Ecosystem services:
  - Research the ecosystem services provided by the Amazon rainforest, such as climate regulation, water purification and habitat preservation.
- Analyse the environmental impacts of deforestation, including changes in carbon emissions, water cycles and loss of biodiversity.
  - Estimate the impacts on ecosystem services.
- Visualise the adverse effects of deforestation on ecosystem services.
  - Create an infographic showing the effects of deforestation on ecosystem services; include negative and positive feedback loops.

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While preparing the final infographics, you should include:

- deforestation patterns, causes, and impacts
- impacts on biodiversity, carbon sequestration and local communities
- predicting future deforestation trends
- ecosystem services.

Finally, comment on the effectiveness of using infographics as a medium for delivering information to the community.

5 section questions

Sustainability

D4.2.5: Role of keystone species in the stability of ecosystems D4.2.6: Assessing sustainability of resource harvesting

Learning outcomes

By the end of this section you should be able to:

- Explain the role of keystone species in the stability of ecosystems.
- Evaluate the sustainability of resource harvesting from natural ecosystems.

The role of keystone species

Some species in an ecosystem may have a disproportionately large impact on the community compared to their abundance or biomass. Their presence or absence deeply affect the stability of the ecosystem. These species are known as

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keystone species. A keystone species is an organism that helps define an entire ecosystem. Without its keystone species, the ecosystem would be dramatically different or cease to exist altogether.

Originally, keystone species were thought to be only top predators, such as lions, wolves or tigers, since they limited herbivore abundance and reduced the herbivory of plants. Modern approaches accept that any species can play the role of keystone. For example, bees are accepted as a global keystone species. Bees support the reproduction of 80% of the world's flowering plants. They are also the world's most important pollinator in natural ecosystems. They ensure the continued reproduction and survival not only of the plants they pollinate but also of the other organisms that depend on those plants for survival.

When the population of a keystone species declines or becomes imbalanced, it can trigger a cascade of ecological effects, as outlined below.

Trophic cascades

Keystone species often regulate the abundance of other species in their ecosystem. They can control populations of other species by predation, herbivory or other interactions. If the keystone species declines or is removed, it can disrupt the balance within the food web, leading to unchecked growth or decline in certain species. This disruption can have far-reaching effects, altering species interactions and potentially destabilising the entire ecosystem.

Sea otters (*Enhydra lutris*) prey on sea urchins and control their population size. Since sea urchins are grazers of kelp, by keeping sea urchin populations under control, sea otters prevent overgrazing and maintain the health and abundance of kelp forests. Kelp forests are highly efficient in capturing and storing carbon dioxide (CO_2) from the atmosphere. By protecting kelp forests, sea otters indirectly contribute to carbon sequestration, mitigating the impacts of climate change.

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When sea otters are absent, sea urchins increase and overgraze kelp. The decrease of kelp forests can impact the abundance and diversity of associated organisms. This can also affect the availability of food and shelter for other organisms that rely on kelp forests.

The ochre sea star (*Pisaster ochraceus*) is a keystone species in the rocky intertidal zone of the Pacific coast of North America. It preys on mussels and barnacles, which are major competitors for space on the rocks. The sea star's predation helps to keep the mussel and barnacle populations in check, which allows other species, such as seaweeds, to flourish. **Video 1** explains how loss of sea stars reshapes the entire ecosystem.

Video 1. The role of a keystone species in the ecosystem.

Habitat modification

Keystone species can also shape and modify the physical structure of their habitat. For example, beavers create dams that alter water flow, creating new habitats for other species. If the keystone species is lost, the habitat modifications they provide may also disappear, affecting the availability of resources and shelter for other organisms. This can have cascading effects on the community structure and functioning.

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American beavers (*Castor canadensis*) are a keystone species in many North American ecosystems. They build dams, which create wetlands that provide habitat for a variety of other species. Beavers also help to prevent erosion and flooding.

When beavers are removed from the ecosystem, the capacity for water storage in the ecosystem is reduced. This can lead to decreased water availability during dry periods and increased susceptibility to drought conditions. Also, the wetlands they form are important habitats for many aquatic animals. The removal of beavers can result in a loss of habitat, potentially leading to the decline or extinction of species.

Nutrient cycling and ecosystem processes

Keystone species often influence nutrient cycling and key ecosystem processes. For example, some marine keystone species, such as sea otters or seagrass, play crucial roles in carbon sequestration and nutrient recycling. If their populations decline, these important ecological processes may be disrupted, leading to imbalances in nutrient availability and biogeochemical cycles. This can impact the overall health and resilience of the ecosystem.

A well-known case study: Yellowstone and the wolves

Grey wolves (*Canis lupus*) are considered a keystone species in various ecosystems, including North American and European forests. They control the population of herbivores such as deer and elk, preventing overgrazing and promoting the growth of diverse plant species. Their presence also affects the behaviour of prey species, leading to changes in habitat use and movement patterns.

There were no legal protections for wildlife within the park when it was first created in
1872. Animals including the grey wolf were free to be exterminated by hunters and

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others in the park and grey wolves in particular were already targeted across the US as predators harmful to livestock. Sustainable grey wolf packs had been cleared from Yellowstone National Park by 1926.

Once the wolves were gone, elk (*Cervus canadensis*) populations began to rise. Over the next few years, conditions in Yellowstone National Park declined drastically. The elk were multiplying inside the park, and deciduous, woody species such as aspen and cottonwood suffered from overgrazing. Plant diversity decreased, and land erosion increased to an extent where administrators started to kill elks to control their population size. Elk population control methods continued for more than 30 years. Elk control prevented further degradation of the habitat, but didn't improve its overall condition.

As the elk population rose, the quality of the habitat decreased, affecting many other animals. Without wolves, coyote populations increased dramatically, which adversely impacted the pronghorn antelope (*Antilocapra americana*) population. However, it was the overly large elk populations that caused the most profound changes to the ecosystem of Yellowstone with the absence of wolves.

In January 1995, wildlife officials released 21 grey wolves to the park. Scientists have been researching and studying the impacts on the Yellowstone ecosystem since this reintroduction. As the wolf population in the park has grown, the elk population, their favoured prey, has declined. This decline in elk has resulted in changes in flora, most specifically willows, cottonwoods and aspens along the fringes of heavily timbered areas. Although their numbers were not high, the constant presence of wolves has pushed elk into decline. Until the wolves returned, Yellowstone National Park had one of the densest and most stable coyote populations in America due to a lack of human impact. The presence of wolves has also improved the park's beaver population.

Student view

Assessing sustainability of harvesting from the wild

Atlantic cod or simply cod (*Gadus morhua*), which lives in the colder waters and deeper sea regions throughout the North Atlantic, is a popular seafood in several countries. Cod has been an important economic commodity in international markets since the Vikings. In the 17th and 18th centuries in the New World, especially in Massachusetts and Newfoundland, cod became an economically important food.

With the support of developing technology, from the 1950s onwards fishers started to trawl a larger area, fish more in-depth and for a longer time. The historical data shows that for 60 years, the annual catch of cod was around 300 000 tons, however it reached to nearly 800 000 tons per year in the late 1960s (**Figure 1**).

