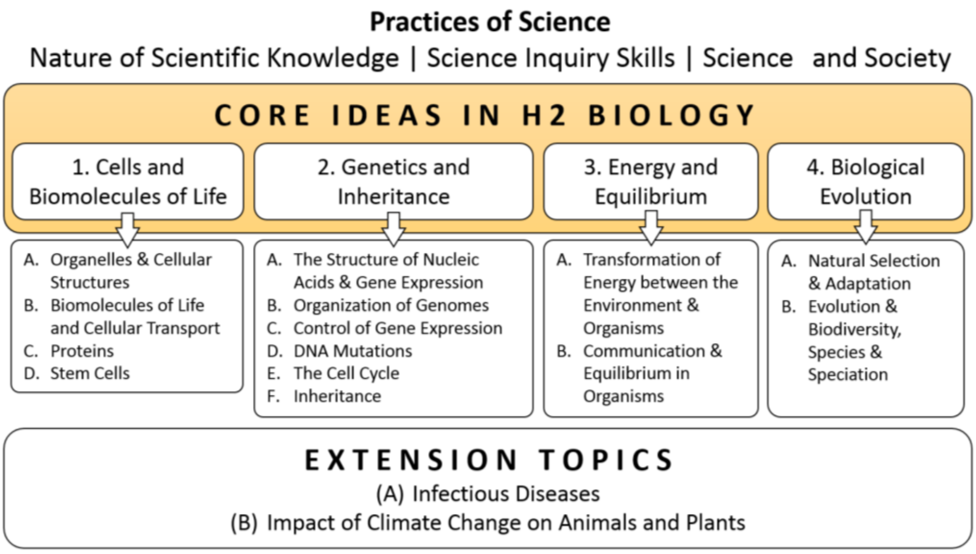
Note: Self-read sections 1-3

Tampines Meridian Junior College
JC2 H2/9744 Biology 2024

Extension Topic (B)
15. Climate Change – Causes and Impacts on Animals and Plants



SYLLABUS OVERVIEW		
No.	**Overarching Idea**	**Topics**
1	**Core Idea 1** The Cell and Biomolecules of Life	Cell – The Basic Unit of Life
2		Biomolecules of Life and Cellular Transport
3	**Core Idea 2** Genetics and Inheritance	Genetics and Inheritance (I) – The Cell Cycle
4		Genetics and Inheritance (II) – DNA Replication and Gene Expression
5		Genetics and Inheritance (III) – DNA Mutations and their Consequences
6		Genetics and Inheritance (IV) – Organisation of Genome & Control of Gene Expression in Eukaryotes *[Includes Core Idea 1D: Stem Cells]*
7		Genetics and Inheritance (V) – Molecular Techniques in DNA Analysis
8		Genetics and Inheritance (VI) – Organisation and Inheritance of Viral Genomes
9		Genetics and Inheritance (VII) – Organisation of Genome & Control of Gene Expression in Prokaryotes
10	**Core Idea 3** Energy and Equilibrium	Transformation of Energy – Photosynthesis and Cellular Respiration
11	**Core Idea 2** Genetics and Inheritance	Genetics and Inheritance (VIII) - Inheritance
12	**Core Idea 3** Energy and Equilibrium	Communication and Equilibrium in Multicellular Organisms
13	**Core Idea 4** Biological Evolution	Biological Evolution
14	**Extension Topic A** Infectious Diseases	Immunity and Infectious Diseases
15	**Extension Topic B** Impact of Climate Change on Animals & Plants	Climate Change – Causes and Impacts on Animals and Plants

What's the Big Picture?
This topic explores the impact of climate change and three main areas of concern: 1. The need for a **safe** and **sufficient food supply**; 2. The **threat** of how **infectious diseases** are **changing**; and 3. The **maintenance** of **ecosystems** as reservoirs for bio-resources like **medicine** and **food**. The following questions should help students frame their learning: • How can our **way of life influence climate change**? • Why is there an **urgent need** to **ameliorate climate change** through an **understanding** and **application of the sciences**?

Climate change, which is attributed to an increase in the emission of greenhouse gases, has great impact on the human population. By the year 2050, climate change is expected to cause the extinction of approximately at least one quarter of all species on land. In the oceans, species such as corals, which are sensitive to warming temperatures, are also at great risk. Many species have evolved to survive within specific temperature ranges and cannot adapt to the new temperatures. In addition, the survival of a species is threatened when the species it depends on for food cannot adapt. The Intergovernmental Panel on Climate Change (IPCC) has predicted that by 2100, the Earth's surface will rise by up to 6°C on average. The effects of this temperature rise on species and ecosystems will be catastrophic. Currently, the following effects of global warming are evident: the melting of glaciers; the bleaching and dying of coral reefs; extreme storms, droughts, and heat waves; and major shifts in the timing of organisms' biological cycles.

Climate change is affecting the global ecology and ecosystem, e.g. loss of biodiversity and impact on food webs. The study of biological processes is important in understanding and taking appropriate action, e.g. the observation that many species are becoming smaller in size can be explained by fundamental ecological and metabolic principles. There are also consequences for both crop plants and protein sources, e.g. fish that are important for human nutrition.

As a small, low-lying city-state with one of the world's most open economies, Singapore is vulnerable to the harmful effects of climate change, such as rising sea levels and the increased frequency of rainfall.

Trends in our local weather records are consistent with the global observations of climate change. The weather has become increasingly hot. Since the 1970s, Singapore has experienced an average warming rate of 0.25°C per decade. The sea level has also risen. Tide gauge data in the Singapore Straits shows that the mean sea level has increased by about 3 mm per year over the last 15 years. More instances of short, intense rainfall have also been recorded within the last few years.

Extreme weather events can lead to changes in rainfall patterns, resulting in more intense rainfall or drier periods. Flood, haze and water management will be of greater importance to Singapore. In addition, an increase in the frequency of extreme weather events may lead to unstable global food prices and disruptions to business supply chains, which will affect our food imports and business activities in Singapore.

Disruption of ecosystems and loss of biodiversity have major impacts on the emergence, transmission, and spread of many human infectious diseases. For example, deforestation reduces the diversity of forest mosquitoes, which are the vectors for dengue. The species that survive and become dominant, for reasons that are not well understood, almost always transmit dengue better than the species that had been most abundant in the intact forests. Deforestation can also result in loss of habitat and food for species that serve as reservoirs for human disease. The resultant disturbance can bring the reservoir species into closer contact with humans, facilitating the spread of the disease to humans. An example is the original outbreak of Nipah virus infections in Malaysia.

Mosquitoes kill more people through the life-threatening diseases they spread than any other predators. Furthermore, mosquito-borne infectious diseases affect millions of people and debilitated people cannot work or support themselves. Climate change has influenced how mosquito-borne diseases have spread in the world through the effects on the diseases' vectors. Being in a region where two of the main mosquito-borne diseases (dengue and malaria) are endemic, an understanding of the intertwined processes of how vectors respond to climate change and how climate change affects the spread of these diseases will be important to Singapore.

LEARNING OUTCOMES

Extension Topic B: Impact of Climate Change on Animals and Plants

Candidates should be able to:

a) identify and explain the human activities over the last few centuries that have contributed to climate change through increased emission of greenhouse gases (limited to CO_2 and methane) including burning of fossil fuels linked to increasing energy usage, clearing of forests and food choices (increasing consumption of meat).

b) explain the effects of climate change as a result of greenhouse emissions, including the melting of polar ice caps, rising sea levels, stress on fresh water supplies, heat waves and heavy rains, death of coral reefs, migration of fishes and insects, release of greenhouse gases in frozen organic matter.

c) explain how climate change affects plant distribution (vertical and latitude) and plant adaptations, including morphology and physiology.

d) discuss the consequences to the global food supply of increased environmental stress resulting from climate change, including the effects on plants and animals of increased temperature and more extreme weather conditions.

e) explain how temperature changes impact insects, including increased temperature leading to increased metabolism and the narrow temperature tolerance of insects.

f) outline the life-cycle of *Aedes aegypti* as an example of a typical mosquito vector.

g) outline the development of the viral dengue disease in humans, including host-pathogen interactions, human susceptibility to the virus, pathogen virulence, transmission and drug resistance

h) explain how global warming affects the spread of mosquito-borne infectious diseases, including malaria and dengue, beyond the tropics.

i) discuss the effects of increased environmental stress (including increased temperatures and more extreme weather conditions) as a result of global climate change, on habitats, organisms, food chains and niche occupation.

j) Discuss how climate change affects the rich biodiversity of the tropics including the potential loss of this rich reservoir for biomedicines and genetic diversity for food.

Use the knowledge gained in this section in new situations or to solve related problems.

LECTURE OUTLINE

1. Introduction

The impact of humans on the Earth's Climate

Did you know...

- **95%** the scientific certainty that human activity is the major cause of climate change
- **1 meter** the amount sea levels could rise if climate change continues unabated
- **5°C** the highest predicted surface temperature increase by 2100

Source: 2013 Intergovernmental Panel on Climate Change report

Global Warming is primarily caused by human activities

Human activities contribute to climate change (**anthropogenic climate change**) by causing changes in Earth's atmosphere in the amounts of greenhouse gases, aerosols (small particles), and cloudiness. The largest known contribution comes from the **burning of fossil fuels**, which releases carbon dioxide gas to the atmosphere. **Deforestation** is the second largest human-made source of carbon dioxide, according to research published by Duke University.

Since the start of the industrial era (about 1750), the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds that due to known changes in natural processes, such as solar changes and volcanic eruptions.

Most of the leading scientific organizations in the world acknowledge the existence of global warming as fact, according to a NASA report. Furthermore, climate scientists agree that the rate of global warming trends the planet is now experiencing is **not a natural occurrence**, but is primarily the **result of human activities**.

This consensus was made clear in a major climate report released Sept. 27, 2013, by the Intergovernmental Panel on Climate Change (IPCC). In that report, climate scientists indicated they are more certain than ever of the link between human activities and global warming.

2. Human activities emit greenhouse gases which cause global warming

Learning Objectives:

a) Identify and explain the human activities over the last few centuries that have contributed to climate change through increased emission of greenhouse gases (limited to CO_2 and methane) including burning of fossil fuels linked to increasing energy usage, clearing of forests and food choices (increasing consumption of meat).

2.1 Global warming and the greenhouse effect

- Global warming is the **gradual heating of the Earth's surface, oceans and atmosphere**.

- Scientists have documented the rise in average temperatures worldwide since the late 1800s. The Earth's average temperature has risen by 0.8°C over the past century, according to the Environmental Protection Agency (EPA). Temperatures are projected to rise another 1.1-6.4°C by year 2100.

The Greenhouse Effect (Fig. 2.1)

- The greenhouse effect is a process caused by greenhouse gases, which occur naturally in the atmosphere. This process, which involves the interaction between Earth's atmosphere and incoming radiation from the sun, plays a crucial role in warming the Earth's surface, making it habitable. Without it, the average temperature at Earth's surface would be below the freezing point of water.

- How does this process work?

  - The Sun powers Earth's climate, radiating energy at very short wavelengths, predominately in the visible or near-visible (e.g. ultraviolet) part of the electromagnetic spectrum.

  - Roughly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space.

  - The remaining two-thirds is absorbed by the surface (land and oceans) and, to a lesser extent, by the atmosphere.

  - The absorbed incoming energy is radiated back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily **infrared radiation**, which is **heat / thermal energy**.

  - Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and re-radiated back to Earth. This is called the greenhouse effect. This is analogous to the glass walls in a greenhouse which reduce airflow and increase the temperature of the air inside.

- However, **human activities**, primarily the **burning of fossil fuels** and **clearing of forests**, have **greatly intensified the natural greenhouse effect**, causing **global warming**.

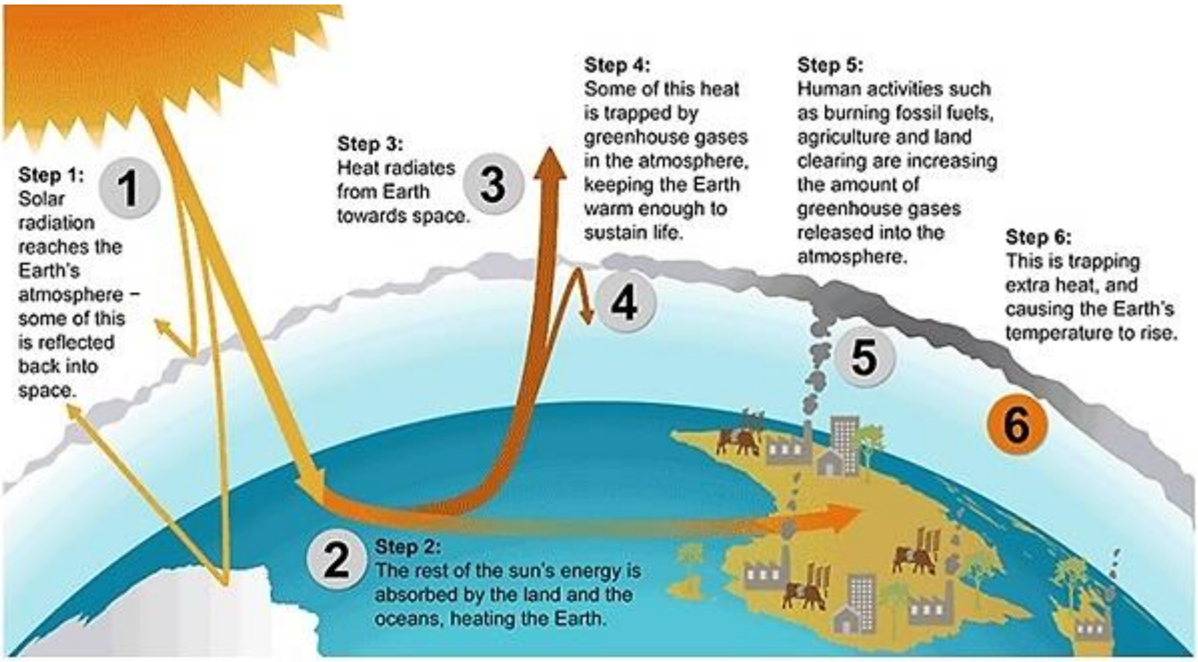


Fig. 2.1: Model of greenhouse effect and how human activities intensify this effect.

2.2 The greenhouse gases (GHGs)

- Gases that **trap heat in the atmosphere** are called greenhouse gases.

- Greenhouse gases and aerosols affect the climate by altering the incoming solar radiation and out-going infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system.

- Greenhouse gas concentrations are usually **measured in parts per million** or **parts per billion.** E.g. 1 ppb for a given gas means there is one molecule of that gas in every 1 billion molecules of air.

- Gases which exert greenhouse effect include
  - **carbon dioxide (CO_2)**
  - **methane (CH_4)**
  - water vapor
  - nitrous oxide
  - ozone
  - other small and less common molecules

- Water vapor is the most abundant and important greenhouse gas in the atmosphere. However, human activities have only a **small** direct influence on the amount of atmospheric water vapor.

- The two most abundant gases in the atmosphere, nitrogen (78% of the dry atmosphere) and oxygen (21%), exert almost no greenhouse effect.

- Human (anthropogenic) activities result in emissions of four principal greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the halocarbons (a group of gases containing fluorine, chlorine and bromine) (Fig. 2.3).

- These gases accumulate in the atmosphere, causing **concentrations** to **increase with time**.

- Prior to 1750, the levels of these gases were relatively low. Fluctuations in levels occurred due to **natural** changes to climatic conditions.

- **Significant increase** in all of these gases have occurred since the industrial era from 1750 (Fig. 2.2). For this syllabus, the focus is on $\mathbf{CO_2}$ and **methane**.

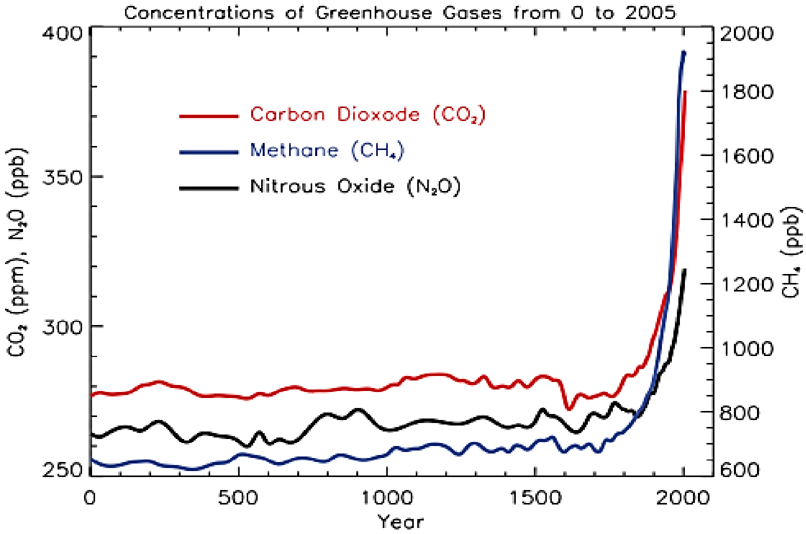
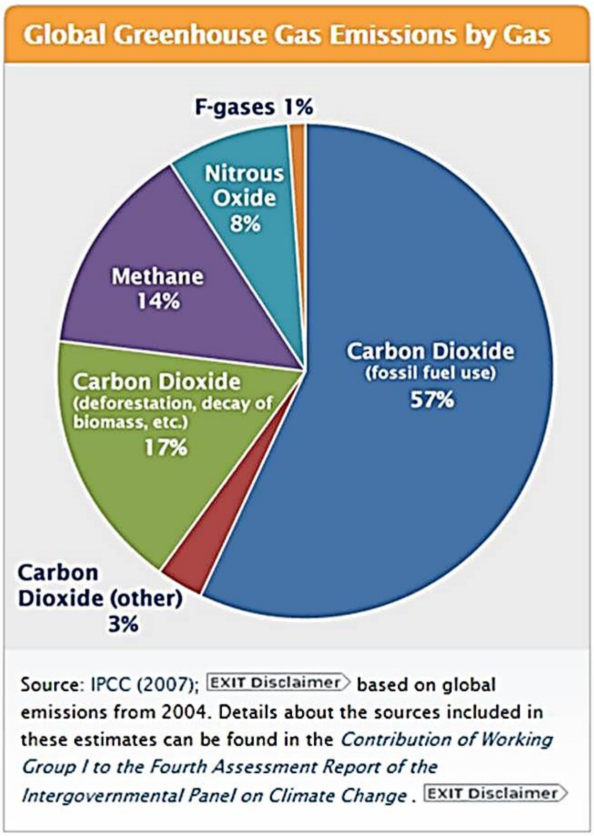


Fig. 2.2: Changes in concentration of greenhouse gases over the millenia. (ppm: parts of million, ppb: parts per billion)



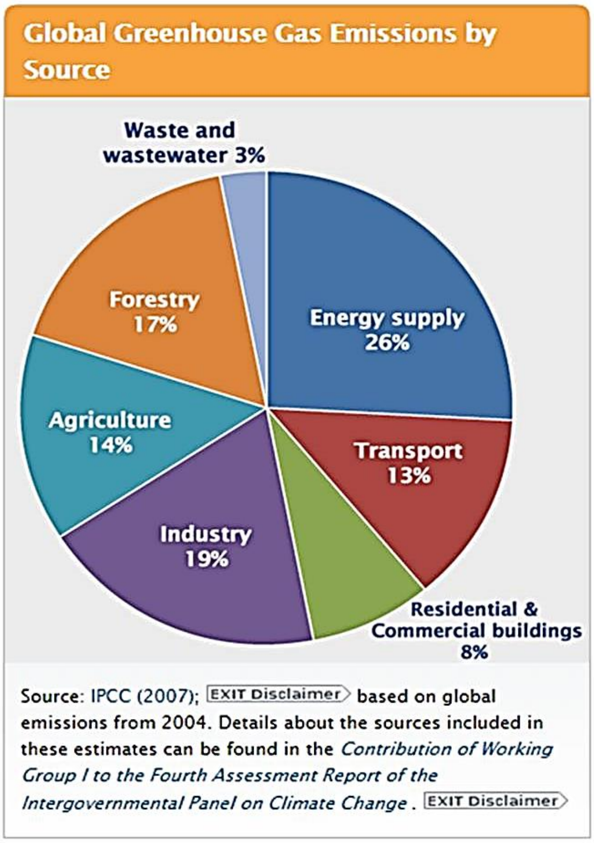


Fig. 2.3: Global emission of greenhouse gases

2.2.1 Carbon dioxide

- **CO_2 sinks** (*natural reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period*) includes the **atmosphere**, **ocean**, **soil** and **forests**.

