DP IB Environmental Systems & Societies (ESS): SL

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Human Population Carrying Capacity

Contents

Carrying Capacity

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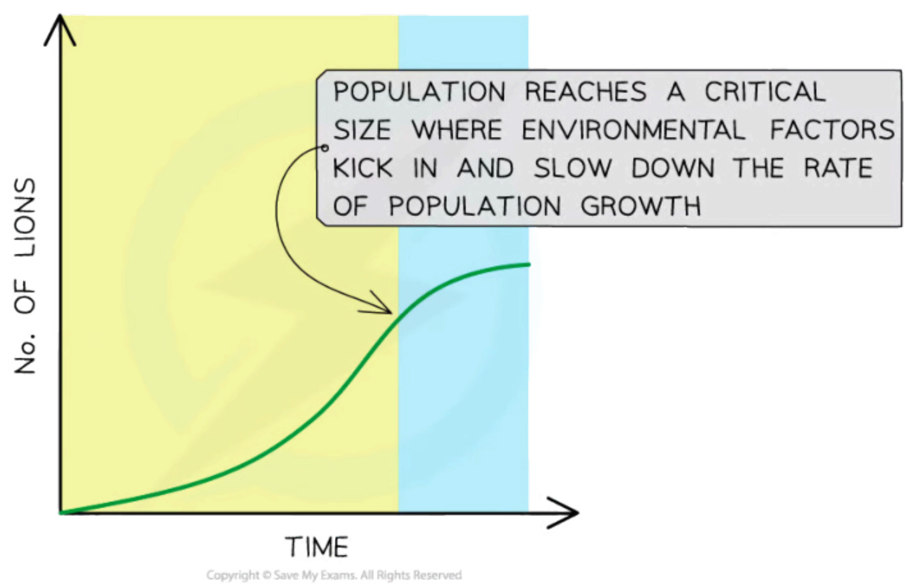
Carrying Capacity

- The **maximum stable population size** of a species that an **ecosystem** can **support** is known as the **carrying capacity**
- Every individual within a species population has the **potential to reproduce** and have **offspring** that will contribute to **population growth**
  - In reality, however, there are many **abiotic** and **biotic** factors that prevent every individual in a population from making it to adulthood and reproducing
- This ensures the population size of each species is **limited** at some point (i.e. the carrying capacity of that species is reached)
  - This is why no single species has a population size that dominates all other species populations on Earth, with the exception of humans (as we have managed to overcome many of the abiotic and biotic factors that could potentially limit the population growth of our species)
- The graph below shows the population growth of a population of lions
  - The point at which the graph starts to flatten out (plateau) is the **carrying capacity** of this population
  - At this point, the environmental (abiotic and biotic) factors that stop all individuals from surviving and reproducing result in the population no longer being able to grow in size



An example graph showing the population growth of a population of lions and the point at which the carrying capacity of this population has almost been reached

- Carrying capacity is determined by factors such as:
  - Resource availability
  - Interactions between species
  - Environmental conditions

Resource Availability

- The carrying capacity of an environment for a species is influenced by the availability of essential resources such as food, water, shelter, and space
  - For example, a grassland ecosystem may have a carrying capacity for a specific number of herbivores based on the amount of grasses available for grazing

Interactions Between Species

- The presence of predator-prey relationships, competition for resources, and symbiotic interactions among species can influence the carrying capacity of an environment
  - For example, the carrying capacity of a freshwater ecosystem for fish species may be influenced by the presence of predators, availability of prey, and competition for food resources
- In a stable community, the numbers of predators and prey rise and fall in cycles, limiting the carrying capacity of both predator and prey populations
- The graph below demonstrates some of the key patterns of predator-prey cycles:
  - The number of predators increases as there is more prey available
  - The number of prey then decreases as there are now more predators
  - The number of predators decreases as there is now less prey available
  - The number of prey increases as there are now fewer predators
  - The cycle now repeats