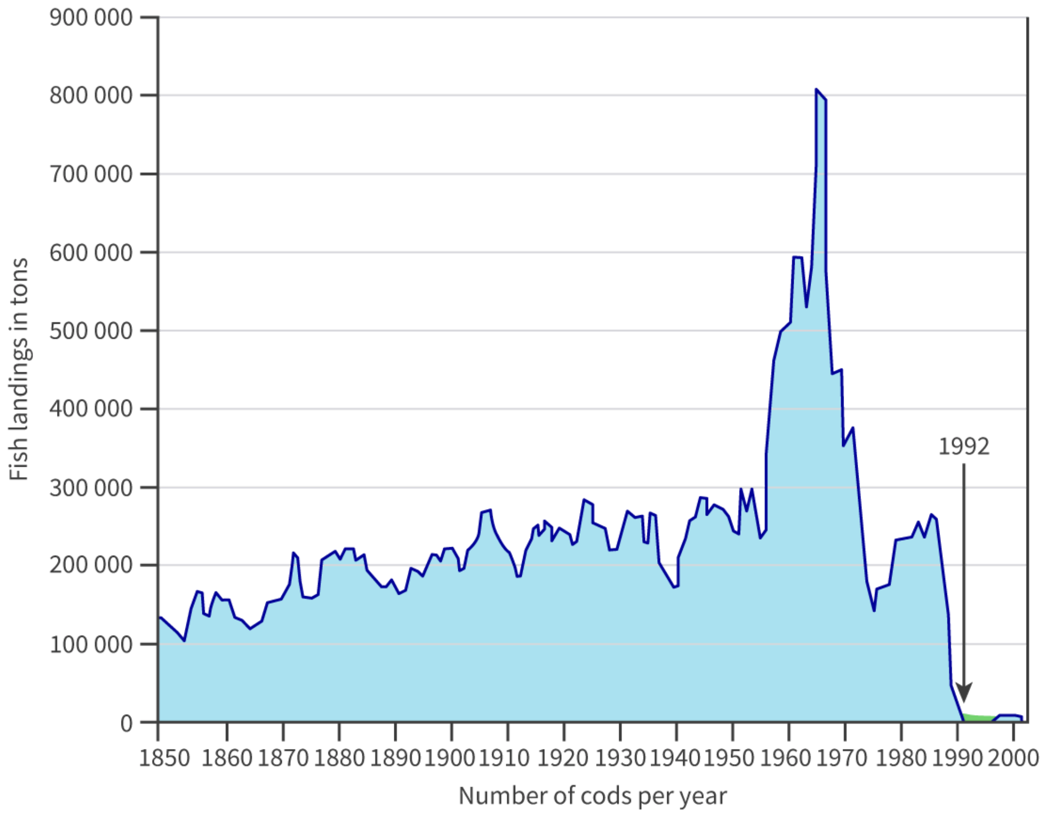

Figure 1. Cod caught per year from 1850 to 2000.

Data source: "Surexploitation morue surpêche" (https://commons.wikimedia.org/wiki/File:Surexploitation_morue_surp%C3%AAche.jpg) by Lamiot is licensed under CC BY-SA 1.0 (https://creativecommons.org/licenses/by-sa/1.0/deed.en)

More information for figure 1

The graph depicts the number of cods caught per year from 1850 to 2000. The X-axis represents the years, ranging from 1850 to 2000, while the Y-axis represents the fish landings in tons, ranging from 0 to 900,000 tons.

From 1850 to 1950, the number of cods caught remains relatively stable, fluctuating around 300,000 tons per year. Beginning in the 1950s, there is a noticeable increase in catch size, with a significant spike in the late 1960s where the catch reaches nearly 800,000 tons. Post this peak, the catch declines sharply in the 1970s, followed by several fluctuations and another decline leading up to 2000. By 1992, the catch rate had drastically reduced to near zero.

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How were the fishers sure that tripling the catch rate would still allow cod to survive in the wild?

The practice of harvesting resources from nature has been a fundamental part of human existence for centuries. From gathering wild berries to hunting wild animals, our ancestors relied on natural ecosystems to meet their basic needs. However, as human populations have grown and technological advancements have expanded our capabilities, the act of harvesting from the wild has become increasingly complex. In some cases, the rate of harvesting has gone beyond the natural renewable rate of the source, resulting in overexploitation.

To avoid overexploitation of renewable wild resources, harvesting should be done sustainably. The term ‘sustainability’ refers to the capacity of meeting the needs of the present generation without compromising the ability of future generations.

Sustainable harvesting considers the stability of ecosystems as its primary goal. Many resources in nature, such as forests or fish in the oceans, are renewable; they can replace the loss at a rate. But if the harvesting rate becomes higher than their renewing rate, due to decreased population size and diversity, ecosystems may

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become unstable with less resilience. There are limits to the amount of resources we can take from ecosystems without causing permanent damage to their balance and health. Assessing the sustainability of harvesting activities from ecosystems is crucial to ensure the long-term viability of renewable resources. The goal of harvesting sustainably is 'during each harvesting effort or in a particular time, removing the maximum number of individuals (or maximum biomass) that can be harvested indefinitely without decreasing the stability of the ecosystem'.

The teak tree (*Tectona grandis*), native to south and southeast Asia, is a highly valued timber tree known for its durability and aesthetic appeal (**Figure 2**). The demand for teak wood in the furniture industry has put significant pressure on teak forests in various regions of the world. But teak trees have a long regeneration period, and their natural regeneration can be slow and limited. Unsustainable harvesting practices, such as clear-cutting large areas of teak forests, have prevented the natural regeneration of teak trees, leading to the degradation of teak forests and a decline in their overall health and productivity.

Figure 2. Mature and young teak trees.

Credit: Ar razzaq, Getty Images

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There is no clear and exact scientific decision on how to measure whether wildlife harvest in a given system is sustainable. Yet several sustainability indicators have been used by researchers. The International Union for the Conservation of Nature (IUCN) has proposed four principles of wildlife conservation:

- A safety factor in terms of population size should be determined, since estimations are not perfect. An interest in harvesting a population should not allow the population to be depleted to some theoretical minimum size.
- Concern with the entire community of organisms and all the renewable resources, so that policies developed for one species are not wasteful of other resources.
- Maintenance of the ecosystem, minimising risk of irreversible change and long-term adverse effects.
- Continual monitoring, analysis and assessment. The application of science and the pursuit of knowledge about the wildlife of interest and its ecosystem should be maintained and the results made available to the public.

These new principles provide a starting point for an improved approach to wildlife harvesting. View **Interactive 1** to see the most commonly used indicators to assess the sustainability of harvesting from wild.

> **Population abundance/density**

> **Population age/sex structure**

> **Trends in distance**

> **Harvest composition**

> **Catch-per-unit-effort (CPUE)**

Interactive 1. Indicators to assess the sustainability of harvesting.

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Theory of Knowledge

For centuries, local fishers used technology that limited the volume of their catch and the area they fished, and let them target specific species and ages of fish.

By the 1960s, powerful trawlers were equipped with sonar that allowed crews to follow fish. The new technologies adversely affected the northern cod population by increasing both the area and the depth that was fished.

When the adverse effects of technology on life are considered, should there be ethical limits to the production of technological knowledge?

Try the activity below to analyse some data on the number of bison, wolves and elk in Yellowstone National Park over a 30-year period.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Comparing, contrasting and validating information
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

The grey wolf was present in Yellowstone when the park was established in 1872. Between 1914 and 1926, at least 136 wolves were killed in the park; by the 1940s, wolf packs were rarely reported. By the mid-1900s, wolves had been almost entirely eliminated from the 48 states. In the 1970s, national awareness of environmental issues and consequences led to the passage of many laws designed to correct the mistakes. In 1995*, 21 grey wolves from western Canada were relocated to Yellowstone.

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Table 2 shows the estimated number of individuals of three species from 1985 to 2015.

Table 2. Estimated number of bison, elk and wolves from 1985 t

	Number of individuals (average)		
Year	**Bison**	**Elk**	**Wo**
1985	647	15 387	0
1990	461	14 829	0
1995*	346	16 791	0
2000	634	11 743	44
2005	1464	8 333	106
2010	2321	6 418	144
2015	3957	5 216	203

1. Describe the trend of population sizes.
2. Outline and explain the effect of introduction of wolves into Yellowstone.

5 section questions

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Agriculture and eutrophication

D4.2.7: Factors affecting the sustainability of agriculture D4.2.8: Eutrophication of aquatic and marine ecosystems

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Learning outcomes

By the end of this section you should be able to:

- Outline the factors affecting the sustainability of agriculture.
- Explain eutrophication and its effects on ecosystems.

During the early 20th century, the Great Plains in North America experienced a period of intense agricultural expansion. Large-scale mechanised farming techniques were introduced, and vast areas of native grasslands were converted into farmland. The predominant practice was monoculture farming, where farmers planted extensive areas with a single crop, such as wheat, and relied heavily on tilling the soil.