- CO_2 are released through **natural processes** such as respiration of animals/plants, soil respiration, natural forest fires and volcanic eruptions.

- During most of the past 800,000 years, atmospheric CO_2 fluctuated between about 180 ppm during ice ages and 280 ppm during interglacial warm periods.

- Since the Industrial Revolution from 1750, **anthropogenic activities** caused CO_2 level to increase sharply to hit the historic high of 400 ppm in 2015 and rising. (Fig. 2.4).

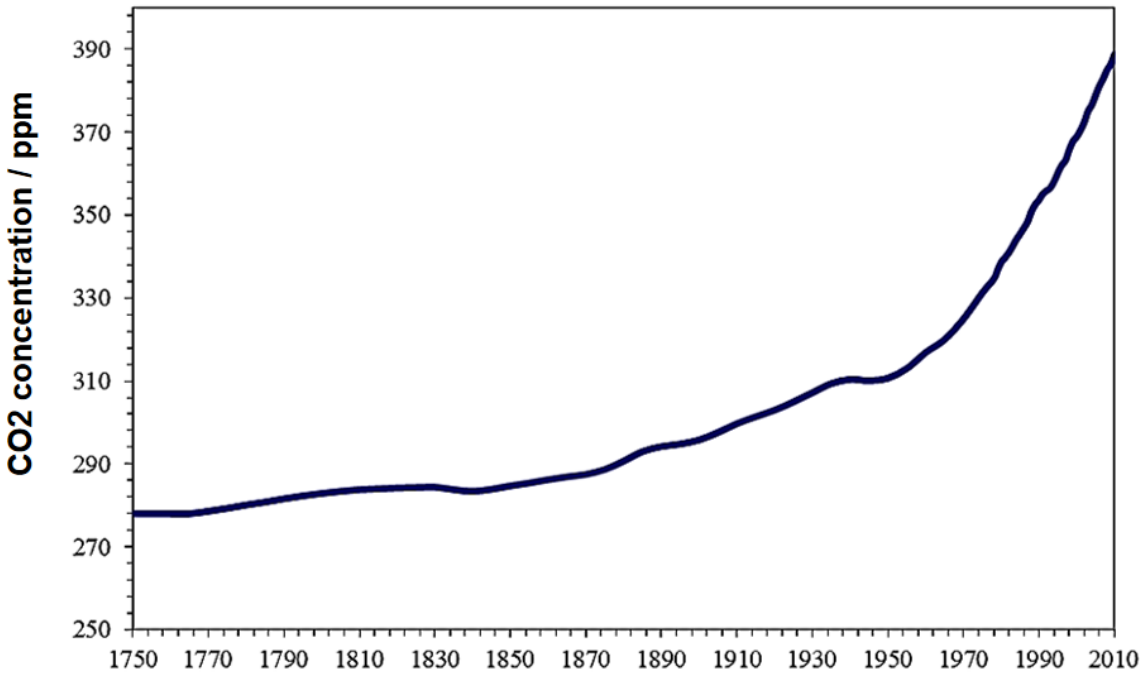


Fig. 2.4: Global CO_2 emission from fossil fuels between 1750 and 2010.

2.2.2 Methane

- Methane can come from many natural sources. **Wetlands** are the largest source, emitting methane from bacteria that decompose organic materials in the absence of oxygen. Others include ruminant digestion and manure decomposition.

- Methane is the second most prevalent greenhouse gas emitted in the United States from human activities. In 2013, methane accounted for about 10% of all U.S. greenhouse gas emissions from human activities.

- Globally, over 60% of total methane emissions come from **anthropogenic activities**, emitted from industry, agriculture, and waste management activities.

- Efforts were made to reduce the emission of methane. These efforts include:

Examples of Reduction Opportunities for Methane

Emissions Source	How Emissions Can be Reduced
Industry	Upgrading the equipment used to produce, store, and transport oil and gas can reduce many of the leaks that contribute to CH_4 emissions. Methane from coal mines can also be captured and used for energy.
Agriculture	Methane can be reduced and captured by altering manure management strategies at livestock operations or animal feeding practices.
Waste from Homes and Businesses	Because CH_4 emissions from landfill gas are a major source of CH_4 emissions in the United States, emission controls that capture landfill CH_4 are an effective reduction strategy.

2.3 Human activities contributing to increased emission of GHGs

1) **Burning of fossil fuel** (coal, natural gas and oil) releases **CO_2**

    - To meet energy needs in the production of electricity and heating.

    - For land, rail, air and sea transportation: almost all (95%) of the world's transportation energy comes from petroleum-based fuels, largely gasoline and diesel.

    - **Methane** is the primary component of **natural gas**. Methane is emitted to the atmosphere during the production, processing, storage, transmission, and distribution of natural gas. The gas is often found alongside petroleum. Hence, the production, refinement, transportation, and storage of **crude oil** is also a source of methane emission.

2) **Deforestation**

    - Deforestation is the long-term reduction of tree canopy cover to below 10–30% for the purpose of **other land uses**, e.g. cropland, pasture, industry, urbanization, etc.

    - Lesser trees to remove **CO_2** from the air through photosynthesis.

    - When trees are killed, the combustion of forest biomass and decomposition of remaining plant materials and soil carbon release the carbon they store as **CO_2**.

    - Deforestation releases nearly a billion tons of carbon into the atmosphere per year and estimated to account for about 20% of global anthropogenic CO_2 emissions (source: 2010 Global Forest Resources Assessment).

3) **Livestock farming** due to **increased meat demand/consumption**

    - Domestic livestock such as cattle, buffalo, sheep, goats, and camels produce large amounts of **methane** as part of their normal digestive process (ruminant digestion).

    - Also, when animals' manure is stored in holding tanks and not properly treated, methane is naturally emitted.

    - Due to ten times more land required for animal production as compared to vegetable products, deforestation is more extensive hence more **CO_2** is emitted (*refer to point 2*).

4) **Landfills and wastewater treatment**

    - **Methane** is generated when waste from homes and businesses dumped at landfills decomposes and in the treatment of wastewater.

3. The Effects of Climate Change on the Abiotic and Biotic Environment

Learning Objectives:

b) Explain the effects of climate change as a result of greenhouse emissions, including the melting of polar ice caps, rising sea levels, stress on fresh water supplies, heat waves and heavy rains, death of coral reefs, migration of fishes and insects, release of greenhouse gases in frozen organic matter.

c) Explain how climate change affects plant distribution (vertical and latitude) and plant adaptations, including morphology and physiology.

d) Discuss the consequences to the global food supply of increased environmental stress resulting from climate change, including the effects on plants and animals of increased temperature and more extreme weather conditions.

i) discuss the effects of increased environmental stress (including increased temperatures and more extreme weather conditions) as a result of global climate change, on habitats, organisms, food chains and niche occupation.

j) Discuss how climate change affects the rich biodiversity of the tropics including the potential loss of this rich reservoir for biomedicines and genetic diversity for food.

Climatic Changes as a Result of the Emission of Greenhouse Gases

Is global warming already happening?

- The IPCC concluded in its Fourth Assessment Report, that nearly 90% of the 29,000 observational data series examined revealed changes consistent with the expected response to global warming, and the observed physical (**abiotic**) and biological (**biotic**) **impacts** have been greatest in the regions that warmed the most.

- The kinds of changes already observed that create this consistent picture include:

(a) Examples of observed abiotic changes

- Increase in global average surface **temperature** of about 0.8°C in the 20th century
- Rise in global average **sea level** and the increase in ocean water temperatures
- Likely increase in average **precipitation** over the middle and high latitudes of the northern hemisphere, and over tropical land areas
- Increase in the frequency of **extreme precipitation** events in some regions of the world
- Decrease of snow cover and sea ice extent and the **retreat of mountain glaciers** in the latter half of the 20th century
- Thawing of permafrost

(b) Examples of observed biotic changes

- Lengthening of the growing season of plants in middle and high latitudes
- Pole-ward (latitude) and upward shift (altitude) of plants and animals
- Decline of some plant and animal species
- Earlier flowering of trees/plants
- Earlier emergence of insects
- Earlier egg-laying in birds

3.1 Abiotic environment

- **Abiotic environment** refer to **non-living** physical and chemical elements in the ecosystem. Examples of abiotic factors are water, air, soil, sunlight, and minerals.

3.1.1 Increasing global temperatures leads to retreating polar ice caps, rising sea levels, and threatens global supply of freshwater

- Polar ice caps consist of

  1. **Sea ice** formed from the **freezing of sea water (salt water)**.
  2. **Glaciers** formed from the **accumulation and compaction of falling snow (fresh water)**.

- Glaciers are extended masses of ice formed from snow falling and accumulating over the years and moving very slowly, either descending from high mountains (valley glaciers), or moving outward from centers of accumulation (continental glaciers, also known as **ice sheets**).

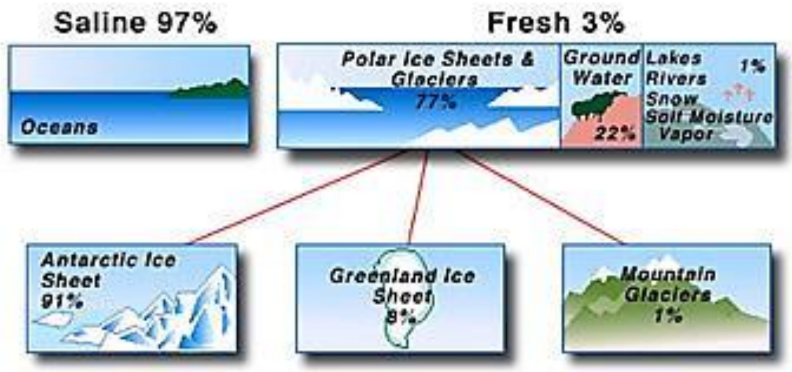


Fig. 3.1: Global locations of ice sheets and glaciers

- **Rising global temperatures** have caused

  - the **melting of polar ice caps** and **reduced their thickness and extent** over the last 30 years. In the Arctic and the Antarctica, the extent of permafrost (*Section 3.1.3*) has also decreased significantly.

  - **shrinking** of areas covered by **sea ice** in the **Arctic** during summer.

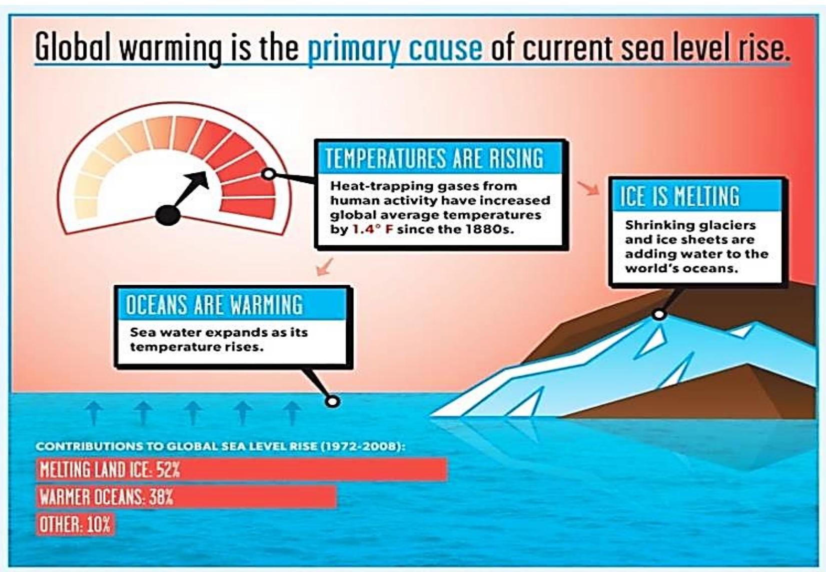


Fig. 3.2: Rising sea levels caused by ocean thermal expansion and melting of glaciers and ice sheets.

- The ocean, being darker, absorbs much more heat from the sun than a layer of snow or ice, which easily reflects light off its white surface. As snow and ice melt, the more exposed ocean leads to increased absorption of heat energy that further warms the planet in what is called a **positive ice-albedo feedback** (Fig. 3.3).

- Water, like other substances, expands as it warms. This causes a **thermal expansion of the warming ocean**, which has been the primary driver for **sea level rise**.

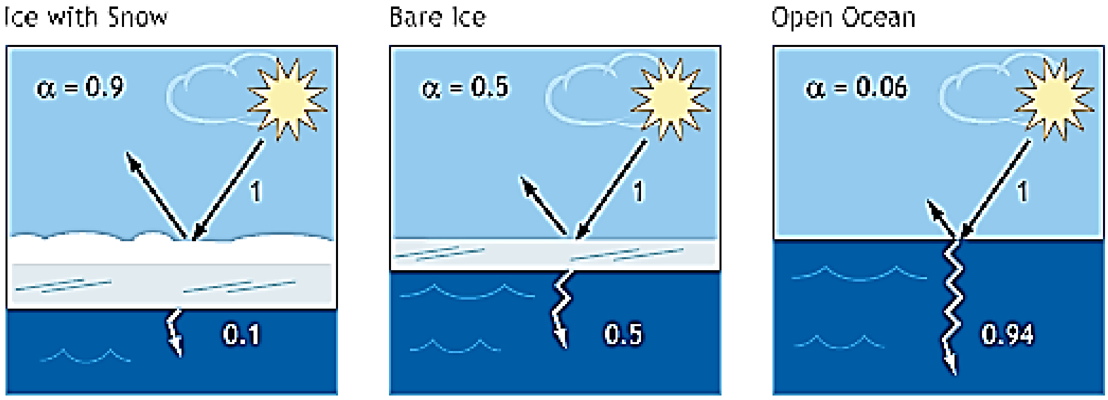


Fig. 3.3: Ice-albedo effect. The fraction of radiation that is reflected back into space is known as *albedo*. These diagrams illustrate how albedo (α) is higher over ice and snow than over bare ice or open ocean.

- According to NASA, the polar ice cap is now melting at the alarming rate of 9% per decade. Arctic ice thickness has decreased 40% since the 1960s. Because of this, the IPCC predicts that sea levels could rise between 25 cm to 58 cm by 2100, but in recent years sea levels have been rising faster than the upper end of the range predicted.

- In addition, the release of water from the **melting land ice** and **glaciers** into the oceans **further** causes the **sea level to rise**.

- Greenland holds 10 percent of the total global ice mass. If it melts, sea levels could increase by up to 6.4 meters. In fact, if all land ice melted, the seas would rise about 70 meters.

- **Consequences of sea level rise**
  - Small islands, whether located in the tropics or higher latitudes, are already exposed to extreme events and changes in sea level.
  - Deterioration in coastal conditions, such as **beach erosion** and **coral bleaching**, affect local resources such as **fisheries**, as well as the value of **tourism destinations**.
  - Sea level rise is projected to worsen flooding, **storm surge**, erosion, and other coastal hazards. These impacts would threaten vital infrastructure, **settlements**, and facilities that support the **livelihood** of island communities. (Fig. 3.4). When large storms hit land, higher sea levels mean bigger, **more powerful storm surges** that can strip away everything in their path.
  - Furthermore, when **salt water intrudes into freshwater aquifers** (underground layer of water-bearing permeable rock), it increases the salinity of freshwater and threatens sources of drinking water and makes raising crops problematic.
    - Low-lying, gentle-sloping coastal areas are particularly vulnerable to contamination of freshwater supplies.
    - In the Nile Delta, where many of Egypt's crops are cultivated, widespread erosion and saltwater intrusion would be disastrous since the country contains little other arable land.