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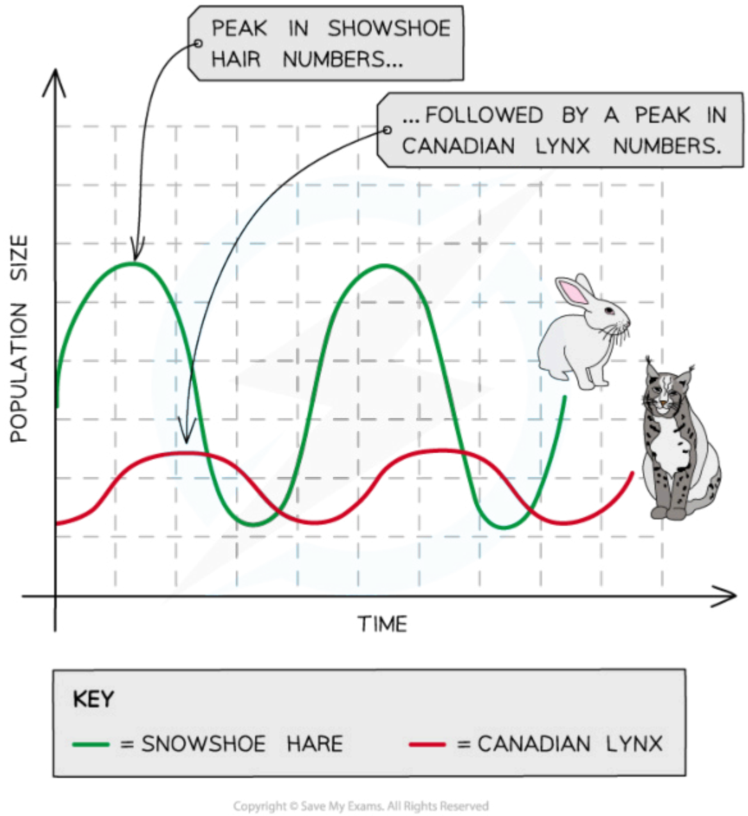

An example of a graph used to model a predator-prey cycle between the Canadian lynx and the snowshoe hare

Environmental Conditions

- Factors like climate, temperature, rainfall patterns, and soil fertility can affect the carrying capacity of species within an environment
  - For example, a forest ecosystem with favourable environmental conditions may have a higher carrying capacity for a certain bird species due to the availability of suitable nesting sites (e.g. the temperature, humidity and rainfall is suitable for incubating eggs and raising chicks)

Estimating Carrying Capacity

- Scientists use various methods to estimate the carrying capacity of an environment for a given species
  - These methods include field observations, population surveys, mathematical modelling, and data analysis

- By studying population trends, resource availability, and species interactions, researchers can make **informed estimates** of carrying capacity
- However, estimating carrying capacity becomes challenging when it comes to **human populations** due to several reasons:
- **Technological advancements**:
  - Human societies have the ability to modify their environment and **overcome** traditional carrying capacity limitations through technology
  - For example, the development of agriculture and irrigation techniques has allowed humans to increase food production and support larger populations beyond what the natural environment could sustain
- **Cultural and social factors**:
  - Human population dynamics are influenced by cultural norms, social behaviours, and economic factors
  - These can affect fertility rates and migration patterns, for example, making it difficult to accurately predict or estimate carrying capacity for human populations
- **Changing lifestyles and consumption patterns**:
  - Human populations are characterised by varying lifestyles and consumption rates, which can significantly impact resource demands and environmental impacts
  - For example, urbanised societies with high levels of consumption may **strain** the carrying capacity of their surrounding areas due to increased **resource demands** and **waste generation**
- **Adaptive capacity**:
  - More so than any other species, humans have the ability to **adapt** and **innovate** in response to **changing environmental conditions**
  - This adaptability can affect carrying capacity by influencing **resource use efficiency** and the development of **technological solutions**

Balancing Population and Resources

- The concept of **population growth dynamics** refers to how humans interact with their environment to change in number over **space** and **time**
- The global population has grown **exponentially** over the **past 200 years**
  - In 1800 it was 1 billion
  - In November 2022 it reached 8 billion
- Due to humans' ability to **resist** the **limiting environmental factors** (such as disease and food supply)

    - Humans have overcome these by finding medicines and vaccines to reduce or control rates of disease, and developing technologies to increase food supply to allow for population growth
- Continued population growth puts **pressure** on **scarce resources**
    - The balance between population and resource use determines a place's standard of living
    - Careful management of population and resources is needed to maximise income per capita
    - Countries aim to achieve a perfect balance between population and resources, known as **optimum population**
    - An imbalance between population and resources leads to **overpopulation** or **underpopulation**