The problems arose when drought conditions hit the region in the 1930s. The combination of prolonged drought, poor land management practices and the absence of effective soil conservation methods led to severe soil erosion. The topsoil, which is crucial for supporting plant growth and retaining moisture, was easily lifted by strong winds, creating massive dust storms. These dust storms devastated agricultural lands, causing crop failures, loss of livelihoods and mass migration of affected farmers.

The unsustainable agricultural practices played a significant role in exacerbating the Dust Bowl. The removal of native grasses, which had deep root systems that held the soil in place, left the land exposed to erosion. Excessive ploughing and lack of crop rotation further depleted the soil's nutrients and structure, making it susceptible to wind erosion.

How did agricultural practices cause an ecological disaster?

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Sustainability of agriculture

Agriculture is the practice of cultivating plants and livestock. Around 10 000 years ago, humans began to domesticate animals and plants. They also began to cultivate land. This allowed humans to produce more food than they could before. It led to the development of new technologies, the growth of cities and the rise of civilizations.

Sustainability in agriculture refers to the practice of cultivating and producing agricultural products in a manner that preserves and enhances the long-term environmental, social and economic well-being of farming systems. It involves the adoption of practices that minimise negative impacts on the environment, promote efficient resource use, protect biodiversity and support the livelihoods of farmers and communities.

Agriculture can become unsustainable when practices and systems are not properly managed.

Soil erosion

Excessive tillage and monocropping can lead to soil degradation and erosion. Soil erosion is a process that involves the detachment, movement and transportation of soil particles from one location to another. While it is a natural phenomenon, human activities significantly accelerate soil erosion rates, leading to serious environmental and agricultural consequences. The removal of vegetation, such as forests and grasslands, reduces the protective cover of the soil. Without plants to hold the soil in place, erosion rates can increase significantly. Excessive grazing by livestock and poor agricultural practices such as improper ploughing, leaving fields bare between planting seasons and planting on steep slopes can damage plant cover and expose the soil surface, making it susceptible to erosion by wind and water.

Student view

Agrochemicals

Agrochemicals, including synthetic fertilisers and pesticides, can have significant effects on soil degradation and erosion. Some fertilisers can contribute to soil acidification, reducing soil pH levels. Acidic soils are less productive and can become more susceptible to erosion.

Agrochemicals, especially synthetic fertilisers, may lead to a decline in soil organic matter. This decreases the soil's ability to hold water and nutrients, making it more susceptible to erosion.

Water use

Inefficient water use and improper management of agricultural runoff can lead to water scarcity and pollution. Over-extraction of groundwater can deplete aquifers.

If irrigation is not managed properly, excessive water application can lead to the leaching of nutrients beyond the crop root zone. Water-soluble nutrients can be carried downwards with the excess water.

Excessive use of fertilisers and pesticides can contaminate water bodies, harming aquatic ecosystems and human health. The use of pesticides can also harm beneficial insects, birds and other wildlife, disrupting ecological balance.

Biodiversity

Intensive agricultural practices often prioritise high-yielding crop varieties and livestock breeds, leading to the loss of biodiversity.

Monocropping and genetic homogeneity make agricultural systems more vulnerable to pests, diseases and climate change impacts.

Deforestation and land conversion, particularly in regions with valuable forests and natural ecosystems, contributes to habitat loss, biodiversity decline and disruption of ecosystem services.

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Carbon footprint

During agricultural activities such as tilling, fertilisation, livestock farming, transportation and food processing, greenhouse gases are produced and emitted. These emissions primarily consist of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The total greenhouse gas emissions produced throughout the various processes is known as the carbon footprint of agriculture.

Agriculture is both a contributor to and a victim of climate change. The carbon footprint of agriculture contributes to the increasing concentrations of greenhouse gases in the atmosphere. These gases trap heat, leading to global warming and climate change.

As temperatures rise and weather patterns become more unpredictable, agriculture faces challenges such as altered growing seasons, increased frequency of extreme weather events and shifting patterns of pests and diseases. These impacts can affect crop yields, livestock health and overall agricultural productivity.

Eutrophication

Eutrophication is the process by which water bodies become enriched with excessive nutrients, particularly nitrogen and phosphorus, leading to an overgrowth of algae and other aquatic plants. This excessive growth can disrupt the balance of the ecosystem and have detrimental effects on water quality, aquatic life and overall ecosystem health. The process of eutrophication occurs in several steps, outlined in **Interactive 1**.

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> Nutrient enrichment of water bodies

> Rapid reproduction of algae and plants

> Accumulation of organic matter

> Increased decomposition and decrease of oxygen

> Collapse of the aquatic ecosystem

Interactive 1. The Process of Eutrophication.

Watch **Video 1** to see an explanation of eutrophication.

Video 1. Eutrophication explained.

Try the activity below to design a plan to prevent eutrophication.

Activity

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- **IB learner profile attribute:** Caring

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- **Approaches to learning:** Communication skills — Using terminology, symbols and communication conventions consistently and correctly
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

Design your own eutrophication prevention plan

Choose an ecosystem, such as a local lake, river or coastal area, where eutrophication is a known or possible issue. You can use online maps for your search.

Identify the key stakeholders who are involved or affected by the eutrophication issue in your chosen ecosystem. This could include local communities, environmental organisations and government agencies.

Using your research and understanding of eutrophication, design a comprehensive plan to prevent or mitigate eutrophication in the selected ecosystem. Your plan should include the following components.

1. Identifying the primary sources of nutrient pollution:
   Identify the main sources that contribute to eutrophication in the ecosystem.
2. Implementing best management practices:
   Propose specific measures and best management practices that can effectively reduce nutrient inputs into the ecosystem. Consider strategies such as nutrient management, erosion control, wastewater treatment and sustainable agriculture practices.
3. Promoting public awareness and education:
   Develop strategies to raise awareness among the local community and stakeholders about the importance of preventing eutrophication. Consider creative ways to educate people about the issue and encourage them to adopt sustainable behaviours.
4. Monitoring and evaluation:
   Outline a plan for monitoring and evaluating the effectiveness of your prevention measures. Identify key indicators and data collection methods that will help assess the success of your plan.

Justify your choices based on scientific evidence, ecological principles and the specific characteristics of your chosen ecosystem. Discuss the potential impact of your plan on the ecosystem's health and sustainability.

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5 section questions

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Pollution and restoration

D4.2.9: Biomagnification of pollutants D4.2.10: Effects of microplastic and macroplastic pollution
D4.2.11: Restoration of natural processes in ecosystems

Learning outcomes

By the end of this section you should be able to:

- Outline biomagnification of pollutants.
- Describe the effects of microplastic and macroplastic pollution of the oceans.
- Describe the strategies for restoration of natural processes in ecosystems by rewilding.

DDT (dichloro-diphenyl-trichloroethane) was a modern synthetic insecticide produced and used in the 1940s. It was initially used against the causing organisms of malaria, typhus and other insect-borne human diseases. It was also effective for insect control in agriculture. DDT's quick success as a pesticide led to broad use of this chemical in many countries.

DDT was thought to be harmless, or the harmful effects ignored. However, data on DDT’s negative effects on insects, birds and fish started accumulating. The publication in 1962 of Rachel Carson's *Silent Spring* stimulated widespread public concern over the dangers of improper pesticide use. The stability of DDT led to its accumulation in the tissues of organisms.

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How did the widespread use of DDT as a pesticide for insect control impact the environment and non-target organisms?

Video 1 shows a TV advertisement promoting the use of DDT.

Video 1. A TV campaign: DDT so safe you can eat.

Biomagnification of pollutants

When pollutants enter an ecosystem, organisms can receive them through absorption, ingestion or contact. These chemicals can be persistent and resist breakdown in the environment, leading to their accumulation within the tissues of organisms. This is called bioaccumulation, the gradual buildup of chemical substances in the tissues of organisms over time (**Figure 1**).