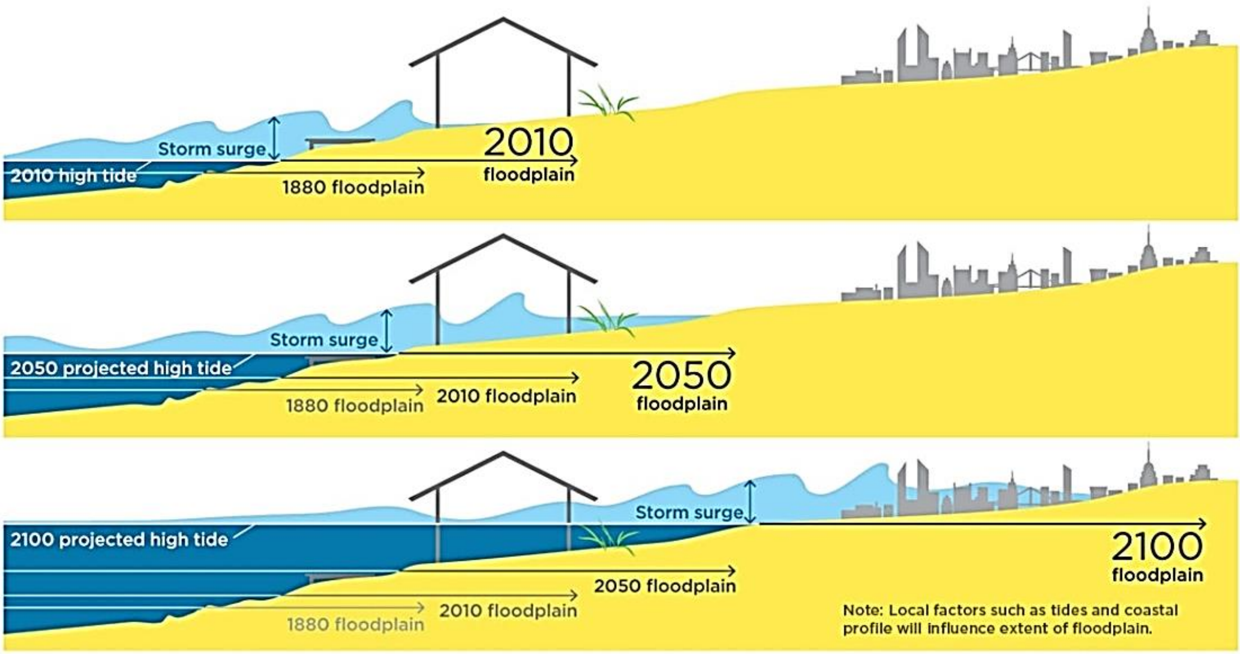


Fig. 3.4: Sea level rise could worsen storm surge, the potentially destructive rise in sea height that occurs during a coastal storm

- The **retreating of ice sheets / glaciers stresses the global supply of freshwater**.
  - Since glaciers provide a major source of freshwater, shrinking glaciers will reduce the availability to accessible freshwater.
  - Glaciers are like reservoirs that store water in the winter and release it in the summer (due to melting). In winter, falling and compaction of snow rebuilds the glaciers.
  - Global warming cause **glaciers / ice sheets to melt** for a longer period of time (into autumn). Coupled with reduction in snow fall, ice sheets and glaciers are retreating at an alarming rate (Fig. 3.5).

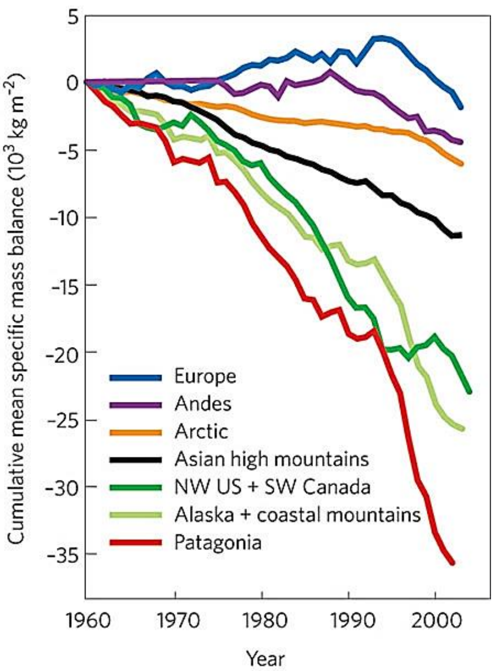


Fig. 3.5: The increasing trend of negative glacial mass balances.

- The continuing loss of glaciers from mountains may cause a temporary increase in water flows in the streams they feed, but will also eventually **reduce the availability of water downstream**.

- Example: Himalayan Glaciers
  - The total freshwater resource in the Himalayan glaciers of Bhutan, China, India, Nepal and Pakistan is estimated to range from 2100 to 5800 Gt. [1Gigaton (Gt) = 1 billion tons]

  - Scientific evidence shows that most glaciers in the Himalayan region are retreating, leading to concerns that, over time, **normal glacier melt will not be able to contribute to the region's water supply** each year.

- In addition, freshwater resources along the coasts face risks from **sea level rise**. The rising sea-levels increase the risk of **saltwater intrusion into freshwater sources** near the coast.

- Climate change is expected to **further reduce the freshwater supply** for people, agriculture and industry in presently **dry areas of the Tropics and subtropics**.

- Example: Quelccaya ice cap in Peru
  - The largest ice cap in the tropics. If it continues to melt at its current rate, contracting more than 182.8 meters a year in some places, it will be gone by 2100, leaving thousands who rely on its water for drinking and electricity high, dry, and in the dark.

3.1.2 Extreme heat waves and heavy rains

- Significant trends in temperature and precipitation extremes over the recent decades have been observed and attributed to greenhouse gases emission:
  - **Heat waves** that will become **more frequent**, **longer** as well as **more intense.**
  - An increase in **heavy precipitation**, particularly in the high latitudes, the tropics and during winters in the northern mid-latitudes. **Warmer air holds more moisture**. When warm air holding moisture meets cooler air, the moisture condenses into droplets that float in the air. If the drops get bigger and become heavy enough, they fall as precipitation.

- Substantial changes in the frequency and intensity of extreme events can result from a relatively small shift in the average of climatic variables, such as temperatures and precipitation (Fig. 3.6).
  - A **small increase in temperature shifts the entire curve towards hotter temperatures**. The rarest and most extreme record heat events become much more severe and much more frequent.
  - The same concept applies to **precipitation**. Light and moderate rains are being **replaced by more heavy rain events**.

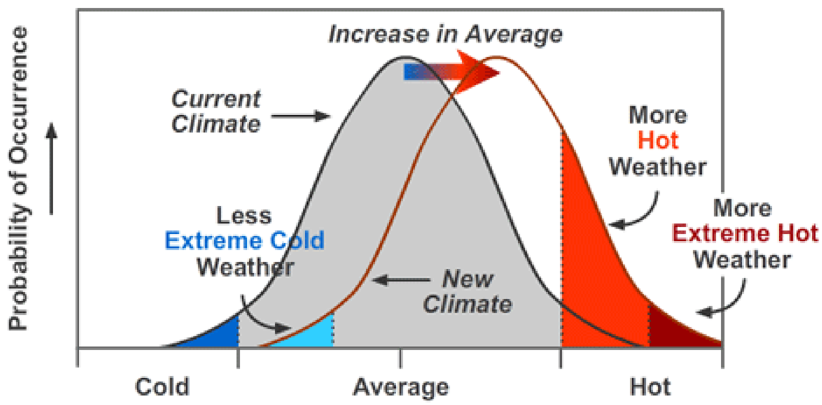


Fig. 3.6: Climate change affects extreme weather events

- Heavy rain and other extreme weather events are becoming more frequent. This can lead to **floods** and **decreasing water quality**, and also **decreasing availability of water resources** in some regions.

- Global warming over the last century means heat extremes that previously only occurred once every 1,000 days are happening four to five times more often.

- It was found that 1 in 5 extreme rain events experienced globally are a result of the 0.85°C global rise in temperature since the Industrial Revolution, as power plants, factories and cars continue to pump out greenhouse gas emissions.

  - 18% of heavy precipitation is due to global warming. This is expected to increase to 40% if temperatures continue to rise.

  - Projections show that future precipitation and storm changes will vary by season and region. Some regions may have less precipitation, some may have more precipitation, and some may have little or no change.

- Changing precipitation patterns as a result of climate change:

  - Some areas such as mid-latitude continental interiors to have **more frequent droughts**.

  - At the same time, **heavier snowstorms and rainstorms** may cause more frequent flooding in other areas.

  - Changes in precipitation patterns could affect the availability and quality of freshwater in many places: arid/semiarid areas (e.g. Sahel region just south of the Sahara Desert) may have the most serious water shortages as the climate changes.

  - Water shortages were predicted in the American West because warmer winter temperatures will cause more precipitation to fall as rain rather than snow. Melting snow currently provides 70% of stream flows during summer months.

3.1.3 Thawing of Permafrost

- Permafrost is ground (including soil, gravels, sands, rocks) that has been frozen for at least 2 years.

- Comprises 24% of northern hemisphere land and in the southern hemisphere (to a lesser extent).
  - IPCC estimates that by the mid-21st century, the area of permafrost in the northern hemisphere will decline by 20-35%.
  - Additionally, the United Nations Environmental Programme suggests the depth of thawing could increase by 30-50% by the year 2080.

- The upper layer of **permafrost** (the **active layer**) sometimes thaws in the summer.

- Permafrost stores an immense amount of **carbon and methane** (twice as much carbon as contained in the atmosphere).

- One-third of the Earth's soil carbon is found in the Arctic tundra soil, stored in frozen organic matter.

- If the high northern latitudes warm significantly, **permafrost will thaw,** allowing the **organic matter** within the permafrost to **decompose**. The decomposition will **release carbon** into the atmosphere (Fig. 3.7).

- Researchers at the National Snow and Ice Data Centre estimate that by 2200, 60% of the northern hemisphere's permafrost will probably be melted, which could release around 190 billion tons of carbon into the atmosphere.

- Other GHGs such as methane will possibly be released into the atmosphere (Fig. 3.7).
  - As the ground warms, methane will either be released directly into the atmosphere or bacteria will break it down into carbon dioxide, which will then be released.
  - If areas of thawed permafrost exist at depth between frozen layers, it is possible that microbial activities will continue unabated, even during the winter, to synthesise new methane from organic material.

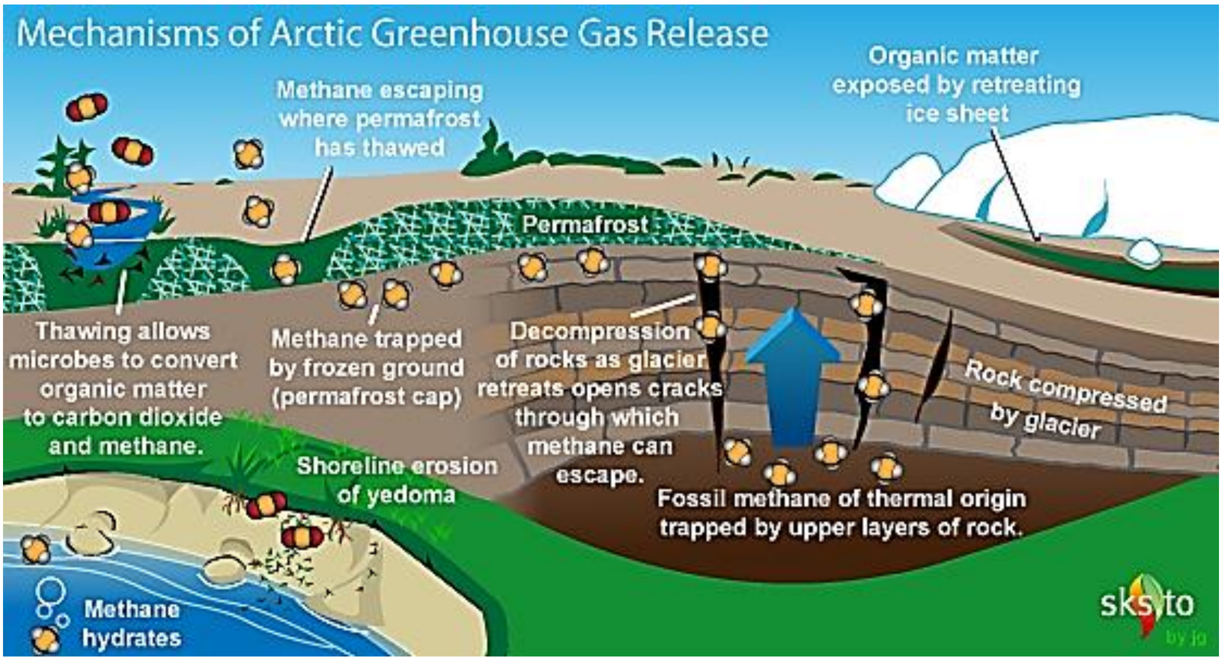


Fig. 3.7: Mechanisms of greenhouse gas release from permafrost

3.2 Biotic environment

- **Biotic environment** refers to **living organisms** in the ecosystem. Examples of biotic factors are animals, birds, plants, fungi, and other similar organisms.

3.2.1 Death of coral reefs

Corals are multicellular animals that are related to anemones and jellyfish.

- There are thousands of different coral species.
- Individual coral animals, called polyps, build external skeletons made of calcium carbonate (similar to limestone).
- Hundreds of polyps make up coral colonies.
- Each polyp sits in its skeleton cup, and has a central mouth surrounded by tentacles with stinging cells on them.

Fig. 3.8:
Coral is made up of many individual polyp.
Each 'cup' in this diagram is a single polyp

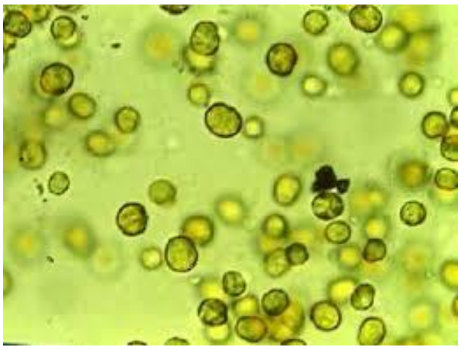


Fig. 3.9: Zooxanthellae

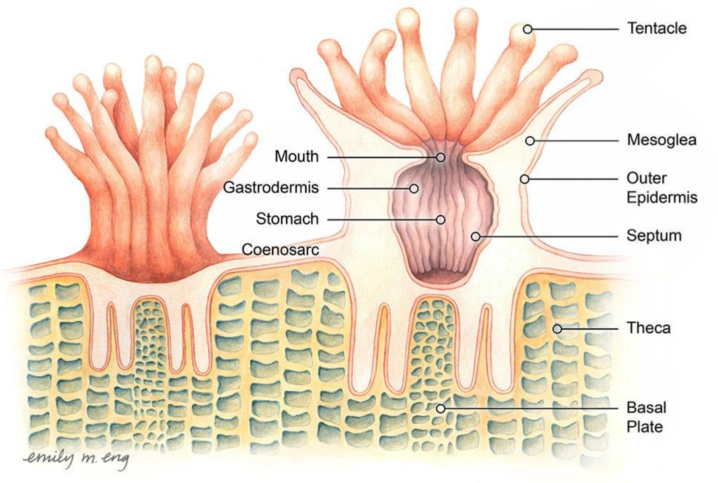


Fig. 3.10: Structure of a single polyp

Corals live in a mutually beneficial relationship (symbiosis) with a type of microalgae called **zooxanthellae.**

- Zooxanthellae are single-celled dinoflagellate microalgae.
- They are responsible for the brown colour of many corals.
- The bright pinks, greens and blues also seen in coral reefs are produced by fluorescent compounds made by the coral host that protect the zooxanthellae from getting too much sunlight, which can be a problem at the middle of the day on coral reefs in the tropics.

Corals and Zooxanthellae have a **symbiosis relationship.**

- Zooxanthellae provide corals with food
  - Zooxanthellae undergo photosynthesis to produce organic carbon in the form of sugars and other compounds.
  - These compounds make up over 95% of the coral's food and nutrition requirements.
  - At night in the absence of photosynthesis, corals stretch out their stinging tentacles and catch the microscopic organisms that float in the water and digest them in their stomachs.

- Corals provide nutrients for zooxanthellae
  - Inorganic nitrogen and phosphorus from the waste products of the coral polyps' metabolic processes are taken in by zooxanthellae.

- Corals provide protection for zooxanthellae
  - Corals make compounds (called mycosporine-like amino acids) which act as a sunscreen, protecting them from too much ultraviolet radiation.

Coral bleaching occurs when the close symbiotic relationship between the zooxanthellae and their coral hosts breaks down.

Causes of coral bleaching:
- Heat stress (causes mass bleaching)
- Changes in pH of ocean water (ocean acidification)
- Excessive light and ultraviolet (UV) radiation
- Coral diseases
- Chemical compounds such as cyanide, herbicides and pesticides

Warmer water temperatures brought on by climate change stress corals

- Both corals and zooxanthellae are very sensitive to changes in temperature as the enzymes/proteins may be denatured at temperatures above the optimum.
- Cellular processes in corals such as respiration are disrupted
- The photosynthesis process in the zooxanthellae is disrupted
- Zooxanthella produce an excess of toxic products which in turn damages the metabolism of the coral polyp, which expels the zooxanthellae, leaving the coral skeleton a stark, 'bleached' white.

The bleached coral can recover if water temperature cools back.

- Zooxanthellae will have time to be able to repopulate the cells of the coral host.
- However, if temperatures remain above the bleaching threshold, zooxanthellae will be lost for substantial periods of time.
- Without nutrients provided by their zooxanthellae, corals will eventually die from starvation and disease.

Coral reefs generally occur in areas where average water temperature is only 1–2°C below the temperature at which the corals become stressed and undergo bleaching.

- Thus, the projected 3-4°C increase in temperature by the end of this century will result in massive death of corals.