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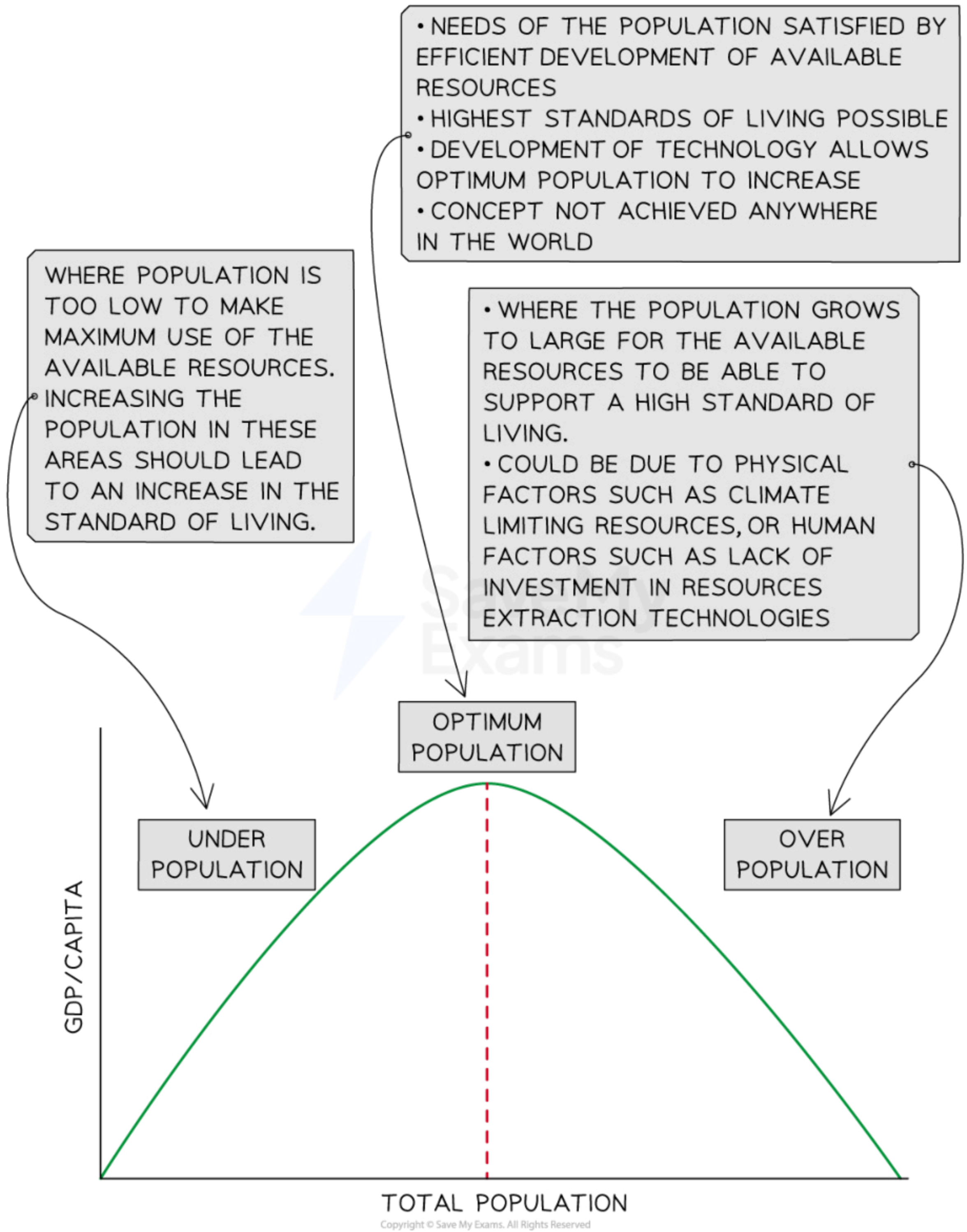
• NEEDS OF THE POPULATION SATISFIED BY EFFICIENT DEVELOPMENT OF AVAILABLE RESOURCES
• HIGHEST STANDARDS OF LIVING POSSIBLE
• DEVELOPMENT OF TECHNOLOGY ALLOWS OPTIMUM POPULATION TO INCREASE
• CONCEPT NOT ACHIEVED ANYWHERE IN THE WORLD
WHERE POPULATION IS TOO LOW TO MAKE MAXIMUM USE OF THE AVAILABLE RESOURCES. INCREASING THE POPULATION IN THESE AREAS SHOULD LEAD TO AN INCREASE IN THE STANDARD OF LIVING.
• WHERE THE POPULATION GROWS TO LARGE FOR THE AVAILABLE RESOURCES TO BE ABLE TO SUPPORT A HIGH STANDARD OF LIVING.
• COULD BE DUE TO PHYSICAL FACTORS SUCH AS CLIMATE LIMITING RESOURCES, OR HUMAN FACTORS SUCH AS LACK OF INVESTMENT IN RESOURCES EXTRACTION TECHNOLOGIES
OPTIMUM POPULATION
UNDER POPULATION
OVER POPULATION
GDP/CAPITA
TOTAL POPULATION
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The relationship between population, resources and standard of living