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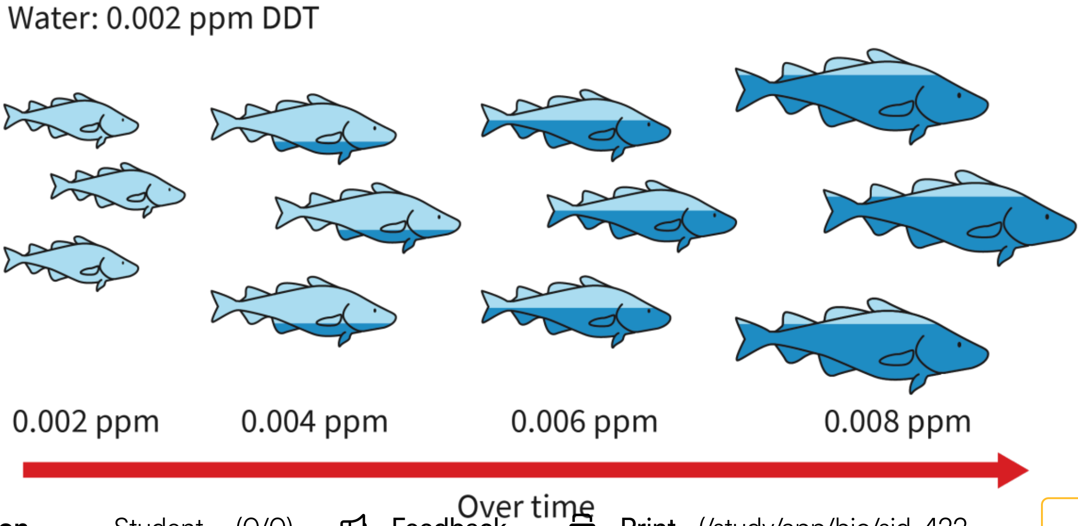

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Figure 1. The persistent chemicals accumulate in the body of organisms.

More information for figure 1

The image depicts a sequence showing the bioaccumulation of DDT in fish over time. It consists of four groupings of fish, each increasing in size and number to represent the increasing concentration of DDT. The concentrations are marked as 0.002 ppm, 0.004 ppm, 0.006 ppm, and 0.008 ppm, shown beneath the respective groups of fish. The fish grow larger and more numerous as the DDT concentration increases. There is a red arrow along the bottom labeled "Over time" to indicate temporal progression from left to right. The text "Water: 0.002 ppm DDT" is situated above the first group, indicating the initial concentration in the water.

[Generated by AI]

While pollutants may only accumulate in low levels in individual organisms, the process of bioaccumulation becomes significant when organisms are consumed by other organisms in the food web. The consumption of contaminated organisms by predators results in the transfer and accumulation of the pollutants in higher trophic levels. With each successive level of the food chain, the concentration of the pollutant can become magnified in the long term, which is called biomagnification (**Figure 2**).

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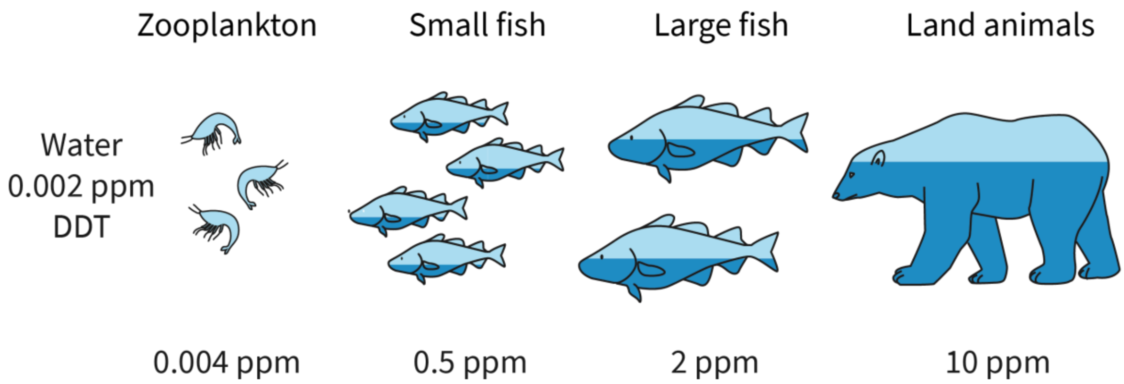

Figure 2. The persistent chemicals accumulate and magnify in the successive levels of the food chain.

More information for figure 2

Mercury is a heavy metal that exists naturally in the environment. However, human activities, such as industrial processes and burning fossil fuels, have significantly increased its release into ecosystems. Since organisms are not able to effectively metabolise or excrete mercury, it can bind to proteins and become incorporated into tissues, where it accumulates over time. Because organisms at higher trophic levels consume a large number of lower trophic level organisms, they accumulate the mercury from each prey item. This leads to a magnification of mercury concentration as it moves up the food chain.

Effects of microplastic and macroplastic pollution of the oceans

Plastic, a synthetic product made from a variety of organic compounds, is a persistent (non-biodegradable), strong and durable material. Due to its persistent nature, it can accumulate in soil and water bodies, where it can harm wildlife and pollute the environment.

Microplastics are small plastic particles or fragments that measure less than 5 mm in size. They can either be intentionally manufactured as small plastic beads used in personal care products or can result from the breakdown of larger plastic items over time.

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Macroplastics refer to larger pieces of plastic debris that are typically visible to the naked eye. These can include items such as plastic bottles, bags, fishing nets and other discarded consumer products. Unlike microplastics, macroplastics have not broken down into smaller fragments.

Plastics reach the oceans through various pathways, facilitated by human activities and natural processes such as improper waste disposal, direct littering and dumping, runoff, spills and marine debris from fishing and shipping.

The Great Pacific Garbage Patch has been a major figure of plastic pollution in the oceans. It is a high concentration of marine debris, primarily composed of plastic. It is not a solid mass or an island of trash, as commonly depicted, but rather a collection of floating microplastics, macroplastics and other waste materials dispersed over a large area.

Video 2 gives some statistics about the Great Pacific Garbage Patch.

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Video 2. How big the Great Pacific Garbage Patch really is.

Plastic pollution in the oceans has profound and wide-ranging effects on marine ecosystems, wildlife and even human health.

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Disruption of marine food webs

Plastic pollution can disrupt the marine food webs. Small marine organisms filter-feed on microplastics, and can then be consumed by larger organisms. This transfer of plastics through the food chain can have cascading effects, potentially affecting the reproductive success, growth and survival of the species. The bioaccumulation of toxins on plastic surfaces can also biomagnify as they move up the food chain, posing risks to higher-level predators, including humans.

Chemical pollution

Plastics are not inert substances but can absorb and release harmful chemicals. When marine organisms consume plastics, they can be exposed to these toxic chemicals, which can have detrimental effects on their health and reproductive systems. Furthermore, microplastics can act as carriers, transporting pollutants to new locations and potentially contaminating remote areas.

Wildlife entanglement and ingestion

Marine animals, including sea turtles, seabirds, dolphins and whales, often eat plastic debris for food or become entangled in it. Plastic items such as fishing nets, ropes and six-pack rings can entangle animals, causing injuries, amputations or even death. Ingestion of plastic is another significant issue, as animals may consume plastic particles, mistaking them for prey. This can lead to internal injuries, blockages in the digestive system, malnutrition and starvation.

Habitat degradation

Plastic debris can degrade marine habitats, including coral reefs, seagrass beds and estuaries. As plastic accumulates, it can damage sensitive habitats, hindering their ability to provide food, shelter and breeding grounds for marine organisms. The presence of plastic can also alter the light and nutrient dynamics in the water, impacting the overall health and productivity of ecosystems.

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Aspect: Global impact of science

Scientists can have a significant impact on public perception if they provide clear and understandable information. The power of scientific communication lies in its ability to deliver complex scientific concepts to the public by translating it to understandable language, making it relevant to the general public.