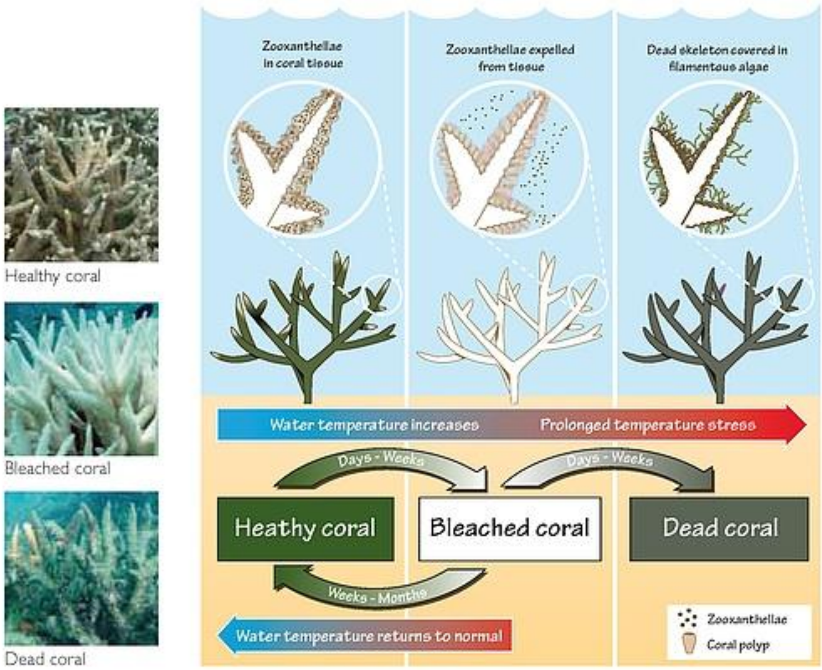


Fig. 3.11: Bleached coral can recover if water temperature returns to normal. However, if the temperature continues to increase, the bleached coral will be dead.

Ocean acidification occurs when the ocean pH decreases.

- Not only are ocean waters warming, but they also absorb more carbon dioxide.
- The oceans have absorbed about 1/3 of the carbon dioxide produced from human activities since 1800 and about 1/2 of the carbon dioxide produced by burning fossil fuels.
- As carbon dioxide in the ocean increases, ocean pH decreases or becomes more acidic.

Ocean acidification affects hard corals.

- For protection and support, hard corals build skeletons made of calcium carbonate. Soft corals do not build calcium carbonate skeletons. Instead they have spines that support them.
- Healthy coral polyps absorb calcium carbonate from the ocean water to build their skeleton.
- With ocean acidification, hard corals cannot absorb the calcium carbonate they need to maintain their skeletons and the stony skeletons that support corals will dissolve.
- The pH of the ocean is about 30% more acidic now than it was in 1751.
- If nothing is done to reduce carbon dioxide emissions into the atmosphere, ocean acidification will increase and more and more corals will be damaged or destroyed.
- Corals in warmer and more acidic seas will find it harder to recover after natural disturbances, leading to an ever diminishing amount of coral on the world's coral reefs

Fig. 3.12: (a) Healthy coral polyps **(b)** Damaged coral polyps due to ocean acidification.

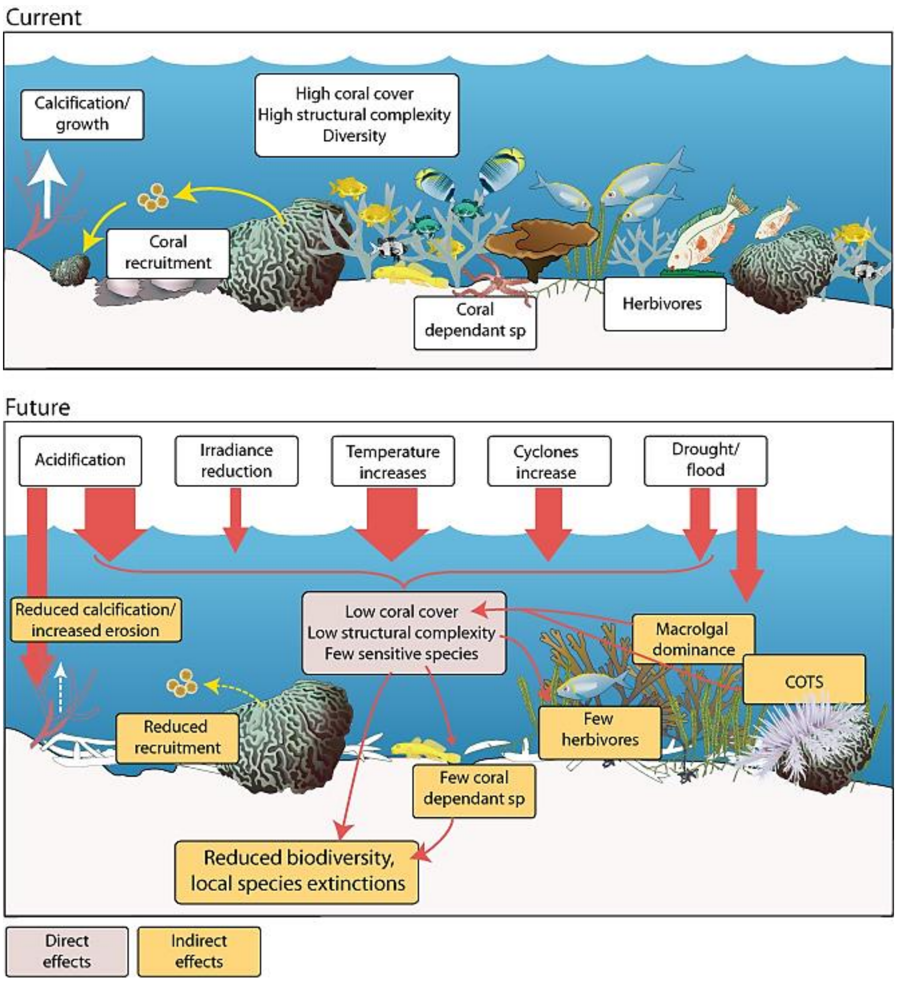


Fig. 3.13: Impacts of climate change on coral reefs.

Coral reefs generally occur in areas where average water temperature is only 1–2°C below the temperature at which the **corals become stressed and undergo bleaching.** Thus, the projected 3-4°C increase in temperature by the end of this century will result in **massive death of corals. Corals** in **warmer** and **more acidic seas** will find it **harder to recover** after natural disturbances, **leading to an ever diminishing amount of coral on the world's coral reefs.**

Important Uses of Corals are as follows:

- Home to numerous species of marine life
- Provide nurseries for many species of commercially important fish
- Protection of coastal areas from storm waves
- The **venom** in ***Conus* sea snails** has been used as **painkiller**.
- **Marine sponges** found on a **Caribbean reef** were found to contain **antiviral and anticancer compounds**.
- Other **medicinal products**, such as **Dolostatin 10,** tested as a **cancer drug** in clinical trials, is also **extracted from a marine organism in a coral reef**.
- Most people are unaware of the importance of **coral reefs** in **providing natural products,** which can be used as **medicine, supplements, and cosmetics**. There is a potentially a large untapped source of chemical products with enormous potential as novel commercial products.
- **Coral reefs** also support fishery industries indirectly because of ecosystem functions that **reef grounds provide, e.g. shelter as spawning grounds and nursery for numerous marine organisms including fish**.

3.2.2 Migration of animals

- Increasing global temperatures are expected to disrupt ecosystems, and even pushing to extinction those species that cannot adapt. Plants and animals can be affected in these aspects:

a) Changes in the timing of seasonal life-cycle events

- Plants and animals exhibit seasonal patterns in their activities because there is a **clear seasonality in the suitability in their environment**. There is often only a limited period in the year when conditions are favourable enough to successfully reproduce or grow.

- For many species, the climate where they live or spend part of the year **influences key stages of their annual life cycle**, such as **migration**, blooming, and mating. As the climate has warmed in recent decades, the timing of these events has changed.

- For example, in a California study, 16 out of 23 butterfly species shifted their migration timing and arrived earlier in spring. The Red Admiral (*Vanessa atalanta*) has advanced its return date to Britain over the past two decades, while the flowering period of one of its host plants, the stinging nettle (*Urtica dioica*), has not advanced. As a consequence, the interval between arrival and flowering date has decreased.

- Changes like these can lead to **mismatches in the timing of migration, breeding, and food availability**. Growth and survival are reduced when migrants arrive at a location before or after food sources are present.

b) Shift in range of animals

- As temperatures increase, the habitat ranges of many North American species are moving **northward in latitude** and **upward in elevation/altitude**.

- Ectothermic organisms (insects) are very sensitive to the ambient temperature which directly affects their physiology → temperature increases have a significant effect on the distribution of several groups of insects, resulting in range shifts.

- Warmer temperatures associated with climate changes will tend to influence (and frequently amplify) insect species' population dynamics directly through effects on survival, generation time, reproductive fitness and dispersal.

- Insect populations in mid to high latitudes are expected to benefit most from climate change through more rapid development and increased survival.

- Insect species' mortality may decrease with warmer winter temperatures, thereby leading to expansion of range towards the poles.

- *Implications illustrated with examples:*

  Range expansion for some species, but a **range reduction** or a movement into less hospitable habitat or increased competition for other species.

  1. As rivers and streams warm, warm-water **fish** are migrating into areas previously inhabited by cold-water species. Coldwater fish, including many highly valued trout species, are losing their habitats.

2. Drosophila parasitoid (a parasitic wasp) is adapted to a hot environment with a narrow thermal niche. It has undergone a very rapid northward progression that parallels a significant temperature increase. The average temperature during the period of the parasitoid activity is quickly approaching the thermal optimum for this species.

3. Studies of the distributions of butterfly species in many countries show their populations are shifting. Surveys of Edith's checkerspot butterfly (*Euphydryas editha*) in western North America have shown it to be moving north and to higher altitudes.

4. Studies of sea life along the Californian coast have shown that between 1931 and 1996, shoreline ocean temperatures increased by 0.79ºC and populations of inverterbrates including sea stars, limpets and snails moved northward in their distributions.

5. An Australian study in 2004 found in the centre of distribution for the AdhS gene in *Drosophila,* which helps survival in hot and dry conditions, had shifted 400 kilometres south in the last twenty years.

Some species have **nowhere to go** because they are already at the northern or upper limit of their habitat.

1. **Cod fish** in the North Atlantic require water temperatures below 12°C. Even sea-bottom temperatures above 8°C can reduce their ability to reproduce and for young cod to survive. In this century, temperatures in the region will likely exceed both thresholds.

2. **Polar bears** in the arctic. Some polar bears are drowning because they have to swim longer distances to reach ice floes. The U. S. Geological Survey has predicted that two-thirds of the world's polar bear sub-populations will be extinct by mid-century due to melting of the Arctic ice cap.

3. **Antarctic penguin**. Over the past 25 years, some populations have shrunk by 33% due to declines in winter sea-ice habitat.

4. **American pika**. Found in the mountain peak of western North America. They have disappeared from more than one-third of their previously known habitats. They have been retreating upwards in altitude over the past 12,000 years.

3.2.3 Changes to plant distribution and adaptation

- Like animals, plants require specific environmental conditions, such as the right temperature, moisture, light levels, in order to thrive. Small changes in environmental parameters can affect the reproduction and survival of plant species.

a) Plant distribution

- Global warming will have an especially severe impact on plants as they cannot migrate as quickly as animals when environmental conditions change.

- During past climate warming, such as during the glacial retreat that took place 12,000 years ago, the upper limit of dispersal for tree species was probably 200km per century.

- If the earth warms as much as during the 21st century as projections indicate, the ranges for some temperate tree species may **shift northward** as much as 480km (Fig. 3.14).

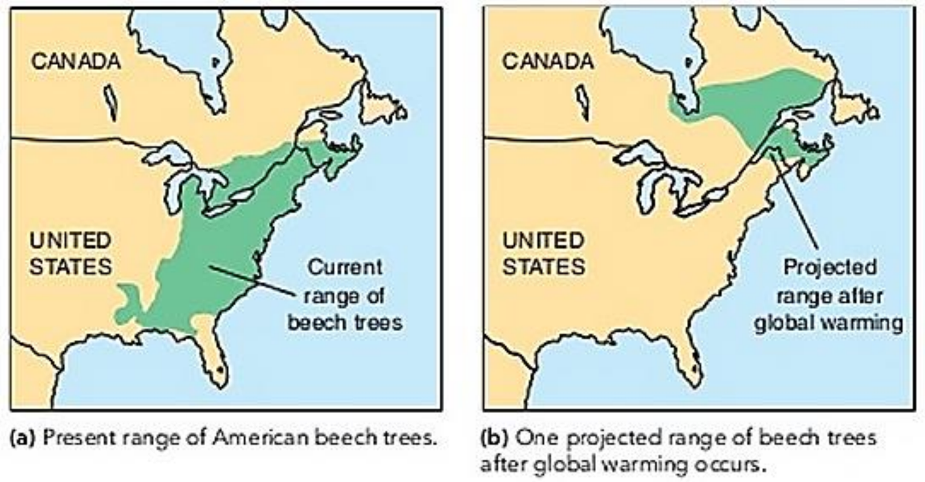
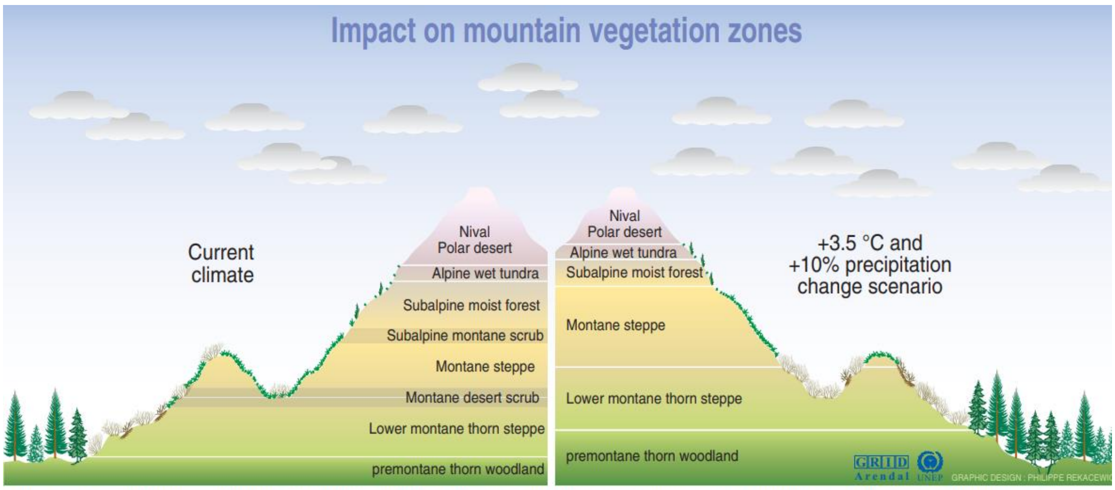


Fig. 3.14: Effect of global warming on the distribution of beech trees in North America**.**

- Habitats of some types of trees are likely to **move northward** or **to higher altitudes**. Other species may **die** if conditions in their current geographic range are no longer suitable. For example, species that currently exist only on mountaintops in some regions may die out as the climate warms since they cannot shift to a higher altitude (Fig. 3.15a&b).



Sources: Martin Benitson, Mountain environments in changing climates, Routledge, London, 1994; Climate change 1995, Impacts, adaptations and migration of climate change, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change (IPCC), UNEP and WMO, Cambridge press university, 1996.

Fig. 3.15 (a): Projected shift of mountain vegetation to higher altitudes. Some species may not be able to adapt and die.

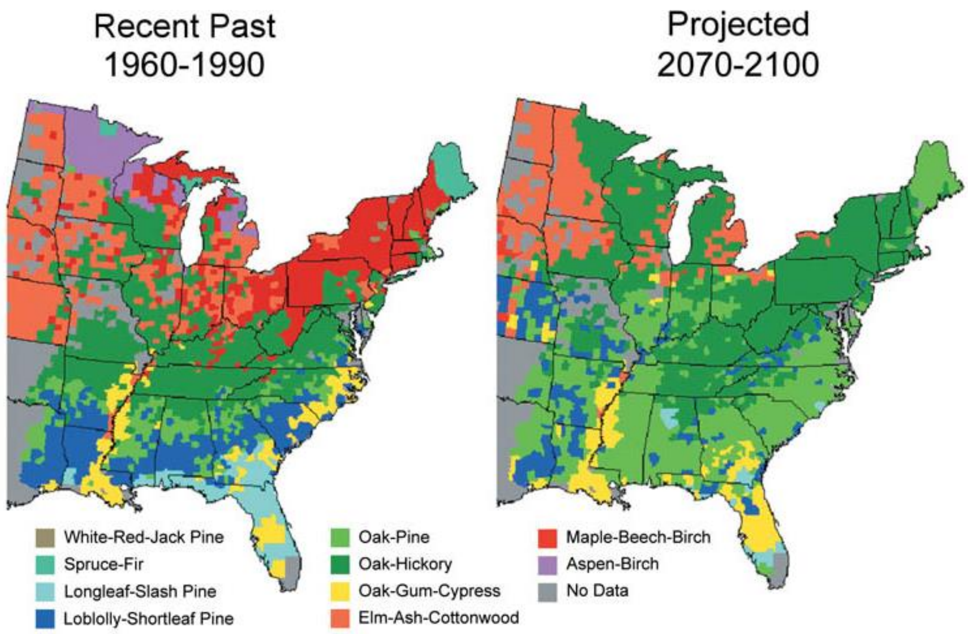


Fig. 3.15 (b): Projected shifts in forest types.

- Studies of forests in the United States have shown that although there will increases and decreases in the distribution ranges of various tree species, overall there will be an 11% decrease in forest cover, with an increase in savanna and arid woodland. Communities of oak/pine and oak/hickory are predicted to increase in range while spruce/fir and maple/beech/birch communities will decrease.

- Due to the inability of individual plants to move and relocate, plants can only adapt in response to changes in environment.

b) Plant adaptation: **morphology** (structural features)

  - Climate change is expected to drive adaptive shifts within species. There is evidence suggesting that **leaf morphology** has **adaptive significance linked with climate.**

  - Some plants have **evolved various mechanisms** to ensure **survival under elevated temperatures and carbon dioxide levels**. Examples include:

1) Changing leaf orientation
2) Transpiration cooling to reduce heat stress
3) Alterations in the membrane lipid composition

    - One of the typical heat stress symptoms is **tissue senescence**, characterized by membrane damage associated with increased fluidity of membrane lipids and protein degradation in various metabolic processes.