- If resources are consumed at **sustainable rates**, a larger population may be supported
- Countries going through industrialisation tend to consume and waste resources at unsustainable levels which leads to a **lower carrying capacity**
- Technological innovation can either lead to:
    - Increases in supply of resources such as energy and minerals, increasing carrying capacity
- Or:
    - Improved resource use efficiency, increasing carrying capacity
- Wealthier countries usually have a larger carrying capacity than poorer countries because:
    - They export waste to poorer countries
    - They import products from poorer countries
    - This means that although poorer countries use fewer resources, they are supporting the resource use of the richer countries

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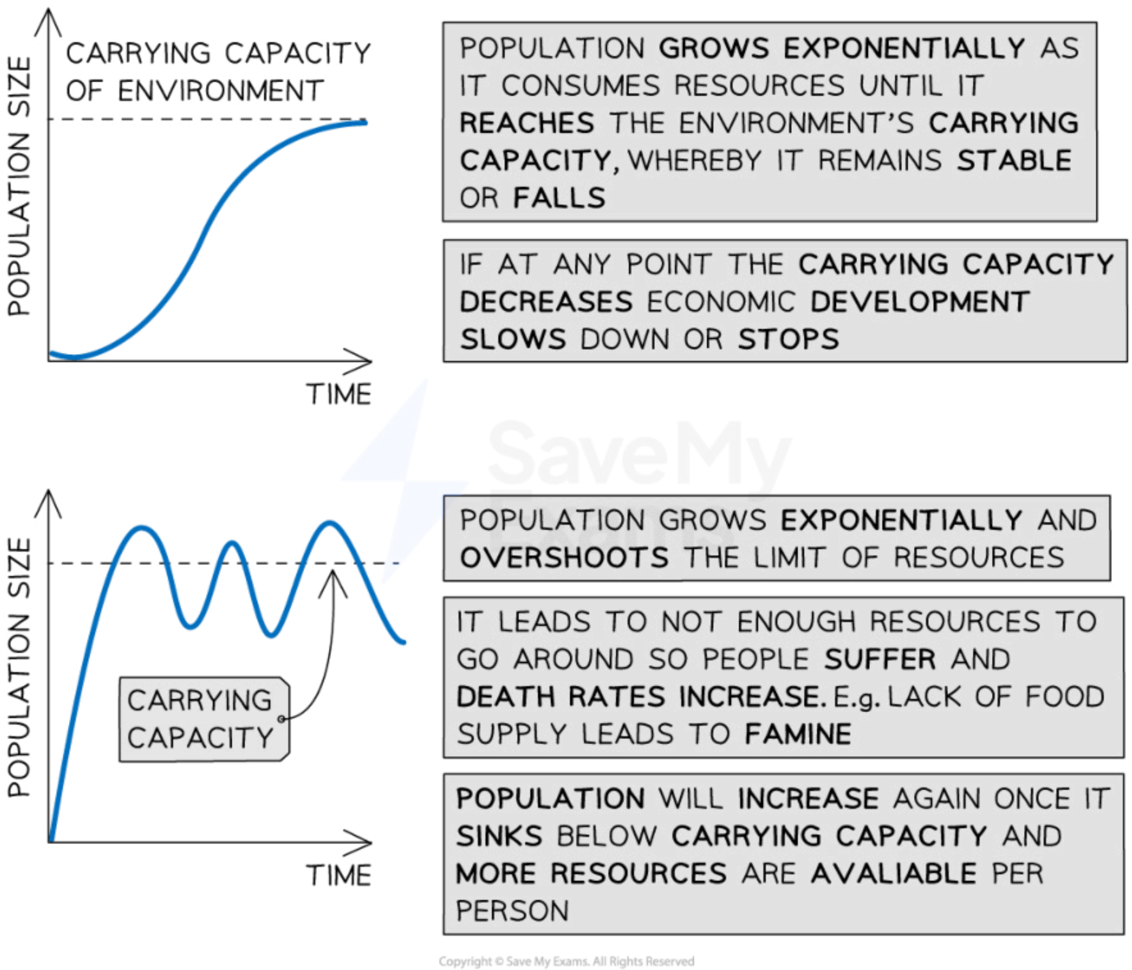