The case of plastic pollution in the ocean is a good example of how scientists can influence public opinion and behaviour. In recent years, there has been a growing body of research that has shown the devastating effects of plastic pollution on marine life. The research has been widely covered in the popular media, which has helped to raise awareness of the problem and change public perception. As a result, there has been a growing movement to reduce plastic pollution, with governments and businesses taking steps to address the issue.

Restoration of natural processes in ecosystems by rewilding

Rewilding is an approach to conservation and ecosystem restoration that involves reintroducing and restoring natural processes and biodiversity to ecosystems that have been degraded or altered by human activities.

- **Species reintroduction:** This may involve bringing back keystone species, such as apex predators or large herbivores, which play critical roles in shaping ecosystems.
- **Habitat restoration:** Actions such as reforesting areas, removing invasive species, restoring wetlands and creating wildlife corridors to reconnect fragmented habitats are some rewilding strategies. Habitat restoration aims to provide suitable conditions for native species to thrive and facilitate natural processes within ecosystems.
- **Rewilding urban areas:** Urban rewilding focuses on reintroducing nature into cities and urban environments. It involves creating green spaces, rooftop gardens and wildlife-friendly habitats within urban areas. Urban rewilding

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initiatives aim to increase biodiversity, improve air and water quality, and provide opportunities for people to connect with nature in urban settings.

- **Rewilding rivers and waterways:** Restoring natural processes in rivers and waterways is another rewilding strategy. This may involve removing barriers such as dams or weirs, restoring meanders and allowing rivers to flow more naturally.
- **Ecological management and natural processes:** Rewilding also emphasises allowing natural ecological processes to occur without excessive human intervention. This includes minimising human impacts, such as reducing intensive farming practices, reducing pesticide use and allowing natural successional processes to take place.

Hinewai Reserve, located on the Banks Peninsula in New Zealand, is an example of ecological restoration (**Figure 3**). The story of Hinewai Reserve begins in the 1980s when Maurice White Native Forest Trust bought the degraded and deforested landscape. At the time, the Banks Peninsula was primarily dominated by pastureland, with only fragmented patches of native vegetation remaining.

Source: "Hinewai Reserve 7194" (https://commons.wikimedia.org/wiki/File:Hinewai_Reserve_7194.jpg) by Schwede66 is

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Figure 3. The Hinewai nature reserve.

The restoration efforts at Hinewai focused on allowing nature to take its course and facilitating natural regeneration processes. Rather than relying on large-scale planting or intensive management, the conservation team implemented a hands-off approach. They removed grazing livestock, halted the use of herbicides and allowed the land to naturally recover.

Over the years, Hinewai Reserve has undergone a remarkable transformation. Native vegetation began to reclaim the land, with a wide array of indigenous plant species regenerating and thriving. This, in turn, attracted various native wildlife species, including birds, insects and reptiles, which returned to the rejuvenated ecosystem.

Student view

Try the activity below to learn more about your daily use of plastics.

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Activity

- **IB learner profile attribute:** Caring
- **Approaches to learning:** Communication skills — Using terminology, symbols and communication conventions consistently and correctly
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

Watch **Video 3** on the history of plastics.

Video 3. A brief history of plastics.

Answer the following questions:

- How has plastic benefited society?
- How has plastic harmed the world?

Make a list of every plastic item that you use in the course of one day using this list (https://itsinourhands.com/en/challenge/hidden-plastic-in-everyday-life).

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Read this article: [Microplastics (https://marinedebris.noaa.gov/what-marine-debris/microplastics)](https://marinedebris.noaa.gov/what-marine-debris/microplastics)

Answer the following questions:

- How much microplastic is estimated to float on the ocean surface?
- How much has sunk below the surface of the ocean, according to new models?
- How much marine snow do the world's oceans produce in a single year?
- How many tons of microplastic would that snow transport to the sea floor each year?

5 section questions

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Ecological succession (HL)

D4.2.12: Ecological succession and its causes (HL) D4.2.13: Changes occurring during primary succession (HL)
D4.2.14: Cyclical succession in ecosystems (HL) D4.2.15: Climax communities and arrested succession (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Define ecological succession and outline the causes.
- Describe the changes during primary succession.
- Describe cyclical succession.
- Distinguish between climax communities and arrested succession.

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Ecological succession is a natural progression of changes in species composition and community structure over time. Through ecological succession, ecosystems undergo a series of transformations, shifting from bare and disturbed environments to thriving and diverse habitats. This phenomenon can be observed in different settings, from volcanic islands to abandoned agricultural lands.

One notable example of ecological succession occurred after the eruption of Mount St. Helens, an active volcano in Washington, United States, in 1980. The volcanic eruption devastated a vast area, leaving behind a barren landscape of ash and debris. In the years that followed, nature gradually began its remarkable recovery. Pioneer species such as fireweed and lupine took root in the nutrient-rich volcanic soil, paving the way for the establishment of shrubs and fast-growing trees. As time passed, the ecosystem underwent further transformations as coniferous forests reclaimed the land.

As the composition of species and interactions within ecosystems undergo transformation, how do they maintain their functionality and ecological integrity?

Ecological succession

Ecological succession occurs in response to various causes, including natural disturbances, human activities and changes in environmental conditions.

Natural disturbances

Natural disturbances such as wildfires, volcanic eruptions, hurricanes or floods disrupt the existing vegetation and community composition, which creates opportunities for new communities to colonise the area. For example, after a forest fire, pioneer species that are adapted to colonising open, sunlit areas will be the first to establish themselves (**Figure 1**). As time progresses, other species better suited to the new environmental conditions will replace the pioneers, leading to a gradual change in the community composition.

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Figure 1. Seedlings growing after a forest fire.

Credit: Krit of Studio OMG, Getty Images (https://www.gettyimages.co.uk/detail/photo/seedling-growing-from-the-ash-after-wildfire-royalty-free-image/1357074936?phrase=wildfire+seedling&adppopup=true)

Human activities

Human activities can also trigger succession. Deforestation, agriculture, urbanisation and mining are examples of activities that can disturb natural ecosystems and initiate a sequence of changes in species composition. When a forest is cleared for agriculture, for instance, the absence of trees allows sunlight to reach the forest floor, facilitating the growth of grasses and other herbaceous plants. Over time, shrubs and eventually trees may colonise the area, leading to a different community structure compared to the original forest.

Changes in environmental conditions

Environmental changes, both natural and human-induced, can also drive succession. These changes may include shifts in temperature, precipitation patterns or soil fertility, or the introduction of new species. As the environment undergoes alterations, different species may become

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better adapted to the new conditions and outcompete or replace the previous inhabitants. This gradual shift in species composition over time characterises the process of succession.

Aspect: Models

Since succession — without any disturbance — takes a long time, in most cases scientists use simple models to observe progress in controlled environments.

In science, the term 'model' can mean several different things, such as an idea about how something works, a physical model of a system that can be used for testing or demonstrative purposes or a mathematical model (a set of equations that indirectly represents a real system). These equations are based on relevant information about the system and on sets of hypotheses about how the system works.

The use of a model is supported when the model generates expectations that match the behaviour of its real-world counterpart.

Modelling often involves idealising the system in some way, leaving some aspects of the real system out of the model to isolate particular factors or to make the model easier to work with computationally.

Changes occurring during primary succession

Primary succession is the process of ecological change that occurs in an area that has never been colonised by living organisms or has been completely devoid of life due to extreme conditions, such as newly formed volcanic rock or a retreating glacier.