    - **Membrane lipid saturation** is therefore considered an important factor for **high temperature tolerance** in plants.

    - A **higher percentage of saturated fatty acids** in **membrane lipids increases** the **lipid melting temperature** and **prevents** a **heat-induced increase** in the **membrane fluidity**. Therefore, to maintain membrane fluidity, plants increase the content of saturated and monounsaturated fatty acids, modulating their metabolism in response to increasing temperatures. Thus, **increasing the saturation level of fatty acids** appears to be **critical** for **maintaining membrane stability** and **enhancing heat tolerance**.

4) Increased CO_2 levels cause the **closing** and **reduction** in the number of **stomata** per leaf. This in turn reduces the loss of water by transpiration when temperatures rise excessively.

5) Other short-term stress avoidance and acclimation mechanisms

    - E.g. The **leaves** of the Hopbush in South Australia have **narrowed by 2 mm** over the past 127 years, a **40% decrease in width**. It was found that the **closer** the **plants grew to the equator** (warmer and drier their climates), the **narrower their leaves were**. This adaptation will help to **decrease water loss due to transpiration**

c) Plant adaptation: **physiology**

- High temperatures **negatively affect various physiological processes** including **photosynthesis**, primary and secondary metabolism, or lipid and hormonal signaling.

- Heat stress has **negative effects on plant growth and development** by disrupting the stability of various proteins, membranes, and cytoskeleton structures.

- Various **physiological injuries** have been observed under **elevated temperatures**: scorching of leaves and stems, leaf abscission and senescence, shoot and root growth inhibition or fruit damage. Such injuries consequently lead to a decreased plant productivity.

- Heat stress induces **changes in respiration and photosynthesis** and thus leads to a shortened life cycle and diminished plant productivity.

- E.g. high temperature during wheat reproductive development hastened decline in photosynthesis and leaf area, decreased shoot and grain mass as well as weight and sugar content of kernels and reduced water-use efficiency.

3.2.4 Threat to global food supply

- Changes in climate have significant impacts on food production around the world. Heat stress, severity of droughts and flooding may lead to **reductions in crop yields and livestock productivity**.

a) Effects of increased temperature and more extreme weather on crop yield

- Crops tend to grow faster in warmer conditions. However, for some crops (e.g. grains), **faster growth reduces the amount of time that seeds have to grow and mature**. This can reduce yield.

- For any particular crop, the effect of increased temperature will **depend on the crop's optimal temperature** for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there. However, if **warming exceeds a crop's optimum temperature, yields can decline**.

- At mid to high latitudes (further from equator), cereal crop yields are projected to increase slightly, depending on local rates of warming and crop type. At lower latitudes, cereal crop yields are projected to decrease. The greatest decreases in crop yields will likely occur in dry and tropical regions. In some African countries, for example, yields from rain-fed agriculture in drought years could decline by as much as 50% by 2020. This decline will likely be exacerbated by climate change.

- **Higher CO_2 levels may accelerate the growth** of some crops and **increase yields**. The yields for some crops, like wheat and soybeans, could increase by 30% or more under a doubling of CO_2 concentrations. The yields for other crops, such as corn, exhibit a much smaller response of less than 10% increase.

- However, some factors may **counteract** these potential increases in yield. For example, if temperature exceeds a crop's optimal level or **if there is insufficient water and nutrients**, yield increases may be reduced or reversed.

- Extreme events, especially **floods and droughts**, can **harm crops and reduce yields**. For example, in 2008, the Mississippi River flooded just before the harvest period for many crops, causing an estimated loss of $8 billion for farmers.

- Many **weeds, pests and fungi** thrive under warmer temperatures, wetter climates, and increased CO_2 levels.
    - Increased use of pesticides, herbicides and fungicides becomes more costly to farmers and may negatively affect human health.
    - When the ranges of weeds and pests expand, this would cause new problems for farmers' crops previously unexposed to these species.

Case Study 1: Rice

Rice grain production drops 10% for each 1°C increase in temperature.

This is due to the vulnerability of its flowering process in response to environmental stress.

- Heat stress during the reproductive stage results in reduced yield.

- Rice that is exposed to temperature of more than 35°C for 5 days during the flowering period is sterile.

Rice is grown in vast low-lying deltas and coastal areas in Asia; sea-level rise would therefore make rice production very vulnerable to climate change. More than half of Vietnam's rice produce, for instance, is grown in Mekong River delta – all of which would be affected by sea-level rise. Salinity is associated with higher sea levels as this will bring saline water further inland and expose more rice-growing areas to salty conditions. Rice is only moderately tolerant of salt and yields can be reduced when salinity is present.

Case study 2: Wheat

Wheat has a relatively low optimum temperature for growth.

- For certain wheat, a period of low temperature is required to initiate the flowering process. (known as vernalisation)

- With global warming, there will be low flower bud initiation, ultimately reduce the yield of wheat.

In a study performed in Kansas, high temperature has shown to reduce the yield of wheat production.

Case study 3: Corn and Soybean

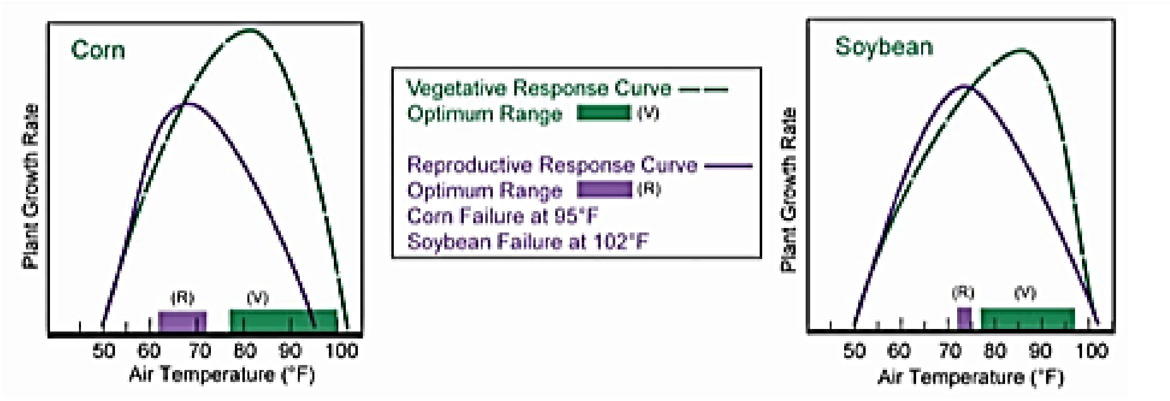


Fig. 3.16: For each plant variety, there is an optimal temperature for vegetative growth, with growth dropping off as temperatures increase or decrease. Similarly, there is a range of temperatures at which a plant will produce seed. Outside of this range, the plant will not reproduce. As the graphs show, corn will fail to reproduce at temperatures above 95°F and soybean 102°F.

Case study 4: Grapes

Climate change is a major challenge in wine production. Temperatures are increasing worldwide, and most regions are exposed to water deficits more frequently.

- Higher temperatures trigger advanced phenology. This shifts the ripening phase to warmer periods in the summer, which will affect grape composition, in particular with respect to aroma compounds.
- Increased water stress reduces yields and modifies fruit composition.
- The frequency of extreme climatic events (hail, flooding) is likely to increase. Depending on the region and the amount of change, this may have positive or negative implications on wine quality.
- Adaptation strategies are needed to continue to produce high-quality wines and to preserve their typicity according to their origin in a changing climate. The choice of plant material is a valuable resource to implement these strategies.

b) Effects on livestock

- Changes in climate could affect animals both directly and indirectly.
  - **Heat waves**, which are projected to increase under climate change, could directly threaten livestock and cause **death**. Over time, heat stress can **increase vulnerability to disease, reduce fertility,** and **reduce milk production.**
  - **Increase the prevalence of parasites and diseases** that affect livestock. The earlier onset of spring and warmer winters could allow some parasites and pathogens to survive more easily. In areas with increased rainfall, moisture-reliant pathogens could thrive.
  - **Drought reduces the amount of quality forage** available to grazing livestock. For animals that rely on grain, drop in crop production means less animal feed available.
  - **Increases in CO_2** may **increase the growth** of plants on which livestock feed, but **may also decrease their quality**. As a result, cattle would need to eat more to get the same nutritional benefits.
- Studies analysed that heat stress has resulted in reduced milk yield and increased mortality (death) of cows.

Fig. 3.17:

Holstein-Friesian cow and calf. A change in average temperature over the hot dry period and a change in the number of extreme days will both likely lead to changes in dairy production. In dairy cows, heat stress reduces the amount of milk produced, reduces milk fat and protein content, and decreases reproduction rates.

Fig. 3.18:

Shelter from the sun provided for cattle at a feedlot. Beef cattle in feedlots subject to heat stress can experience reduced health and a reduction in growth, influencing the amount of beef product sent to market.

Increase in prevalence of parasites and diseases affecting livestock

- The earlier onset of spring and warmer winters could allow some parasites and pathogens to survive more easily.
- In areas with increased rainfall, moisture-reliant pathogens could thrive.
- The temperate regions may become more suitable for tropical vector-borne diseases such as Rift Valley fever and malaria, which are highly sensitive to climatic conditions.
- Vector-borne diseases of livestock such as African horse sickness and bluetongue may expand their range northward to the Northern Hemisphere because rising temperatures increase the development rate and winter survival of vectors and pathogens.

- The distribution, composition and migration of wild bird populations that harbour the genetic pool of avian influenza viruses will be affected by climate change.

c) Effect on fishery

- Fisheries are important for the food supply and economy of many countries. For example, more than 40 million people rely on the fisheries in the Lower Mekong delta in Asia.

- Many fisheries already face multiple stresses, including overfishing and water pollution. Climate change may worsen these stresses. In particular, temperature changes could lead to significant impacts.

    - Increasing ocean temperatures have caused some marine species including fish and shellfish **to shift to cooler waters outside of their normal range**.

    - Many aquatic species can find colder areas of streams and lakes or **move northward** along the coast or in the ocean. However, moving into new areas may put these species into **competition with other species** over food and other resources.

    - Reductions in water flow and increases in sea level may negatively affect **local water quality and survival of fish species**. This would affect the food supply for communities that depend on these resources.

3.2.5 Changes to habitats, organisms, food chains and niche occupation

- **Ecological niche** - takes into account all biotic and abiotic aspects of the species' existence.
    - It encompasses the organism's interactions with other organisms and its effects on the environment.
    - In short, the ecological niche is the totality of an organism's adaptations, its use of resources and the lifestyle to which it is fitted in its community; how an organism uses materials from its environment as well as how it interacts with other organisms.

- The niche includes the local environment in which a species lives – its **habitat**.

- The **food chain** is a series of organisms through which energy flows in an ecosystem. A complex interconnection of all the food chains in an ecosystem is the **food web**.

The Effects:

- In response to global warming, some species may disperse into new environments or adapt to the changing conditions in their present habitats. Some species emerge as winners, with greatly expanded numbers and ranges (e.g. weeds, pests, disease-carrying organisms).

- Because of the network of community interactions among populations of different species within an ecosystem, the local extinction of one species can have a negative impact on the overall species richness of the community.

- Climate change will affect patterns and processes of species and food webs in a variety of ways, such as metabolic rates and modification of dispersal rates.

Examples:

1. Warmer temperatures in Antarctica (average annual temperature on the Antarctic Peninsula has increased by 2.6°C) have contributed to reproductive failure in Adélie penguins.

    - The birds normally lay their eggs in snow-free rocky outcrops. Warmer temperatures have caused more snowfall, which melts when the birds incubate the eggs. The melted snow forms cold pools of slush that kill the developing chick embryos.

2. Researchers determined that populations of zooplankton in the California Current have declined 80% since 1951 apparently because the current has warmed slightly.

    - The decline in zooplankton has affected the entire ecosystem's food web, and populations of seabirds and plankton-eating fishes have also declined.

3. Migratory birds experience severe impacts to their habitats following periods of hurricanes and droughts.

3.2.6 Reduction in the rich biodiversity of the tropics

"Healthy ecosystems and rich biodiversity are fundamental to life on our planet. Climate change is affecting the habitats of several species, which must either adapt or migrate to areas with more favorable conditions. Even small changes in average temperatures can have a significant effect upon ecosystems. The interconnected nature of ecosystems means that the loss of species can have knock-on effects upon a range of ecosystem functions."

- Biodiversity refers to the variety of life on Earth, as well as the interactions between them and the ecosystems in which they live.

- The **tropics are the most diverse region** on Earth as they host about 80% of the planet's terrestrial species and over 95% of its corals and mangroves.

- The biosphere is reacting to climate change. This may affect speciation and extinction rates, geographic distribution of species, composition and functioning of ecosystems, ecophenotypic adaptation and biogeochemical cycles.

- Climate change could surpass habitat destruction as the greatest global threat to biodiversity over the next few decades

- **Tropical biodiversity** is particularly **susceptible to environmental changes**. The tropics have the highest number and proportion of threatened species (Fig. 3.19).

Region	Amphibians		Birds		Mammals		Reptiles		Plants	
	# Assessed	Threatened %	# Assessed	Threatened %	# Assessed	Threatened %	# Assessed	Threatened %	# Assessed	Threatened %
Tropics	**5,356**	**43**	**9,117**	**12**	**4,243**	**26**	**2,756**	**27**	**13,225**	**67**
Central & Southern Africa	949	35	2,175	10	1,190	23	599	36	2,683	61
Northern Africa & Middle East	83	1	1,289	3	472	9	162	9	774	29
South Asia	300	57	973	7	305	30	166	22	1,204	47
South East Asia	795	30	2,540	10	1,121	31	797	21	2,897	52
Caribbean	200	74	798	7	190	17	114	47	630	72
Central America	691	62	1,424	6	521	18	533	19	960	59
South America	2,271	38	3,233	12	1,147	20	398	24	4,792	68
Oceania	391	12	1343	10	501	24	314	32	1,593	53
Rest of the World	**1,243**	**25**	**4,398**	**9**	**2,410**	**15**	**1,418**	**20**	**3,918**	**42**
World	**6,355**	**41**	**10,050**	**13**	**5,492**	**25**	**3,744**	**26**	**15,645**	**60**

Fig. 3.19: High number of species under threat in the tropics.

a) Potential loss of **genetic diversity for food**

- Biodiversity plays a crucial role in human nutrition through its influence on world food production, as it ensures the sustainable productivity of soils and provides the genetic resources for all crops, livestock, and marine species harvested for food.
- Reduction in species richness harms the functioning and services of ecosystems.
- Climate change causes decrease in genetic diversity of populations due to **directional selection** and **rapid migration**. This could in turn affect ecosystem functioning and resilience.
- According to the IPCC (2014), if temperatures rise by 2°C or more above late twentieth century levels, without adaptation, **production of the world's major staple crops** (wheat, rice and maize) will be **negatively affected** in the tropics.
- Climate change will **shift the distribution of land suitable for cultivating many crops**. It is predicted that in sub-Saharan Africa, the Caribbean, India and northern Australia, the amount of land suitable for crop production will decline, while there will be gains in the northern United States of America, Canada and most of Europe.
- **New crop varieties will be needed**, and in some cases farmers will have to shift to growing new crop species. The areas that are currently the most food-insecure will be worst affected and will have the greatest need for new crop varieties that are tolerant of drought, high temperatures, flooding, salinity and other environmental extremes.
- **Heat stress** affects animals in a number of ways – **production** and **fertility decline** and **death rates increase**.
    - o High temperatures also increase animals' water requirements and reduce their appetites and feed intakes.
    - o Extreme climatic events such as droughts, floods and hurricanes have the potential to kill large numbers of animals.

b) Potential **loss of biomedicines**

- Biomedicines are bioactive compounds formed in plants and utilized for pharmaceutical products.

- Significant medical and pharmacological discoveries are made through greater understanding of the earth's biodiversity. Loss in biodiversity may limit discovery of potential treatments for many diseases and health problems.

- Biophysical diversity of microorganisms, flora and fauna provides extensive knowledge which carry important benefits for biological, health, and pharmacological sciences.

- Many species that are threatened could potentially provide medicines for human use, making biodiversity a crucial natural resource.

- Example of biomedicines: In the 1970s, researchers discovered that the rosy periwinkle, which grows on the island of Madagascar, contains alkaloids that inhibit cancer cell growth, treatments for Hodgkin's disease and a form of childhood leukemia.

- Although synthetic medicines are available for many purposes, the global need and demand for natural products persists for use as medicinal products and biomedical research that relies on plants, animals and microbes to understand human physiology and to understand and treat human diseases.

- **Forests have species-rich and diverse wildlife communities**. Their destruction will lead to innumerable extinctions of little-known forms of life with the subsequent loss of genetic variety and potential resources. **Tropical forests** have already given us **anti-cancer** and **anti-malarial drugs** and scientists are actively investigating tropical moist forest plants for **drugs to control HIV and many other diseases**.

4. Effects of Climate Change on the Spread of Mosquito-borne Infectious Diseases

Learning Objectives:

e) Explain how temperature changes impact insects, including increased temperature leading to increased metabolism and the narrow temperature tolerance of insects.

4.1 Impact of Temperature Changes on Insects

- Insects are **bio-indicators of current global climate change** because they have:
  - short generation times
  - high reproductive rate and dispersal capacities. This means that they are more likely to **respond quicker to climate change** than long-lived/sedentary organisms

- Insects, like many invertebrates, are **directly affected by changes in weather to a greater extent** than warm-blooded animals. External temperatures is required to be above critical thresholds for adult activity or the development of immature stages. This is because:

  - Insects are **ectotherms**, i.e. internal physiological sources of heat are relatively small. Hence, they have **limited ability to regulate their body temperatures**.

  - Insects have **distinct life stages** that vary in size, morphology and physiology. The different life stages may experience different environmental conditions and climates.

  - It is well-established that there is a range of temperatures over which each species can grow and reproduce (thermal window).

- Due to temperature changes as a result of global warming, many insect species are **shifting their distributions to higher latitudes/altitudes,** where temperatures are cooler. Evolutionary adaptations could be observed at newly available habitats (*Topic 13: Biological Evolution*).