Two different scenarios showing population response to carrying capacity

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Human Population & Ecological Footprints

- An ecological footprint (EF) is a theoretical concept that acts as a valuable tool used to assess the **environmental impact** of human populations
  - It quantifies the area of land and water required to support a specific population at a particular standard of living

Ecological Footprints as a Measure of Demands

- The ecological footprint provides a comprehensive measure of the **demands** that human populations place on the environment
  - It takes into account the **resources consumed** by individuals, such as food, energy, water, and materials, as well as the **waste generated** and the ecosystem services required to **absorb** that waste
  - By considering these factors, ecological footprints help to evaluate the sustainability of human activities

Variation in Ecological Footprints

- Ecological footprints can vary significantly by country and even between individuals
  - This variation is influenced by various factors:
- **Lifestyle choices**:
  - Different lifestyle choices, including consumption patterns, transportation modes, and housing preferences, have a direct impact on ecological footprints
  - In this way, the environmental value system adopted by an individual, a group or a whole country determines the size of its ecological footprint
  - For example, individuals who consume large amounts of **goods** and **services,** have **high energy demands**, or engage in activities with significant environmental impacts will have **larger ecological footprints** compared to those with more sustainable lifestyles
- **Productivity of food production systems**:
  - The **efficiency** and **sustainability** of agricultural practices also contribute to variations in the size of a country's ecological footprint
  - For example, countries with intensive and **resource-intensive** agricultural systems may have **larger ecological footprints** due to high demands for **land**, **water**, and inputs like **fertilisers** and

pesticides
    - In contrast, countries with more sustainable and efficient farming practices typically have smaller ecological footprints
- **Land use and industry**:
    - The type of land use and industrial activities in a region can affect the size of its ecological footprint
    - For example, areas with extensive urbanisation, industrial development, or extractive industries may have larger ecological footprints due to increased resource consumption, energy demands, and waste generation

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Photo by Paul Schellekens on Unsplash

Lifestyle choices, including diets and consumption patterns, affect a region's ecological footprint size – countries that have very high consumption rates of highly processed foods have large ecological footprints due to both the resources required to sustain this diet or lifestyle, and the large amount of solid domestic waste this lifestyle produces

Ecological Footprints and Carrying Capacity

- Comparing the ecological footprint of a human population with the **available land area** provides insights into sustainability and carrying capacity
  - If the ecological footprint of a population **exceeds** the land area available to it, it indicates an **unsustainable** situation where resource consumption surpasses the environment's ability to **regenerate**
  - This suggests that the population is exceeding the carrying capacity of the area, leading to **ecological degradation** and potential **resource depletion**
- As global demand for resources increases, so the whole planet's ecological footprint gets **bigger** and its carrying capacity gets **smaller**
  - Calculations suggest the world is in a state of **overshoot**, currently using the equivalent of 1.6 Earth's worth of resources
  - With the global population predicted to increase to around 9–10 billion by 2050, even more 'Earths' will be required unless more sustainable resource use strategies are put in place
  - Eventually, this may begin to act as a natural 'check' on global population growth and even lead to global population decline
- Other implications of changes to humanity's increasing global ecological footprint and the planet's shrinking carrying capacity include:
  - Destruction of ecosystems such as forests and coral reefs with knock-on effects of extinction of plant and animal species
  - Climate change
  - Deforestation and changes of land use for growing urban areas, transport and industrial development
  - Reduction of availability and quality of fresh water

- Reduction in soil quality through erosion leading to crop and food shortages

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Limits to Human Population Growth