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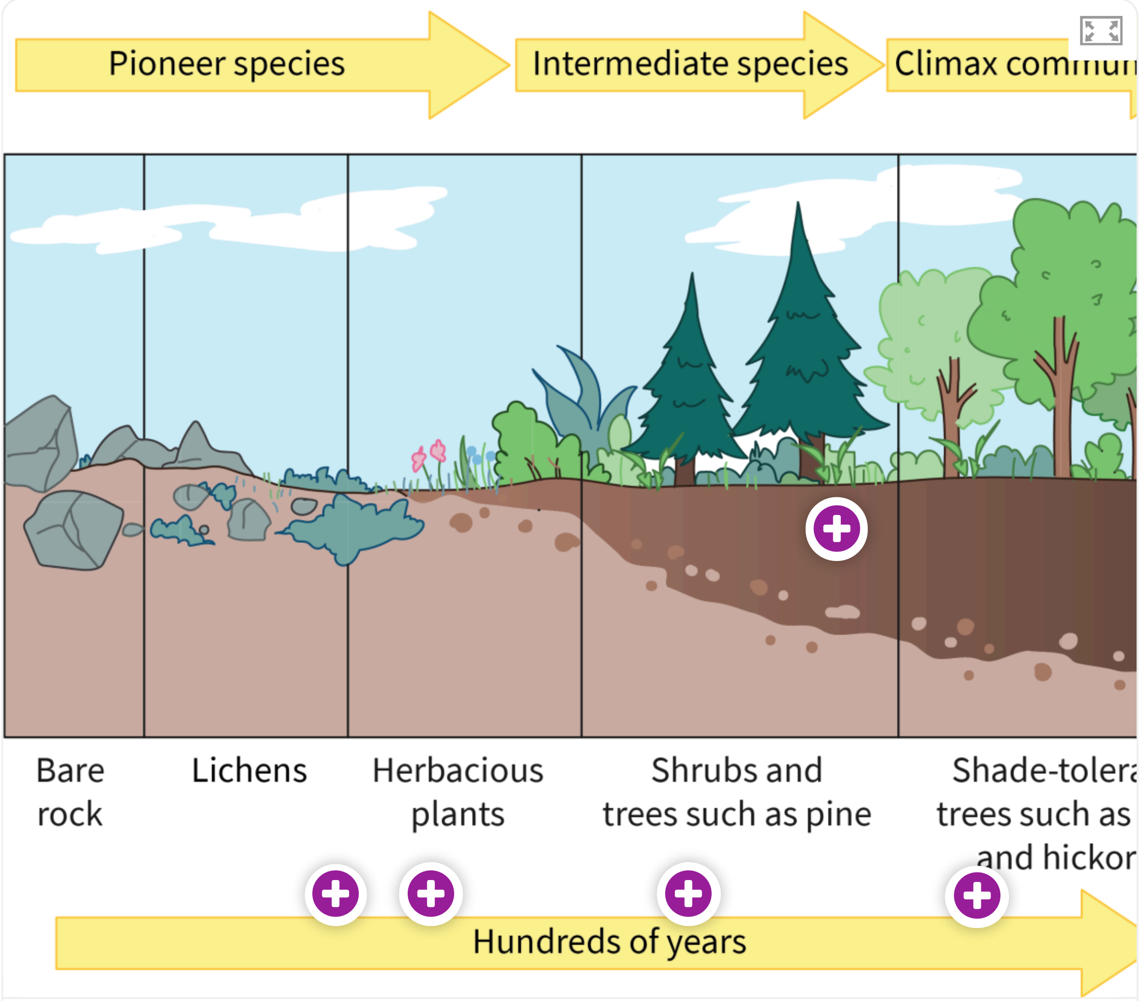
Interactive 1 outlines the changes that take place during primary succession.



Interactive 1. The Stages of Primary Succession.

More information for interactive 1

An interactive illustration outlines the stages of primary succession, the gradual development of an ecosystem in a previously uninhabited environment. The illustration is divided into five vertical sections, representing the stages, which are labeled bare rock, lichens, herbaceous plants, shrubs, and trees such as pine, and shade-tolerant trees such as oak and hickory, progressing over hundreds of years.

At the top, a process arrow diagram depicts the ecological progression through pioneer species, intermediate species, and climax community.

Hotspots are included for certain stages to provide additional information.

Hotspot located between the lichens and herbaceous plants stages:

Pioneer species colonization:
The first organisms to colonize a bare landscape are known as pioneer species. These are typically small, hardy organisms such as lichens and mosses. They can survive in harsh conditions with limited nutrients and help break down rock or organic matter to create a rudimentary soil layer.

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Pioneer species facilitate the weathering of rocks and the accumulation of organic matter through their growth and decomposition. This process, known as soil formation or pedogenesis, gradually develops a thin layer of soil that can support the growth of more advanced plant species.

Hotspot located on the herbaceous plant stage:

Arrival of herbaceous plants: As soil formation progresses, herbaceous plants, including grasses, wildflowers, and ferns, begin to colonize the area. These plants have deeper root systems that help stabilize the soil and enhance nutrient availability. They also provide habitats for small animals.

Hotspot located on the shrubs and trees stage:

Shrubs and small trees:
With the establishment of herbaceous plants, the environment becomes more favorable for shrubs and small trees. These species have deeper root systems and can compete for light and resources. They further enrich the soil through their leaf litter, promote the accumulation of organic matter, and provide shelter and food for a broader range of organisms.

Hotspot located between the intermediate species and climax community:

Establishment of forest canopy:

Over time, the small trees in the ecosystem grow taller and form a dense canopy. The forest canopy creates a shaded environment that restricts the growth of understory plants and creates distinct microhabitats. As the canopy develops, it provides shelter for a variety of organisms, increases vertical stratification in the ecosystem, and influences the availability of light and moisture.

Hotspot located on the shade-tolerant tree stage:

Successional climax:
Eventually, the ecosystem reaches a state of relative stability known as the successional climax. This stage is characterized by a mature and diverse community of plants and animals that are well-adapted to the prevailing environmental conditions.

This interactivity helps users understand the sequential stages of primary succession, from bare rock to a stable climax community and demonstrates how complex communities develop from barren beginnings, driven by species interactions and environmental changes.

The process of primary succession can take hundreds or even thousands of years to reach the successional climax, depending on the specific environmental conditions and the availability of suitable sources for colonisation. It is a dynamic and gradual process.

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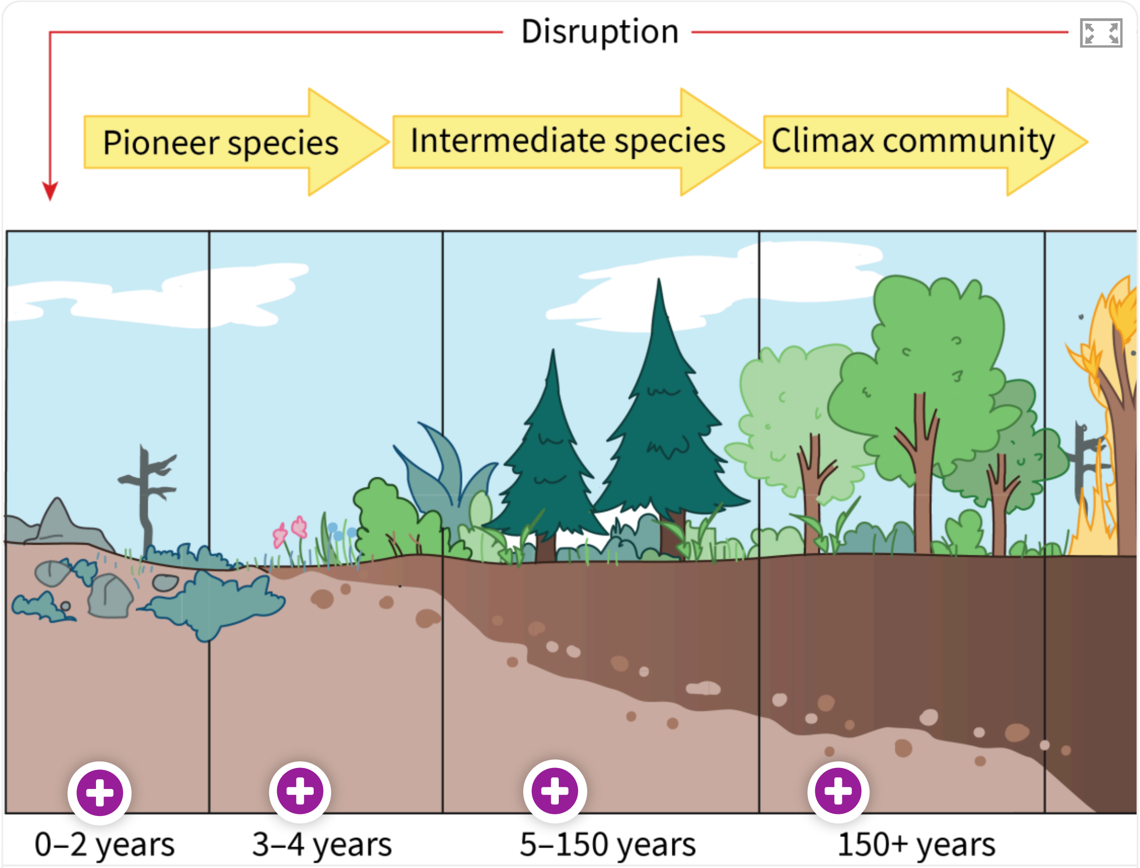
Secondary succession in ecosystems

Secondary succession is the process of ecological change that occurs in an area that has been previously colonised by living organisms but has experienced a disturbance that disrupts the existing community and returns it to any previous stage of the development.