- Until recently, species introduced from warmer regions to temperate areas have been constrained by growing seasons that were too short. However, global warming, which lengthen warmer seasons, is likely to provide new opportunities for insect species to potentially cause **economic**, **ecological** and even **health hazards** in their new habitats.

4.1.1 Increased temperatures lead to increased insect metabolism

- Temperature remains a primary focus for explaining development rate variation in insects.

- Most species perform best in a **fairly narrow range of temperatures**.

- The influence of temperature on the physiological activity of insect species could be measured by their **metabolic rate**.

- It was found that with increased temperature over the past 3 decades, the **rate of metabolism** in insects **increased significantly**, particularly for tropical insects (Fig. 4.1).

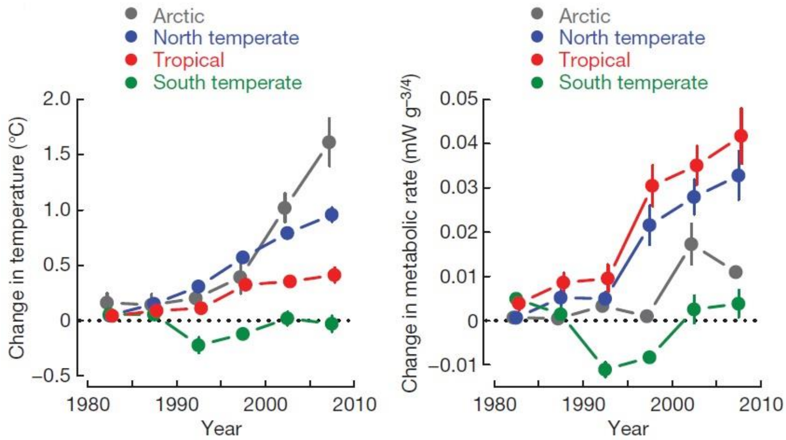


Fig. 4.1: There is a correlation between increased temperature and increase in metabolic rates in insects, especially in the tropics.

- Therefore, **higher temperatures** are usually associated with **faster developmental rate**. This have physiological and ecological impacts on insects:
  1. Increased need for food
  2. Increased vulnerability to starvation unless food resources increase
  3. Altered food web dynamics (leading to elevated rates of herbivory and predation)
  4. Changes in the spread of insect-borne tropical diseases

4.1.2 Narrow temperature tolerance of insects

- **Temperature tolerance** (thermal tolerance) refers to the ability of the organism to **withstand changes in temperatures** before its performance/fitness drops to fatal levels.

- Insects are likely to be vulnerable to climate warming and the resultant temperature changes as their basic **physiological functions** such as locomotion, growth, reproduction are **strongly influenced by environmental temperatures**.

- The temperature tolerance of many organisms has been shown to be **proportional to the magnitude of temperature variation they experience**.

- A recent study (Fig. 4.2) showed that **warming in the tropics** is likely to have the **most deleterious consequences** because tropical insects have **lower temperature tolerance** and are **currently living very close to their physiological limits of high temperature**.

- In contrast, species at higher latitudes (colder, temperate climates) have **broader thermal tolerance** and are living in climates that are currently cooler than their physiological optima, so that warming may even enhance their fitness.

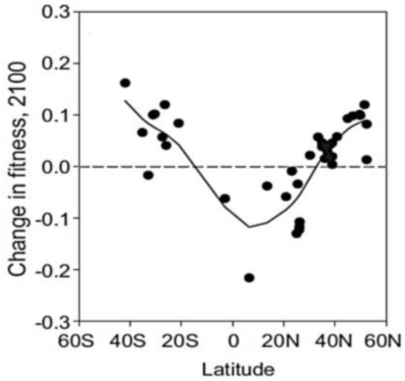


Fig. 4.2: 38 species of insects across latitudes (tropics to temperate and arctic environments) were investigated for their change in fitness (measured by population growth rates) when subjected to warming.

4.2 Mosquito as an Insect Vector

Learning Objectives:
f) Outline the life-cycle of *Aedes aegypti* as an example of a typical mosquito vector.
g) Outline the development of the viral dengue disease in humans, including host-pathogen interactions, human susceptibility to the virus, pathogen virulence, transmission and drug resistance
h) Explain how global warming affects the spread of mosquito-borne infectious diseases, including malaria and dengue, beyond the tropics.

4.2.1 *Aedes aegypti* as a typical mosquito vector

- In epidemiology, a **vector** is any living organism that **carries and transmits an infectious pathogen/parasite into another living organism**. That is, an organism that acts as an **intermediary host** for a pathogen/parasite.

- The *Aedes aegypti* mosquito is the **main vector** that transmits various infectious diseases, including **dengue**, chikungunya and yellow fever.

- These mosquitoes are found throughout **tropical** and **subtropical areas** and have adapted to cohabiting with humans in both the urban and rural environments.

- Moreover, *Aedes aegypti* are predominantly active during daylight hours and breed in and around houses in regular water containers or disposed water-holding vessels.

4.2.2 Life-cycle of *Aedes aegypti* (Fig. 4.3, 4.4)

1. The **adult, female *Aedes aegypti*** mosquito feeds on the blood of a person by injecting its saliva into the human host so as to prevent the host's blood from clotting and ease its feeding.

2. The *Aedes aegypti* mosquito generally lay its eggs above the waterline inside containers that hold water. It can lay 50-100 eggs at a time. The oval-shaped eggs are laid singly in stagnant water and are **resistant to heat** and **desiccation** (drying conditions).

3. When the **eggs are covered by water, the larvae hatch** (emerge from the eggs).
   - The **larva** hangs at the surface of the water and breathes through a snorkel-like siphon at the tip of the abdomen.
   - There are **4 larval stages** that feed on organic materials that they filter out of the water with their mouthparts.

4. The **fourth-stage larva changes into a pupa** that hangs at the surface of the water and breathes air through two snorkel-like siphons at the front end. The **pupa is a non-feeding stage** where the mosquito changes from the larval form into an adult insect.

5. The **adult** mosquito emerges from the pupa.
   - Both adult male and female mosquitoes normally feed on sweet plant juices and nectar from flowers to meet their energy requirement.
   - Only **adult female mosquitoes** feed on humans and animals for **blood to produce their eggs.** The proteins in the blood are required for egg production.
   - After feeding, the female mosquitoes looks for water sources to lay more eggs.
   - Each female mosquito can lay multiple batches of eggs during its lifetime, and often *Aedes aegypti* take several blood meals before laying a batch of eggs.

6. The entire life cycle, from an egg to an adult, takes approximately **8-10 days**.

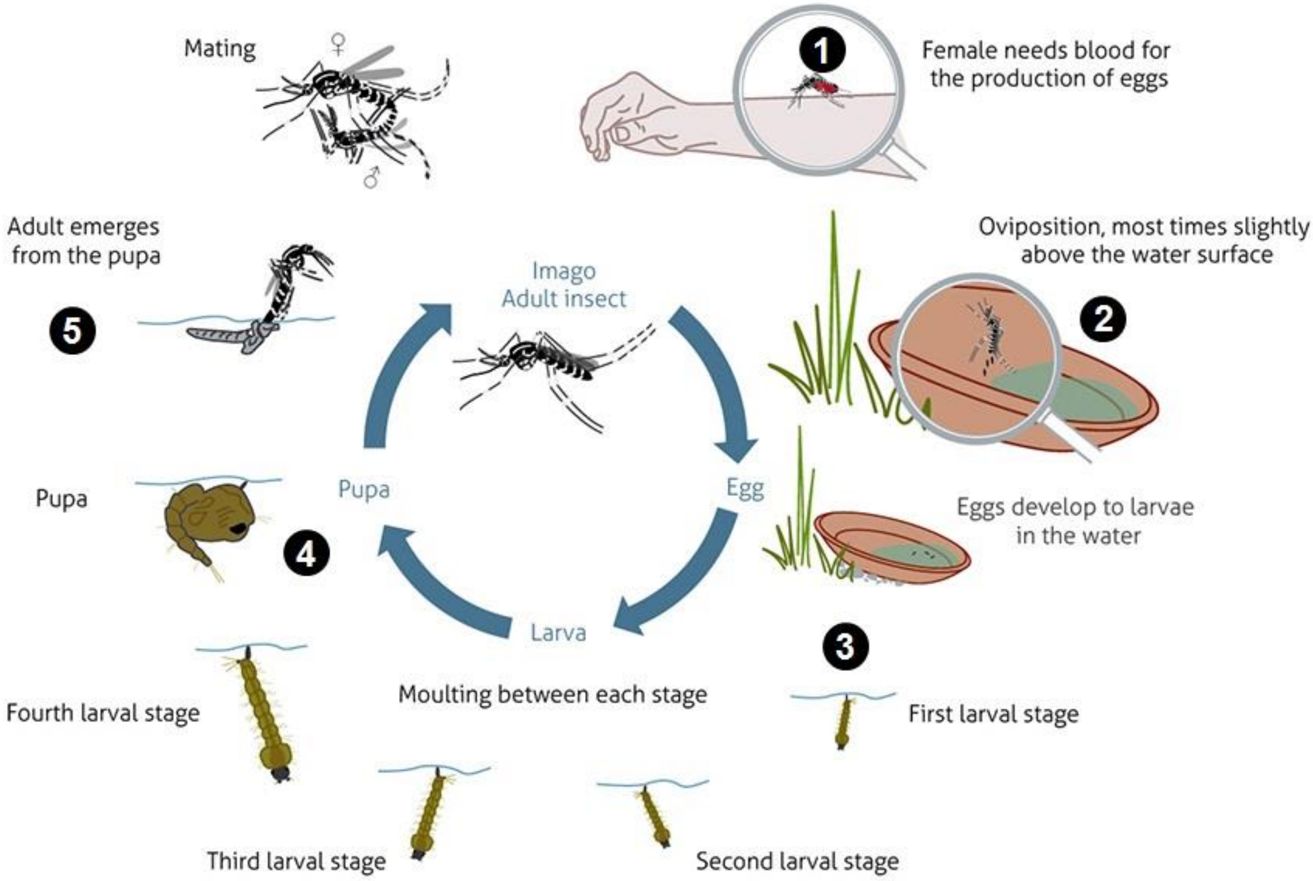


Fig. 4.3: The life-cycle of *Aedes aegypti*

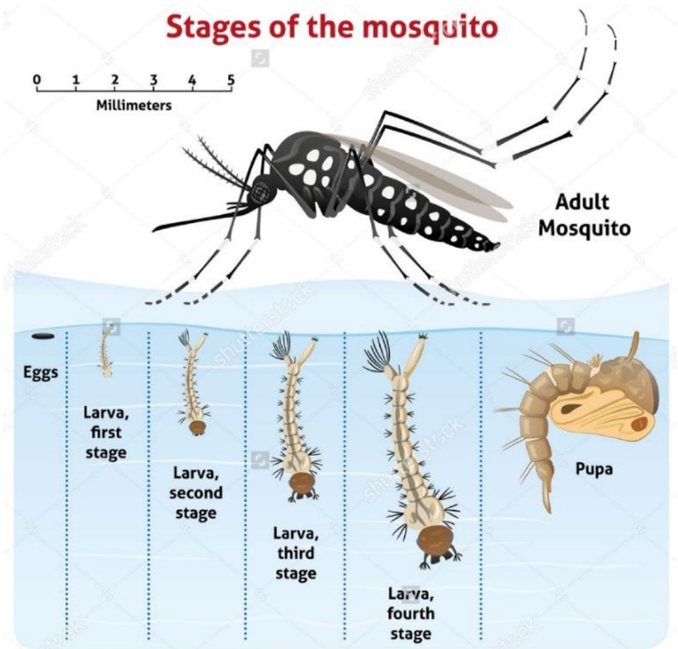


Fig. 4.4: The life-cycle of *Aedes aegypti*

http://www.nature.com/scitable/topicpage/dengue-transmission-22399758

4.3 Dengue: an example of mosquito-borne infectious disease

- Dengue is the most widely distributed and rapidly spreading **arthropod-borne viral infection** of humans. It is currently regarded as the most important **arboviral** (arthropod-borne viral) disease.

- Arthropod: invertebrate animals with an external skeleton called an exoskeleton. E.g. mosquitoes, ticks, lice, flies, and fleas.

- When an *Aedes* mosquito bites a person who has **dengue virus** in his or her blood, the mosquito becomes infected with the dengue virus. An infected mosquito can later transmit that virus to healthy people by biting them. Dengue cannot be spread directly from one person to another, and mosquitoes are necessary for transmission of the dengue virus.

- The risk of contracting dengue infection has increased dramatically since the 1940s. This upward trend is due to:
  1. **increases in long-distance travel**
  2. **population growth** and **urbanization**
  3. **lack of sanitation**
  4. **ineffective mosquito control**
  5. **increases** in the **surveillance** and **official reporting** of dengue cases

- The global incidence rate of dengue infections has increased 30-fold. Approximately 2.5 billion people in dengue endemic (*characteristic of or prevalent in a particular area*) countries are at risk of infection and an estimated 390 million dengue infections occur annually. (Fig. 4.5)

- Dengue has spread through Southeast Asia, the Pacific Island countries, and the Middle East. Today, approximately 40% of people live in regions of the world where there is a risk of contracting dengue.

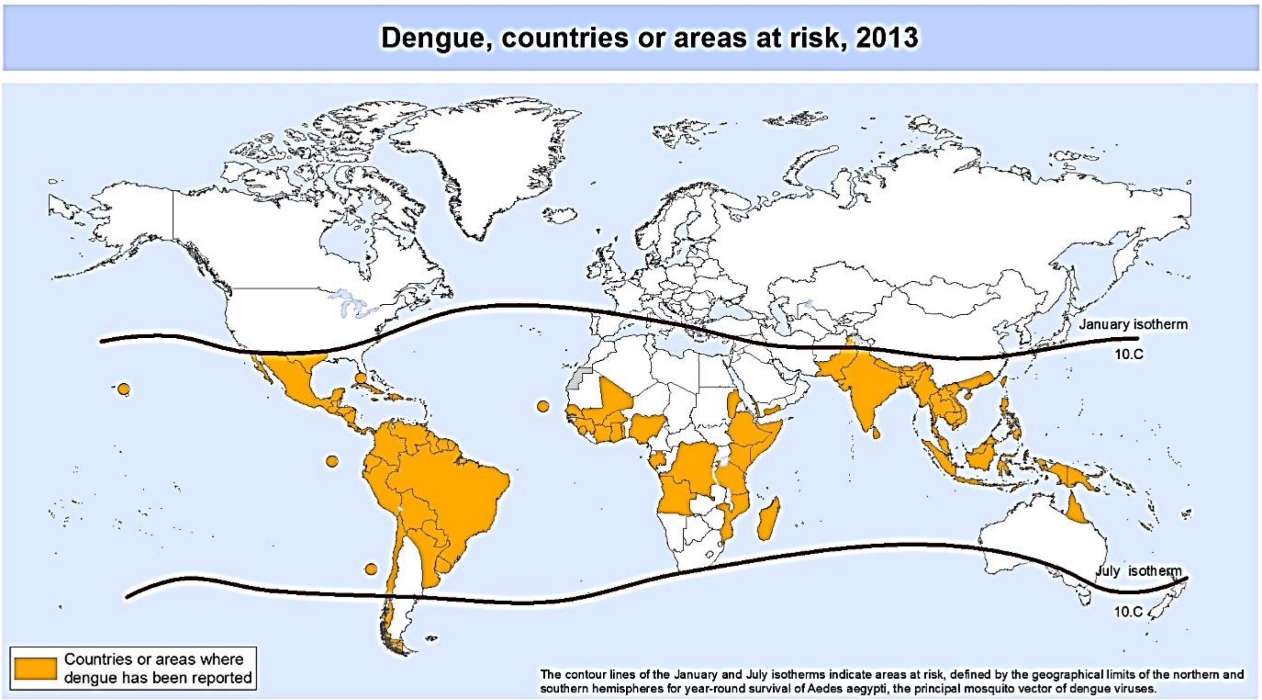


Fig. 4.5: The dengue disease has become endemic in over 100 countries in Africa, the Americas, the Eastern Mediterranean, Southeast Asia and the Western Pacific.

4.3.1 Dengue virus (DENV)

- DENV is a member of the genus *Flavivirus*. It is an **enveloped virus** with **single-stranded (+) RNA genome** (Fig. 4.6, 4.7).

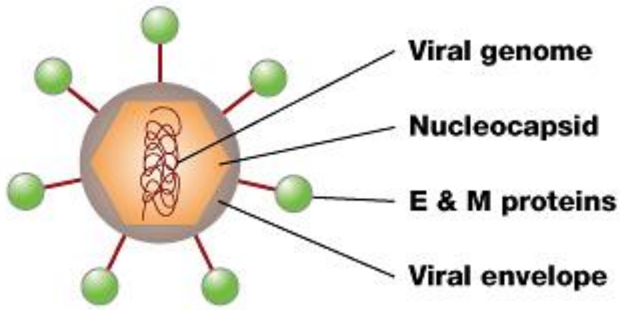


Fig. 4.6: DENV has a roughly spherical shape. Inside the virus is the nucleocapsid, which is made of the viral genome and C proteins. The nucleocapsid is surrounded by the host-derived viral envelope. Embedded in the viral envelope are E and M proteins that span through the lipid bilayer. These proteins control the entry of the virus into human cells. *(Details are not needed in the syllabus)*

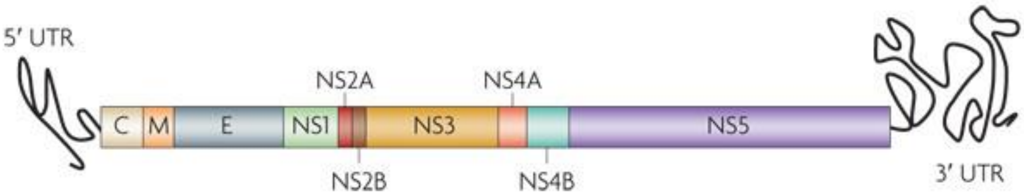


Fig. 4.7: The DENV genome encodes three structural (capsid [C], membrane [M], and envelope [E]) and seven nonstructural (NS1, NS2A, NS2B, NS3, NS4A, NS4B, and NS5) proteins. These nonstructural proteins play roles in viral replication and assembly. *(Details are not needed in the syllabus)*

- Dengue infections are caused by 4 closely related DENV, namely **DENV-1**, **DENV-2**, **DENV-3**, and **DENV-4**.
  - These four DENV are called serotypes because each has different interactions with the antibodies in human blood serum due to **different viral surface antigens**.
  - The four dengue viruses are similar - they share approximately 65% of their genomes - but even within a single serotype, there is some genetic variation.
- Despite these variations, infection with each of the DENV serotypes results in the same disease and **range of clinical symptoms**:
  - High fever (40°C) accompanied by 2 of the following symptoms: severe headache, pain behind the eyes, muscle and joint pains, nausea, vomiting, swollen glands or rash.
  - Severe cases: plasma leaking, fluid accumulation, respiratory distress, severe bleeding, or organ impairment.

