Extension Topic B: Impact of Climate Change on Animals and Plants
Part 1

Learning Outcomes

(a) identify and explain the human activities over the last few centuries that have contributed to climate change through accumulation 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 gas 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 and 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.

<u>**Lecture Outline**</u>

1) Greenhouse Gases & the Greenhouse Effect

1.1 Human activities contributing to increase in greenhouse gas emissions
- 1.1.1 Combustion of Fossil Fuels (coal, natural gas and oil)
- 1.1.2 Industrial processes
- 1.1.3 Reduction in carbon sinks due to deforestation
- 1.1.4 Increased livestock production due to higher demand for meat and dairy

2) Effects of Climate Change as a result of Greenhouse Gas Emissions

2.1 Melting of Polar Ice Caps
2.2 Rising Sea Levels
2.3 Stress on Fresh Water Supplies
2.4 Heat Waves
2.5 Migration of Fishes and Insects
2.6 Release of Greenhouse HGs in frozen organic matter

3) Effects of Climate Change on Plants

3.1 Changes in Plant Distribution
3.2 Changes in Plant Adaptations

4) Effects of Climate Change on Global Food Supply

Learning Outcome (a):

Identify and explain the human activities over the last few centuries that have contributed to climate change through accumulation 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).

1 GREENHOUSE GASES & THE GREENHOUSE EFFECT

A **greenhouse gas (GHG)** is a gas that both absorbs and emits radiation in the infrared range. When present in the Earth's atmosphere, these gases trap radiation in the form of heat, leading to a warming process called the greenhouse effect.

The greenhouse gases in the Earth's atmosphere help keep the average temperature of the Earth at 15ºC, whereas without the greenhouse effect, the average temperature would be a frosty -18ºC.

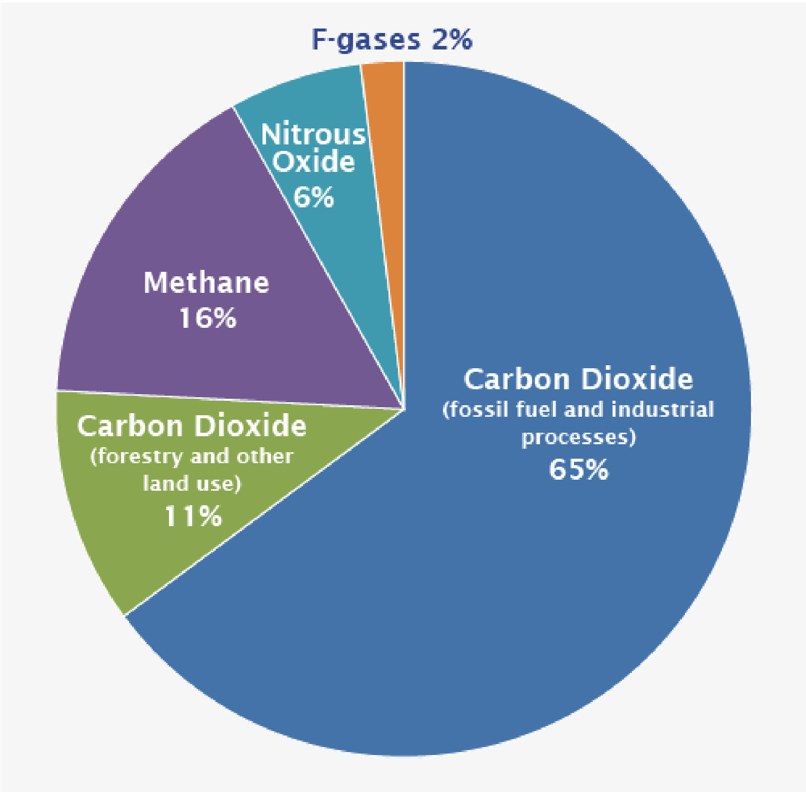


Fig. 1.0.1 Percentage share of greenhouse gases in the earth atmosphere

The **greenhouse effect** is a natural process by which heat radiated from Earth's surface is trapped by greenhouse gases. With more greenhouse gases in the air, more heat is trapped in the Earth's atmosphere, resulting in a warmer Earth.