Unlike primary succession, which starts from a barren landscape, secondary succession begins with a pre-existing soil base and remnant species.

The stages of secondary succession are summarised in **Interactive 2.**



Interactive 2. The Stages of Secondary Succession.

More information for interactive 2

An interactive image summarises the stages of secondary succession, the process by which an ecosystem recovers after a disturbance that removes vegetation but leaves soil intact. A red arrow labeled Disruption denotes the point at which a disturbance occurs, marking a return to the starting point of the succession process.

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The image is divided into five parts. Three yellow arrows at the top are labeled Pioneer species, Intermediate species, and Climax community. Timeframes labeled 0-2 years, 3-4 years, 5-150 years, and 150+ years are given at the bottom of the divisions. Hotspots provide additional information at each stage.

Disruption is the starting point. Soil remains, containing seeds, roots, and organic matter. This sets the stage for recolonization.

At 0-2 years, pioneer species begin to colonize. The hotspot reads, Pioneer species establishment: After a disturbance, such as a forest fire, logging, or agriculture, pioneer species quickly colonise the area. These species are typically fast growing and have high dispersal abilities, allowing them to quickly occupy the available space.

At 3-4 years, intermediate species start colonization and the hotspot reads, Species diversity recovery: As the pioneer species establish themselves, other plant species that were present before the disturbance or are dispersed from neighboring areas start to colonize the site. Over time, the diversity of plant species increases, leading to a more complex and diverse community.

Young forest creates a canopy and supports diverse wildlife around 5-150 years. The hotspot reads, Community development: As the community develops, different plant species interact and compete for resources. This competition leads to changes in species composition, with some species becoming dominant and others becoming less abundant or locally extinct. The community structure becomes more stable and resembles a mature ecosystem.

Climax community develops at around 150+ years, and the hotspot reads, Successional climax: Similar to primary succession, secondary succession reaches a successional climax, where the community becomes relatively stable and exhibits a balance between species composition and environmental conditions. The climax community depends on the specific ecosystem, such as a deciduous forest, grassland or shrubland.

This interactive demonstrates that recovery occurs over decades to centuries but faster than primary succession. Secondary succession is nature’s way of healing disturbed ecosystems, driven by residual soil life and gradual species replacement.

Cyclic succession

Some ecosystems undergo a cyclic ecological succession where the community composition changes repeatedly. At every stage the seral community displays its own characteristic plant and animal population composition. These stages occur in a predictable sequence and eventually

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turn back to the initial or similar starting point. The process involves a continuous cycle of change and regeneration, often driven by natural events.

Cyclic succession can be seasonal or can occur when certain conditions cause organisms to replace each other.

One example of cyclic succession occurs in coastal chaparral ecosystems in California. These ecosystems are characterised by dense stands of shrubs and small trees that are adapted to periodic fires. After a fire, the first plants to colonise the burned area are annual grasses. These plants quickly grow and produce seeds, which are then dispersed by the wind. The seeds germinate in the following season, and the area is soon covered in a growth of grasses.

Over time, the grasses are replaced by shrubs and small trees. These plants are more fire-resistant than the grasses, and they can survive even if the area is burned again. However, if the area is burned too frequently, the shrubs and trees will eventually be killed. In this case, the succession will start over again with the annual grasses.

Climax communities and arrested succession

A climax community refers to a stable and mature ecological community that remains relatively unchanged over an extended period of time. It represents the final stage of ecological succession in a particular ecosystem and is characterised by a balanced interaction between the environmental conditions and the community composition. Climax communities are often associated with the prevailing climate and soil conditions of a region.

Arrested succession refers to a disruption or interruption in the normal progression of ecological succession. It occurs when the development of a community is halted or slowed down due to external factors. These factors can include recurrent disturbances, changes in environmental conditions or the presence of persistent stressors.

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Arrested succession can result in the establishment of a community that remains at an early stage of succession, preventing it from reaching a climax community. For example, frequent fires in grasslands can prevent the growth of woody plants.

Arrested succession can also occur when the environmental conditions become unfavourable for the growth and survival of certain species. This can be due to factors such as soil degradation, pollution or invasive species. These disturbances disrupt the natural succession process and can result in the persistence of a less diverse or less resilient community.

In grassland ecosystems, grazing by farm livestock can significantly impact ecological succession. In a typical grassland, natural ecological succession progresses from a pioneer stage with herbaceous plants to a climax stage dominated by perennial grasses and other vegetation. Grazing by native herbivores, such as wild ungulates, plays a role in shaping the vegetation composition and maintaining a diverse grassland ecosystem.

However, when farm livestock, such as cattle or sheep, graze excessively in the grasslands, they can prevent the natural progression of succession (**Figure 2**). Overgrazing removes the vegetation cover and reduces the number of plant species present, leading to a shift in the plant community composition. The selective feeding habits of livestock may also favour the growth of certain plant species, inhibiting the growth of others.

As a result, the grassland may become arrested in an early successional stage, dominated by a limited number of grass species and forbs. This arrested succession can lead to a decrease in overall biodiversity and negatively impact the ecosystem's resilience to further disturbances. The reduced plant cover can also contribute to soil erosion and the degradation of the grassland ecosystem.

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Figure 2. Livestock farming causes overgrazing and desertification.

Credit: Martin Harvey, Getty Images

Wetlands are ecologically important ecosystems that undergo primary succession when they are formed. Over time, wetlands progress from open water bodies to emergent vegetation, followed by shrubs and, eventually, mature forests in the case of peatland wetlands. Wetlands are vital for water purification and flood control, and provide habitats for various plant and animal species.

Human activities, such as drainage for agriculture, urban development or resource extraction, can disrupt the natural succession of wetlands. When wetlands are drained, the hydrological conditions change, and water levels decrease. This causes alterations in the plant community structure and prevents the wetland from reaching its climax community.

In some cases, the drainage can lead to the complete loss of the wetland and its conversion into dry land, severely impacting the unique habitat and biodiversity that wetlands support (**Figure 3**). The arrested succession of wetlands due to drainage can result in the loss of valuable ecosystem services, such as flood regulation and habitat provision for wetland-dependent species.

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Figure 3. A dried-up bed of a marsh.

Credit: John Wreford, Getty Images

Try the activity below to analyse a case study of secondary succession.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

In 1986, an explosion at the Chernobyl nuclear power station in the Soviet Union cleared everything around it. But Chernobyl's radioactive zone isn't entirely lacking in life. Vegetation has covered the soil and even top carnivores have returned to the forests surrounding the old nuclear plant in northern Ukraine.

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This article – Wildlife and Chernobyl: The scientific evidence for minimal impacts (https://thebulletin.org/2011/04/wildlife-and-chernobyl-the-scientific-evidence-for-minimal-impacts/) — summarises the secondary succession process around the disaster zone. Read the article and answer the following questions:

- Which trees were able to dominate the forest after the disaster?
- How do the old and the new ecosystems differ in community composition?
- One report says that the number of top carnivores is higher than the number before the disaster. Explain the difference in population numbers.