4.3.2 Transmission of dengue

- DENV is spread through a **human-to-mosquito-to-human** cycle of transmission (Fig. 4.8).
- Typically, four days after being bitten by an infected *Aedes aegypti* mosquito, a person will develop **viremia**, a condition in which there is a **high level of DENV in the blood**.
- Viremia lasts for 5 to 12 days. On the first day of viremia, the person generally shows no symptoms of dengue.
- Five days after being bitten by the infected mosquito, the person develops symptoms of dengue fever, which can last for a week or longer.
- In order for transmission to occur, the **mosquito must feed on a person during a 5-day period of viremia,** when **large amounts of DENV are in the blood**.
- After entering the mosquito in the blood meal, DENV will require an additional 8-12 days incubation before it can then be transmitted to another human. The mosquito remains infected for the remainder of its life, which might be days or a few weeks.

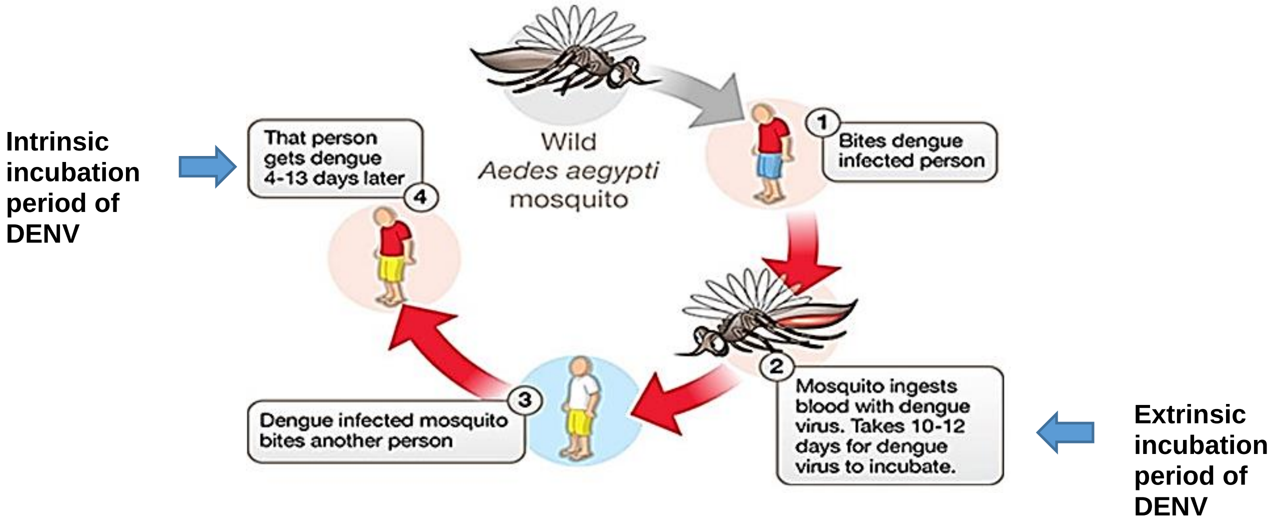


Fig. 4.8: Human-to-mosquito-to-human cycle of dengue transmission

4.3.3 Human-DENV interactions: DENV virulence and human susceptibility

- Normally, monocytes and macrophages ingest and destroy pathogens, but instead of destroying DENV, both types of white blood cells are targeted and infected by DENV.
- **The dengue virus tricks the immune system to get around its defenses and infect more cells.** As the infected white blood cells travel through circulatory system, DENV spreads throughout the body and infect more cells, resulting in viremia.
- Although the dengue virus has tricked the immune system to infect cells and spread throughout the body, the immune system has additional defenses to fight the virus:
    - Infected cells produce and release small proteins that have the ability to **interfere with viral replication**.
    - They help the immune system **recognize DENV-infected cells** and help **protect uninfected cells from infection**.

- The innate immune response also activates the **complement system**, a response that helps the antibodies and white blood cells remove the virus.
- As the immune system fights the dengue infection, the person experiences a fever.

Adaptive response:

- **B cells** produce **IgM** and **IgG** that specifically recognize and neutralize the DENV particles.
- **Cytotoxic T cells** recognize and kill DENV-infected cells.

- Together, the innate and adaptive immune responses neutralize the dengue infection, and the patient recovers from dengue fever.

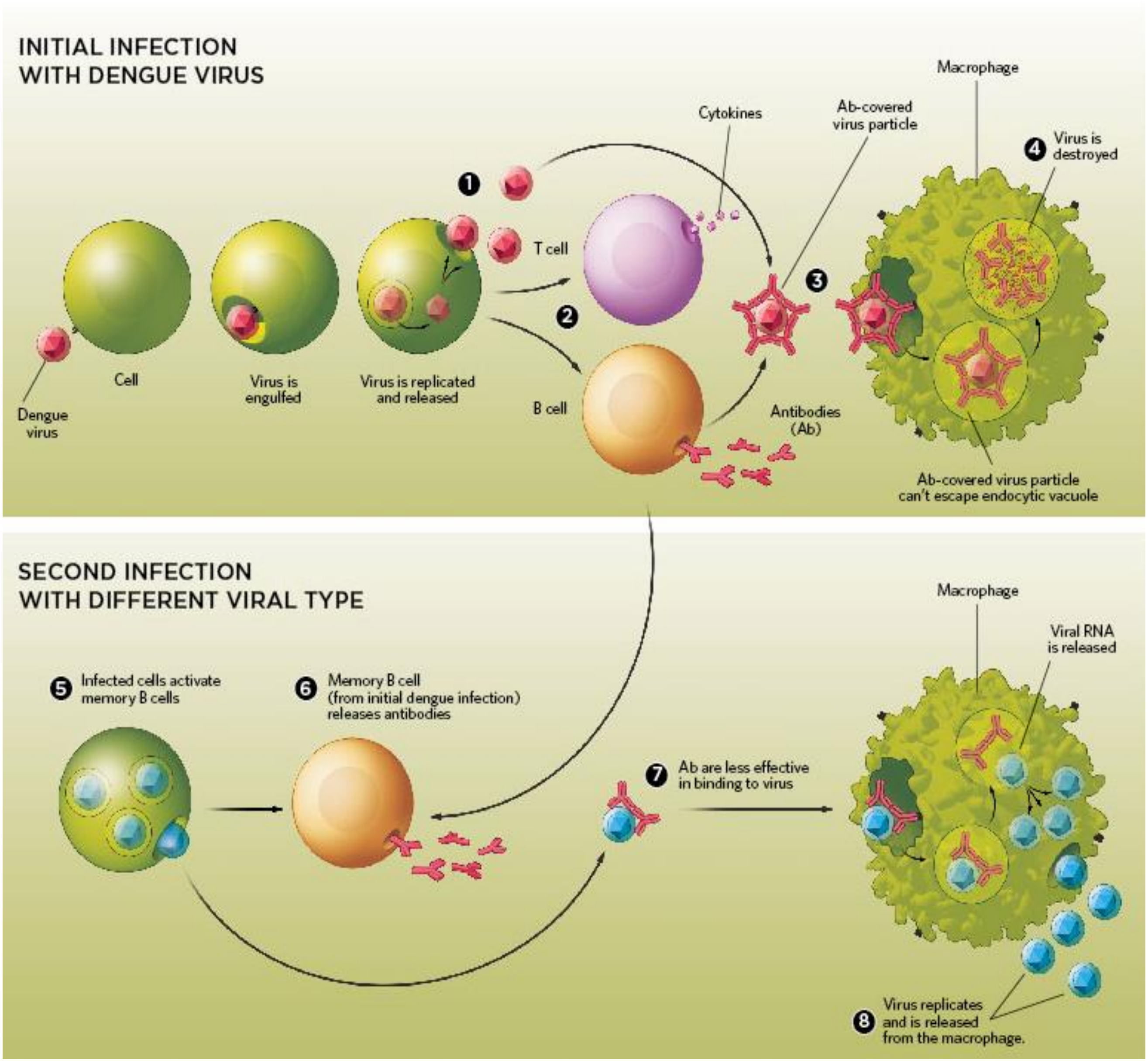


Fig. 4.9: Initial infection with DENV (1) Initial spread of DENV via monocytes. (2) Activation of the innate and adaptive immune responses. (3) Antibody-coated DENV engulfed by phagocytes. (4) Destruction of DENV within the phagocyte. **Second infection with different viral type** (5) Infection with a different serotype. (6) Release of antibodies from memory B cells towards the previous serotype. (7) Antibodies are less effective in binding to virus. Enhanced uptake of DENV into macrophages. (8) Spread of second serotype.

- **<u>DENV virulence could be attributed to</u>**:

  1. The presence of 4 serotypes. A person infected a subsequent time with a <u>different</u> serotype may experience what is known as "**antibody-dependent enhancement**" (Fig. 4.9, 4.10).

     - Antibody-dependent enhancement of infection occurs when pre-existing antibodies from a first DENV serotype infection bind to an infecting DENV particle during a subsequent infection with a **<u>different</u> DENV serotype**.

     - The antibodies from the first infection cannot neutralize the virus. Instead, the Ab–virus complex attaches to receptors (FcγR) on circulating monocytes. The antibodies help the virus infect monocytes more efficiently.

     - The outcome is an increase in the overall replication of the virus and a higher risk of severe dengue. Such infections can result in an acute vascular permeability syndrome known as **dengue shock syndrome (DSS)**.

  2. Ability of DENV to infect a wide variety of human cells, such as dendritic cells, monocytes, macrophages, B cells, T cells, endothelial cells, hepatocytes, and neuronal cells.

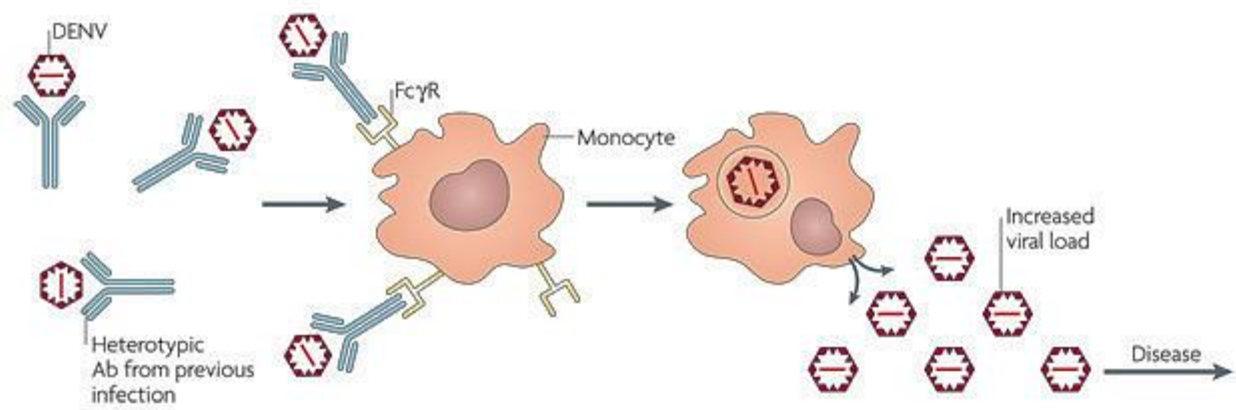


Fig. 4.10: Antibody-dependent enhancement of infection during a subsequent infection with a different DENV serotype.

- In addition, several host factors determine the extent of virulence and pathogenicity of DENV:

  1. **Genetic pre-disposition of host. Various allelic forms of genes** such as human leukocyte antigens (HLAs), tumour necrosis factor-α (TNF-α), glucose-6-phosphate dehydrogenase (G6PD), can **make the host more susceptible** to severe forms of dengue.

  2. DENV infections can be life-threatening when they occur in individuals with asthma, diabetes and other chronic diseases.

  3. Age

     The **severity of dengue shock syndrome (DSS) is age-dependent**, with vascular leakage being most severe in young children. In adults, primary infections often results in dengue fever which is accompanied by a **tendency for bleeding** that can lead to **severe haemorrhages**.

  4. Host immunity

4.3.5 Drug resistance of DENV

- One of the major problems in the treatment of dengue is **drug resistance**. To date, there are **no anti-viral therapeutic agents** available to treat dengue infections.

  - The licensed drug Ribavirin, which has been used to treat a number of RNA viral infections, did not work against DENV. Ribavirin is a nucleoside analog used to stop RNA synthesis and mRNA capping. Both *in vitro* and *in vivo* studies indicated that the drug had little effect on viremia of DENV.

  - Doxorubicin, an antibiotic derived from the fungus *Streptomyces peucetius,* was found to inhibit the early stages of the replication cycle but did not work to effectively prevent the viral replication machinery.

- The development of a **dengue vaccine** has unique **challenges**.

  - The four dengue serotypes circulate globally, and infection with one dengue serotype confers life-long protection against re-infection with the same serotype, but only short-term protection against the other 3 serotypes.

  - There is limited understanding of how the virus interacts with the immune system and how certain types of pre-existing immunity can exacerbate disease.

  - Therefore, a **safe and effective dengue vaccine** must be **tetravalent** (containing antigen from four strains of virus), and induce strong and long-lived protection against all 4 serotypes simultaneously.

- The world's first approved vaccine against all four dengue serotypes, Dengvaxia, was approved in Singapore in late 2016 for use in those aged 12 to 45.

- However, it is more effective only in countries where there is a high prevalence of dengue, and in protecting individuals who already have baseline immunity due to a previous dengue infection. Furthermore, studies also show that the vaccine is less effective against the DENV-1 and DENV-2 strains of dengue, which are the predominant strains in Singapore.

- Going forward, the DENV genome and replication cycle provides a variety of potential targets for the development of inhibitors. Examples include
  - NS5 viral RNA-dependent RNA polymerase and methyltransferase
  - NS3 protease and helicase
  - Viral envelope (E) protein

Project Wolbachia - *Wolbachia-Aedes* Mosquito Suppression Strategy

- Using **male** *Wolbachia*-carrying *Aedes aegypti* mosquitoes to help reduce the dengue mosquito population (Fig. 4.11).
- *Wolbachia* is a bacterium that stops the virus from replicating inside the mosquitoes.
- When male *Wolbachia*-carrying *Aedes aegypti* mosquitoes mate with female *Aedes aegypti* without *Wolbachia*, their resulting eggs **do not hatch.**
- This is because such mating is biologically incompatible. Thus, the release of male *Wolbachia-Aedes aegypti* will lead to a **decline** in the *Aedes aegypti* population in the field over time.
- This mosquito suppression strategy is species-specific. Release of male *Wolbachia-Aedes aegypti* will only impact the *Aedes aegypti* population in the field, and not other insects.

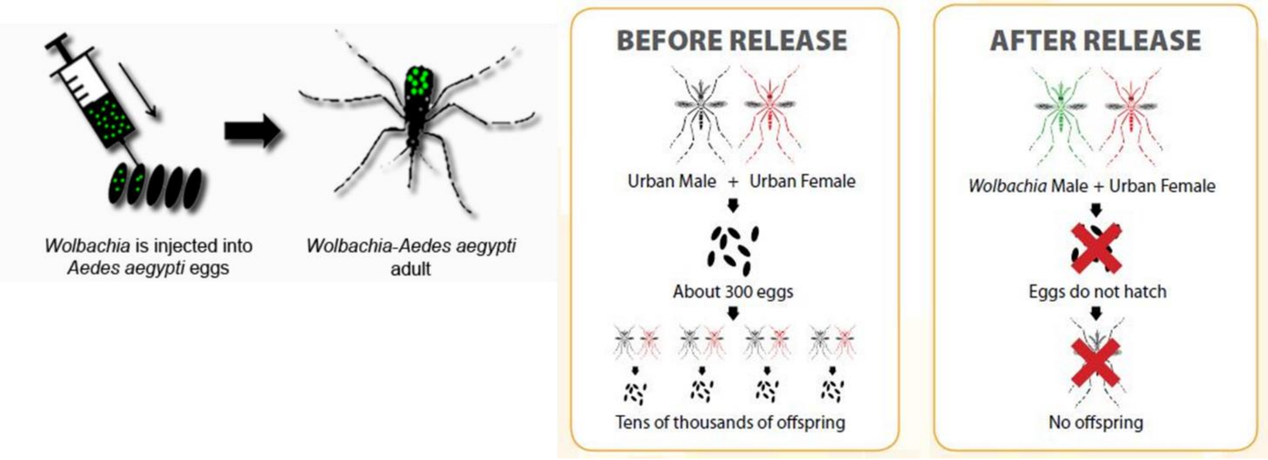


Fig. 4.11: The use of male *Wolbachia*-carrying *Aedes aegypti* mosquitoes to help reduce the dengue mosquito population

Update as on 15 June 2022:
Additional 1,400 HDB blocks to get releases of male Wolbachia-Aedes mosquitoes from July 2022, bringing total coverage of the project to 31% of all HDB blocks in Singapore and more than 300,000 households.

Source : https://www.nea.gov.sg/corporate-functions/resources/research/wolbachia-aedes-mosquito-suppression-strategy

4.4 Effects of global warming on the spread of mosquito-borne diseases beyond the tropics

- Global warming can result in temporal and spatial **changes in temperature, precipitation** and **humidity.** This will affect the biology and ecology of mosquito vectors.

  - It is estimated that average global temperatures would have risen by 1.0–3.5°C by 2100, increasing the likelihood of many insect-borne diseases.