- The **degradation** of the environment and the consumption of **finite resources** have significant implications for human population growth
  - These factors are expected to **limit** population growth and these unsustainable practices can lead to human populations **exceeding** their **carrying capacity**, which can eventually lead to the collapse of these populations

Environmental Degradation as a Limiting Factor

- Human populations rely on the natural environment for resources such as food, water, energy, and materials
- However, the degradation of ecosystems, including deforestation, soil erosion, pollution, and loss of biodiversity, decreases the **capacity** of the environment to **support growing populations**
- For example:
  - Deforestation reduces the availability of forests for timber, biodiversity conservation, and carbon sequestration - this **loss of ecosystem services** can lead to reduced agricultural productivity, increased vulnerability to natural disasters, and decreased availability of clean water, all of which can **limit** human population growth
  - Pollution, such as air and water pollution, can have detrimental effects on **ecosystems** and **human health**, compromising the overall well-being and resilience of human populations - pollution from human activities can lead to the degradation of ecosystems, decline in biodiversity, and **contamination** of essential resources like drinking water

Finite resources as a Limiting Factor

- Human populations rely on **finite** resources, including fossil fuels, minerals, and fresh water
- These resources have limited availability, and their extraction and consumption rates can **outpace** their natural **replenishment**
- For example:
  - Depletion of fossil fuels, such as coal, oil, and natural gas, not only contributes to climate change but also poses challenges for energy production and transportation systems - as these resources become scarcer, their extraction becomes more **challenging** and **expensive**, hindering economic growth and development

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- Overexploitation of freshwater resources can lead to water scarcity, affecting agricultural productivity, human health, and overall societal wellbeing - this is particularly crucial in regions already facing **water stress** or located in arid and semi-arid climates.

Unsustainable Practices and Exceeding Carrying Capacity

Photo by Eelco Böhtlingk on Unsplash

As we deplete our finite resources, we are decreasing the carrying capacity of the planet to sustain the current global population - as the more readily available stocks of resources such as fossil fuels are used up, their extraction becomes increasingly difficult and expensive, which is one of the reasons human populations need to focus on reducing their fossil fuel dependence as quickly as possible

- If human populations continue to deplete resources and degrade the environment at an unsustainable rate, they risk **surpassing the carrying capacity** of their ecosystems
- When carrying capacity is exceeded:
  - Resource scarcity intensifies, leading to food shortages, water scarcity, and **energy crises** - this can trigger **social unrest**, **conflicts**, and **migrations** as populations struggle to meet their basic

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needs
- Ecosystems can start to **collapse,** resulting in a loss of biodiversity, disruption of essential ecosystem services, and increased vulnerability to environmental disturbances - this can have cascading effects on human well-being and livelihoods

Case Study: Easter Island

Photo by Thomas Griggs on Unsplash

Although Rapa Nui (Easter Island) is most famous for its moai, also known as the Easter Island Heads, this island also demonstrates how a human population can collapse if unsustainable resource use causes the population to exceed its carrying capacity

- Easter Island (also known as Rapa Nui), located in the southeastern Pacific Ocean, provides a notable case study where the degradation of the environment and the consumption of finite resources have significantly limited human population growth
  - The island's history provides a clear warning of the consequences of unsustainable practices
- In the past, Easter Island was a thriving Polynesian society with abundant natural resources, including lush forests

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  - The inhabitants of Easter Island relied **heavily** on the island's forests for various needs, such as timber for construction, wood fuel, and agriculture
- Due to overexploitation of timber resources, the island's forests were depleted, leading to significant deforestation
  - The loss of trees resulted in **soil erosion**, **reduced agricultural productivity**, and limited availability of other essential resources
- The degradation of the environment and the depletion of finite resources significantly **decreased** the island's carrying capacity
  - The human population on Easter Island was **no longer sustainable**, and as a result, it declined dramatically
- The decline in food production, scarcity of construction materials, and deteriorating living conditions contributed to societal challenges
  - Historical evidence suggests that the collapse of the society on Easter Island led to social upheaval, conflict, and even cannibalism may have occurred as resources became scarce
- The case of Easter Island clearly demonstrates the consequences of unsustainable practices, emphasising the importance of **responsible resource management** and **sustainable approaches** to ensure long-term human well-being and environmental preservation