5 section questions

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Summary and key terms

- Stability in an ecosystem refers to the ability of the system to maintain its structure and function over time, despite changes or disturbances.
- Many ecosystems, including mature tropical rainforests such as Amazon, Congo and Southeast Asian, have shown continuity over long time periods due to their stable nature.
- An ecosystem requires both resistance and resilience to maintain its stability over time. Resistance is the ability of an ecosystem to remain stable in the face of disturbances, while resilience is the ability to recover after a disturbance.
- The diversity of the producers is a major factor that controls the supply of energy to food webs. An ecosystem with a higher diversity of producers will likely be more resistant to the change of biotic and abiotic factors.

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- Depletion of nutrients can disrupt the functioning and stability of ecosystems. Recycling nutrients allows for the redistribution and regulation of nutrients.
- Genetically diverse ecosystems have greater capacity to absorb and recover from disturbances due to the presence of species with various strategies, tolerances and responses to changing conditions.
- Physical factors such as climate, topography and water availability can greatly affect the stability of an ecosystem.
- The critical threshold of a change that results in a significant and often irreversible change in an ecosystem's structure, function, or composition is called a tipping point.
- Deforestation in the Amazon is one of the biggest ecological crises of our time, and many believe that the threshold for natural recovery is past.
- Scientists aim to simplify complex systems and phenomena by using models so that they can better understand, explain and predict the different aspects. Models are simpler representations of real world phenomena.
- Some species in an ecosystem can have a disproportionately large impact on the community, and their presence can help maintain stability. These species are known as keystone species and they play important roles in regulating populations.
- Sustainability refers to the capacity of meeting the needs of the present generation without compromising the ability of future generations.
- Sustainability in agriculture refers to the practice of cultivating and producing agricultural products in a way that preserves and enhances the long-term environmental, social and economic well-being of farming systems. It involves the adoption of practices that minimise negative impacts on the environment, promote efficient resource use, protect biodiversity and support the livelihoods of farmers and communities.
- Eutrophication is the process by which water bodies become enriched with excessive nutrients, particularly nitrogen and phosphorus, leading to an overgrowth of algae and other aquatic plants. This excessive growth can disrupt the balance of the ecosystem and have detrimental effects on water quality, aquatic life and overall ecosystem health.

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- When a pollutant enters an ecosystem, organisms can receive them through absorption, ingestion or contact. These chemicals can be persistent and resist breakdown in the environment, leading to their accumulation within the tissues of organisms.
- With each successive level of the food chain, the concentration of the pollutant can become magnified in the long term, which is called biomagnification.
- Plastics reach the oceans through various pathways, facilitated by human activities and natural processes such as improper waste disposal, direct littering and dumping, runoff, spills and marine debris from fishing and shipping.
- Rewilding is an approach to conservation and ecosystem restoration that involves reintroducing and restoring natural processes and biodiversity to ecosystems that have been degraded or altered by human activities.
- Ecological succession is a natural progression of changes in species composition and community structure over time.
- Primary succession is the process of ecological change that occurs in an area that has never been colonised by living organisms or has been completely devoid of life due to extreme conditions, such as newly formed volcanic rock or a retreating glacier.
- Secondary succession refers to the process of ecological change that occurs in an area that has been previously colonised by living organisms but has experienced a disturbance that disrupts the existing community and returns it to any previous stage of the development.
- A climax community refers to a stable and mature ecological community that remains relatively unchanged over an extended period of time.

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Key terms

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Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. in an ecosystem refers to the ability of the system to maintain its structure and function over time, despite changes or .
2. is the ability of an ecosystem to remain stable in the face of disturbances, while is the ability to recover after a disturbance.
3. The critical threshold of a change that results in a significant and often irreversible change in an ecosystem's structure, function or composition is called a .
4. is a species in an ecosystem that has a disproportionately large impact on the community.
5. refers to the capacity of meeting the needs of the present generation without compromising the ability of future generations.
6. The concept of refers to the maximum level of harvest that can be sustained over the long term without depleting the targeted population.
7. is the process by which water bodies become enriched with excessive nutrients, particularly , leading to an overgrowth of algae and other aquatic plants.
8. Pollutants can be persistent and resist breakdown in the environment, leading to within the tissues of organisms.
9. is an approach to ecosystem restoration that involves reintroducing and restoring natural processes.
10. [HL] is a natural progression of changes in species composition and community structure over time.
11. [HL] is the process of ecological change that occurs in an area that has never been colonised by living organisms.
12. [HL] refers to the process of repeating ecological sucession that occurs in an area.

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13. [HL] A refers to a stable and mature ecological community that remains relatively unchanged over an extended period of time.

keystone species | resistance | maximum sustainable yield | disturbances | sustainability | cyclic succession | resilience | stability | primary succession | tipping point | rewilding | eutrophication | nitrogen and phosphorus | bioaccumulation | climax community | ecological succession

Interactive 1. Key Concepts on Ecosystem Stability.

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Checklist

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/checklist-id-46661/print/) Assign

What you should know

After studying this subtopic you should be able to:

- Define ‘ecosystem stability’, including some examples of stable ecosystems.
- Outline the factors that affect stability and explain tipping points, using deforestation of the Amazon rainforest as an example.
- Evaluate the use of models to investigate the effect of variables on ecosystem stability.
- Explain the role of keystone species in the stability of ecosystems.
- Evaluate the sustainability of resource harvesting from natural ecosystems.
- Outline the factors affecting the sustainability of agriculture.
- Explain eutrophication and its effects on ecosystems.
- Outline biomagnification of pollutants.
- Describe the effects of microplastic and macroplastic pollution of the oceans.

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- Describe the strategies for restoration of natural processes in ecosystems by rewilding.

Higher level (HL)

- Define ecological succession and outline the causes.
- Describe the changes during primary succession.
- Describe cyclical succession.
- Distinguish between climax communities and arrested succession.

Practical skills

Once you have completed this subtopic, go to Practical 5: Observing a sustainable ecosystem using a mesocosm (/study/app/bio/sid-422-cid-755105/book/observing-a-sustainable-ecosystem-id-46696/) in which you will study the effects of variables on ecosystem sustainability.

D4. Continuity and change: Ecosystems / D4.2 Stability and change

Investigation

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/investigation-id-46662/print/) Assign

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills – Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

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Your task

Use of pesticides

Agriculture can have significant impacts on the environment. Negative impacts are serious, and can include pollution and degradation of soil, water and air.

The OECD (Organisation for Economic Co-operation and Development) database provides the latest and most comprehensive set of agri-environmental indicators from 1990 to 2021.

- Visit the OECD database of environmental indicators (Agri-Environmental other indicators (https://stats.oecd.org/Index.aspx?DataSetCode=AEI_OTHER)).
- From the left-hand menu, select ‘Agriculture and Fisheries’, then ‘Environmental Indicators for Agriculture’, then ‘Agri-Environmental other indicators’, then ‘Agricultural land area’.
- Above the table, click the ‘Country’ button and choose your country. (If your country does not have any data, choose another country.)
- Identify the lowest and highest values of land area between 1990 and 2020. Calculate the percent change.
- From the left-hand menu, select ‘Agriculture and Fisheries’, then ‘Environmental Indicators for Agriculture’, then ‘Agri-Environmental other indicators’, then ‘Pesticide sales’.
- Above the table, click the ‘Country’ button and choose your country. (If your country does not have any data, choose another country. Make sure you choose the same country as the previous task.)
- Describe the trend from 1990 to 2020.
- Calculate the percent change from 1990 to 2020.
- Explain why the agricultural land area stays similar but use of pesticide changes.
- Outline the effects of increased pesticide use.

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Reflection

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46900/print/) Assign

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding questions introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43552/):

- What features of ecosystems allow stability over unlimited time periods?
- What changes caused by humans threaten the stability of ecosystems?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?

Student view

Overview
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- What connections do you see between this subtopic and other parts of the course?

⚠ Once you submit your response, you won't be able to edit it.

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Submit

Rate subtopic D4.2 Stability and change

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