  - Regions most vulnerable to the disease-related impacts of climate change are the temperate latitudes and countries in the Indian and Pacific Oceans and sub-Saharan Africa.

Temperature

- Increased temperature could increase the risk of mosquito-borne diseases by **increasing the rate of mosquito development** and **reducing virus incubation time** in areas where the vector presently exists, thereby **increasing the rate of transmission**.

- Mosquito species responsible for transmitting **malaria** (*Anopheles*) and **dengue** (*Aedes aegypti*) are **sensitive to temperature changes** during their immature stages in the aquatic environment and as adults.

  - If water temperatures rise, the **larvae take a shorter time to mature**. There is a greater capacity to **produce more offspring during the transmission period**.

  - Warmer climates may allow adult female mosquitoes to **digest blood faster and feed more frequently**. This **increases transmission intensity**.

  - Malaria parasites and dengue viruses also complete **extrinsic incubation within the female mosquito in a shorter time** as temperature rises. This **increases the proportion of infective vectors**.

Precipitation

- Changing **precipitation patterns** can also have short and long term effects on vector habitats. Increased precipitation has the potential to **increase the number and quality of breeding sites for mosquitoes.**

- Climate change greatly influences the **El Niño cycle** that is known to be associated with increased risks of some diseases transmitted by mosquitoes, such as malaria and dengue.

- In dry climates, heavy rainfall can provide good breeding conditions for the mosquitoes. Increased humidity and droughts may turn rivers into strings of pools, the preferred breeding sites of mosquitos.

- Climate change will increase the opportunities for malaria transmission in traditionally malarial areas, in areas the disease has been controlled, as well as in new areas beyond the tropics which have been traditionally non-malarial (Fig. 4.12).

- An **increase in temperature, rainfall, and humidity** may cause a **proliferation of the malaria-carrying mosquitoes at higher altitudes** that results in an **increase in malaria transmission** in areas in which it was not reported earlier.

- At lower altitudes where malaria is already a problem, **warmer temperatures** will alter the growth cycle of the parasite in the mosquito which enables it to **develop faster** and **increase transmission**.

- Europe has warmed by a mean of 0.8°C over the last 100 years. This is likely to **reduce the high over-wintering mortality of mosquitoes** and also allow new mosquito species from the tropics to spread northwards.

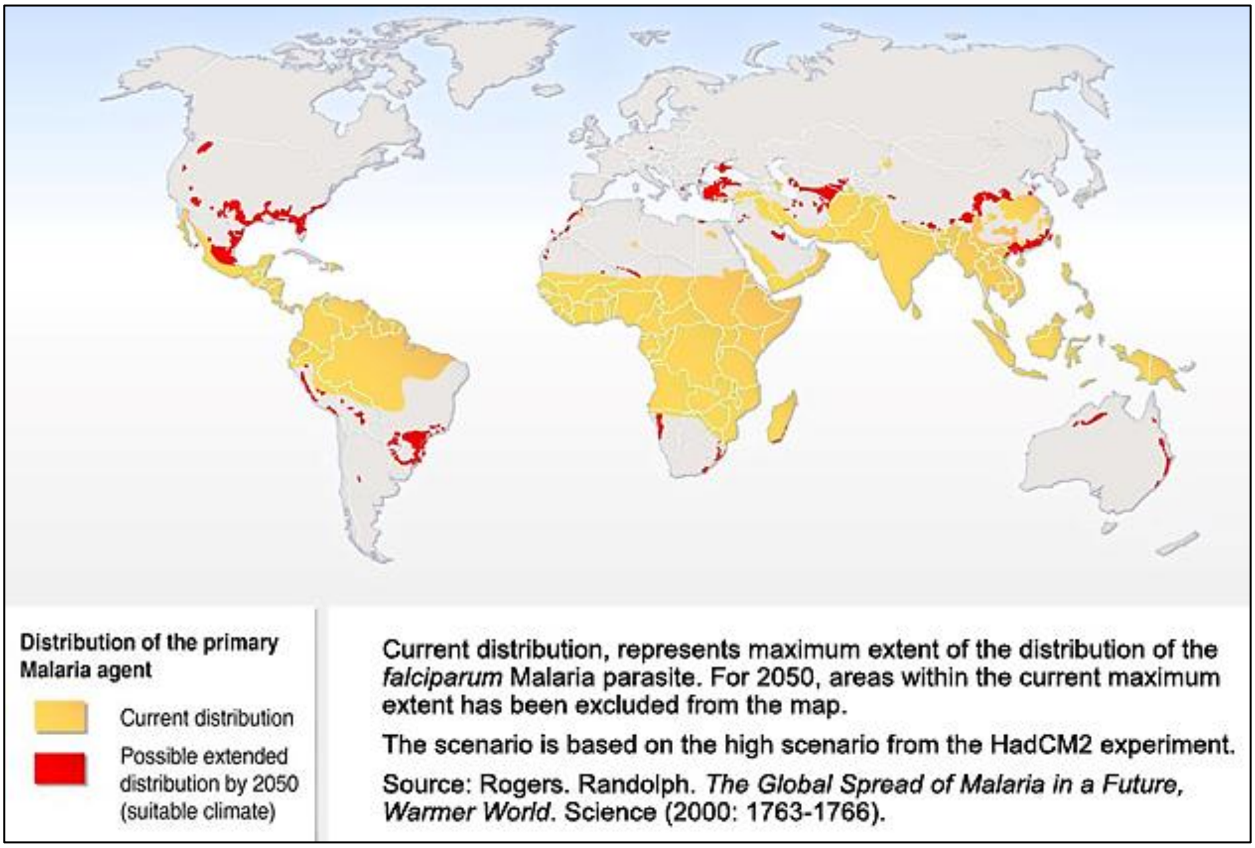
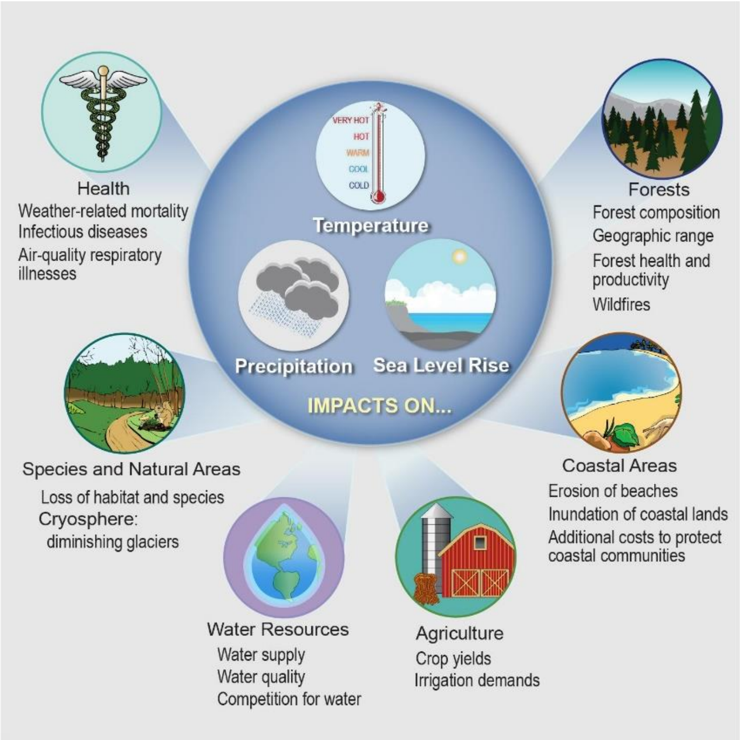


Fig. 4.12: Current distribution of malaria and possible extended distribution beyond the tropics by 2050 if temperatures continue to rise.

THE END

SUMMARY FOR THE CONSEQUENCES OF GLOBAL WARMING

Potential Effects of Climate Change

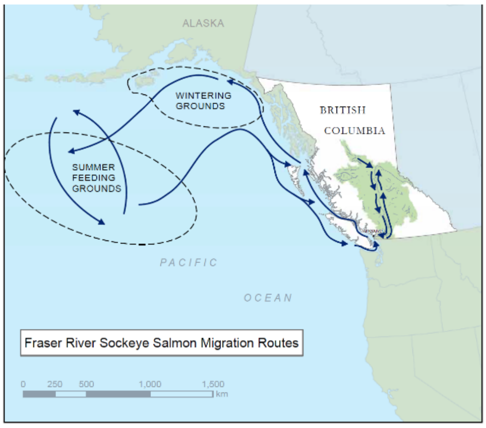


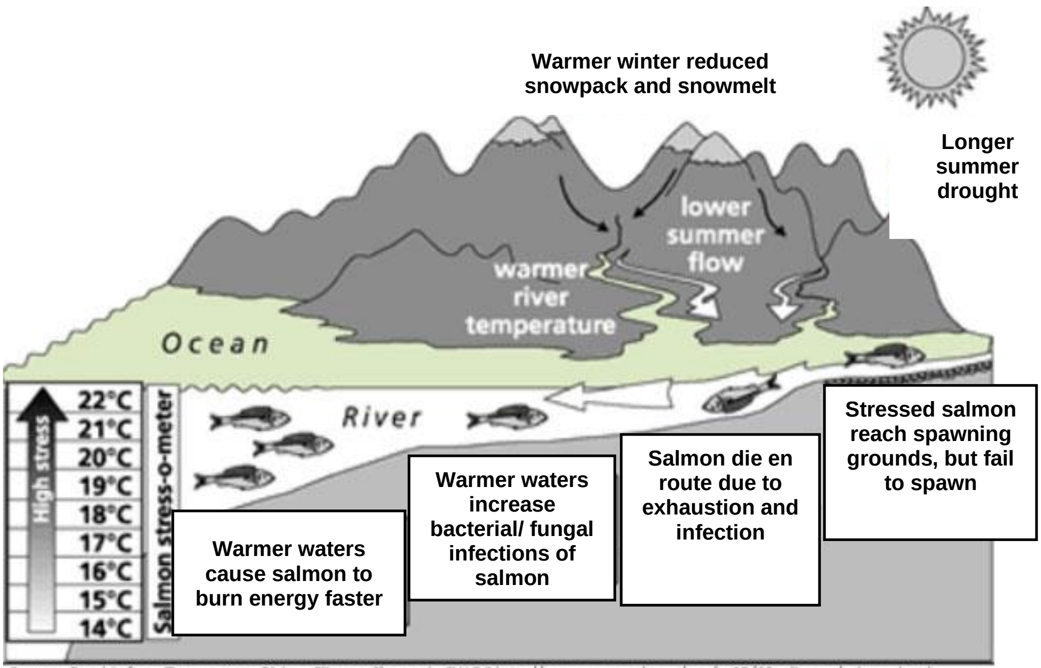
The effects of global warming are already being felt, but they are likely to become much more extreme during the 21st century. Habitats throughout the world will be affected, but the effects on Arctic ecosytems could be particularly catastrophic.

- Glaciers will melt and polar ice sheets will break up into icebergs, which will also eventually melt. The Arctic ice cap may disappear completely.
- Permafrost will melt during the summer, increasing the rates of decomposition of trapped organic matter, including peat and detritus. This will cause release of carbon dioxide, further increasing atmospheric concentrations.
- Species adapted to temperate conditions will spread north, altering food chains and affecting animals in the higher trophic levels.
- Marine species of animal in Arctic waters may become extinct, as they can be very sensitive to temperature changes in seawater.
- Polar bears and other animals will lose their ice habitat, where they feed and breed.
- Pests and diseases may become more prevalent, with warmer temperatures.
- Sea levels will rise and low-lying areas of land will be flooded.
- Extreme weather events, such as storms, will become more frequent, with harmful effects on species that are not adapted.

ADDITIONAL READING

Salmon and Climate Change





Source: Graphic from Temperature Rising: Climate Change in SW BC http://www.env.gov.bc.ca/soe/et02/09_climate/salmon.html

Summary

- **Salmon** have a long historical association with human society and make a large contribution to economies. They also have **important ecological roles**.
- **Some salmon populations have declined significantly** in recent decades. While human activities are largely responsible, climate change could now exacerbate or even supersede these threats, particularly in the southern part of their natural range.
- **Physical changes to freshwater ecosystems** resulting from climate change will degrade and **diminish available habitat, reduce reproductive success** and **jeopardise migration.**
- Although not well understood, impacts on salmon's marine habitat could lead to **temporal and spatial shifts in both their prey and predators. Possible changes to the timing of migration represents an important new threat.**
- These species **highlight the effects of rising temperatures on both freshwater and marine ecosystems,** and illustrate how climate change impacts on wild species can have a direct effect on economies.

Ecological role of Salmon

Salmon play an extremely important role in the functioning of their ecosystems.

- They **provide food** for a suite of predators and scavengers, including seals, whales, otters, bears, birds and countless invertebrates.
- Salmon also **transport essential nutrients from the marine environment to freshwater and terrestrial habitats.** This occurs through the excretion of waste and the decay of carcasses, including those discarded by terrestrial predators.

What do we know about salmon?

Salmon belong to the family Salmonidae, which includes other well known fish such as trout, grayling and char. The salmon species covered here include Chinook, sockeye, pink, coho, cherry and chum (collectively belonging to the 'Pacific salmon'), as well as Atlantic salmon, all of which perform their **renowned migrations from freshwater to marine habitats and back again**. This behaviour is called **'anadromy'**.

Pacific salmon live in coastal and river waters from Alaska and Russia in the north, to Japan and Mexico in the south, while **Atlantic salmon** inhabit areas in the North Atlantic Ocean and Baltic Sea, including associated river ways in USA, Canada, Iceland, Norway, Finland, Sweden and the United Kingdom.

One of the most intriguing aspects of salmon is their **extraordinary life cycle**. **Salmon eggs are laid in small pits (called 'redds') that are excavated in gravel-based freshwater streams by egg-bearing females.** These **nesting sites** are **selected** because of their **specific temperature, currents and oxygen levels.**

Salmon **eggs hatch after about three months**, although **juveniles** remain **dependent** on the **yolk-sac** for **several weeks after hatching**. Eventually the j**uveniles** begin their **downstream migration** during which time they **develop a tolerance to saline waters. Young salmon may remain in fresh water for up to four years, before entering the ocean**. It is during this period that **juveniles** are thought to be **most vulnerable to predation.**

Entry into the ocean coincides with planktonic blooms, upon which the juveniles feed. Older individuals may feed upon small invertebrates, squid and a diversity of marine fishes.

Depending on the species, **salmon may spend between one and seven years at sea**, **where they continue to grow**. **Once sexually mature, the salmon migrate back to their original hatching grounds to reproduce.** Such migrations (which can be extremely long) use a combination of chemical, magnetic and celestial cues for navigation. For most species this landward migration occurs throughout the summer and autumn months, with a few species, such as Chinook, coho and chum salmon, continuing to migrate through the winter months.

Salmons' spawning migration is both risky and energetically costly. Salmon must travel continually against the current and overcome numerous threats and barriers including predators, disease and waterfalls. As a result, **many salmon die during the migration**, and **those that survive are often bruised and battered. Upon arrival at the nesting site a salmon will typically spawn several times before dying, although some species (notably Atlantic salmon) can survive and may even repeat spawn.**

How is climate change affecting salmon?

Freshwater habitats:

As **water temperatures increase**, a number of negative effects on salmon may arise. **Direct biological impacts on salmon include physiological stress, increased depletion of energy reserves, increased susceptibility and exposure to disease and disruptions to breeding efforts.**

Such direct impacts on the biology of salmon may potentially lead on to further, less direct impacts. For example, as the developmental rate of salmon is directly related to water temperature, it is possible that **increasing temperatures** could cause the **more rapidly developing juveniles to enter the ocean before their planktonic food source has reached sufficiently high levels.**

Additional indirect effects to salmon, associated with increasing air and water temperatures, relate to negative changes to their habitat. It has been noted that areas of particularly **warm freshwater can present a thermal barrier to migrating salmon that requires additional energy to navigate around. Such barriers can also delay or even prevent spawning.**

As the air temperatures warm, much of the **snow that feeds the river systems** is expected to **melt earlier.** In many cases **snow** is predicted to be **replaced by rain.** This will lead to a **reduction in the summer flows of many rivers,** coupled with an **increase in freshwater inputs during the winter.**

A reduction in summer flow levels will serve to **increase water temperatures further** and is likely to **reduce the overall habitat available to salmon. Increased winter flows** are likely to **scour the river beds, disturbing nests** and **causing physical damage** to both **salmon eggs** and **juveniles.**

Coupled with an **increase in freshwater inputs,** is an **increase** in the **sedimentation of river and stream beds.** Such sedimentation is likely to **reduce the amount of gravel substrate available for spawning, and to smother both eggs and juveniles.**

Marine habitats:

Predicting the specific effects of climate change on salmon in their marine environment is extremely difficult. This is due to our limited knowledge of the marine habits of salmon, combined with uncertainties about how marine habitats will be affected by climate change.

It has been suggested that many of the **food webs of** which **salmon** are a part will be **disrupted by climate change**. For example, the **timing of the planktonic 'blooms'** required by the young is governed by climatic factors. Changes in the timing of these blooms could cause a **scarcity of food** at a critical stage of the **salmon's life cycle.**

Warmer ocean temperatures have been shown, in certain areas, to **reduce the abundance of other smaller fish into these newly warmed areas**. These two factors, when coupled together, could cause a **significant rise in predation pressure on salmon**.

Can salmon adapt to climate change?

Not all salmon populations will be affected by climate change in the same way, and some populations at higher latitudes may actually benefit from warmer temperatures through increased production. It is possible that a warmer climate could make new spawning habitats available, and this has been observed in parts of Alaska. Such changes are likely to lead to unexpected consequences and shifts in ecosystems and fisheries, and humans will need to be prepared to adapt to these new conditions.

It is important to note that a multitude of other threats to salmon currently exist. These include:

- Overexploitation by the fishing industry.
- Habitat destruction and degradation (particularly • through activities such as mining, forestry, agriculture and/or urbanisation).
- Pollution and sedimentation of river waters
- Obstruction of migratory routes, (especially by dams • and hydropower stations).
- Interbreeding and ecological interactions with • artificially propagated salmon (originating from either farms or hatcheries).

This suite of threats will all serve to jeopardise salmon's chances of adapting to the new threats arising from climate change.