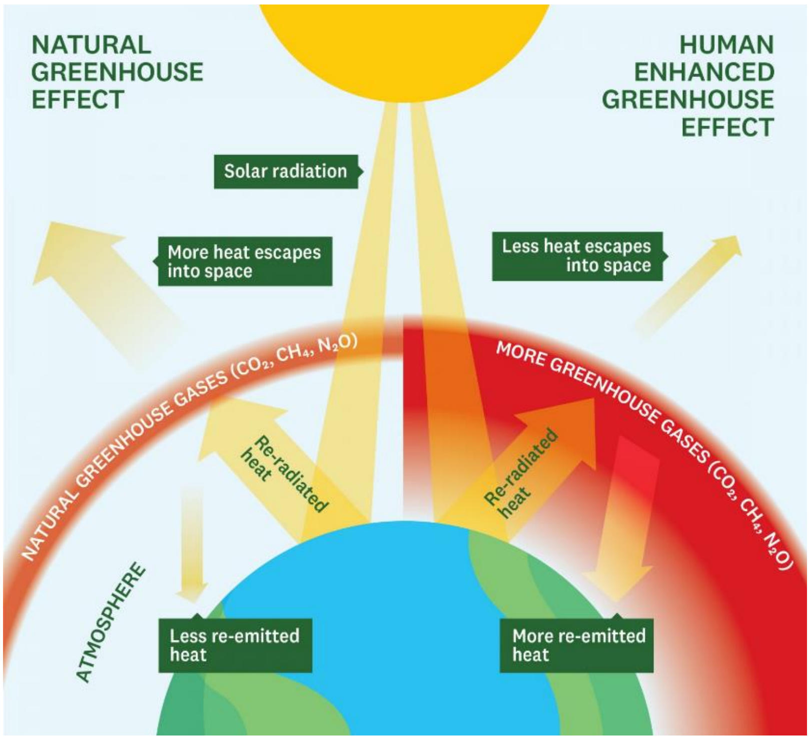


Fig. 1.0.2 Greenhouse effect leading to warming of Earth's surface

Global Warming Potential (GWP) is a measure of how much heat a substance can trap in the atmosphere over a period of 100 years, as compared to an equivalent amount of CO_2. GWP is used to compare the global warming impact of different greenhouse gases. The larger the GWP, the greater the warming effect exerted by that gas compared to CO_2 in the same time period.

Greenhouse Gas (GHG)	Atmospheric Lifetime (yrs)	Global Warming Potental (GWP)
Carbon dioxide (CO_2)	50-200	1
Methane (CH_4)	12±3	21
Nitrous oxide (N_2O)	120	310
Hydrofluorocarbons (HFCs)	1.5 to 209	150 to 11,700
Perfluorocarbons (PFCs)	2,600 to 50,000	6,500 to 9,200
Sulfur Hexafluoride (SF_6)	3,200	23,900

Fig. 1.0.3 Global Warming Potential of Greenhouse Gases

While carbon dioxide is more abundant and longer-lived, **methane** is far more effective at trapping heat while it lasts. Over the first two decades after its release, methane is more than 80 times more potent than carbon dioxide in terms of warming the climate system.

1.1 Human activities contributing to increase in greenhouse gas emissions

Greenhouse gas emissions due to human activities (e.g. industrialisation and development) have increased since the pre-industrial era, driven largely by population and economic growth. This has resulted in greenhouse gases reaching unprecedented levels in over the past centuries.

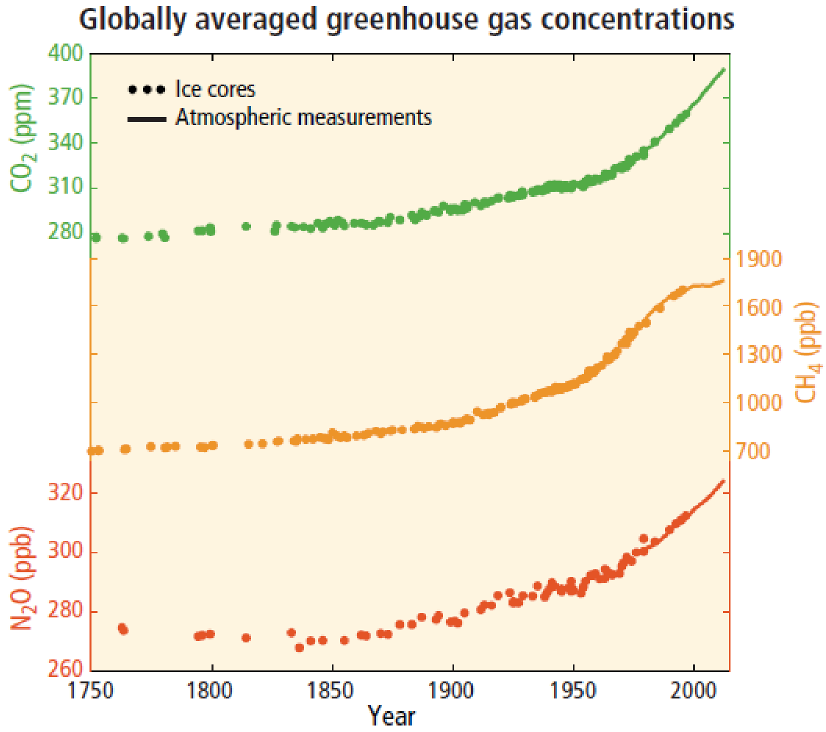


Fig. 1.1 Trends in concentrations of greenhouse gases over the years

The increase in greenhouse gas emissions is correlated with – and likely to be the main cause of – the increasing trend of Earth's surface temperature over the past years.

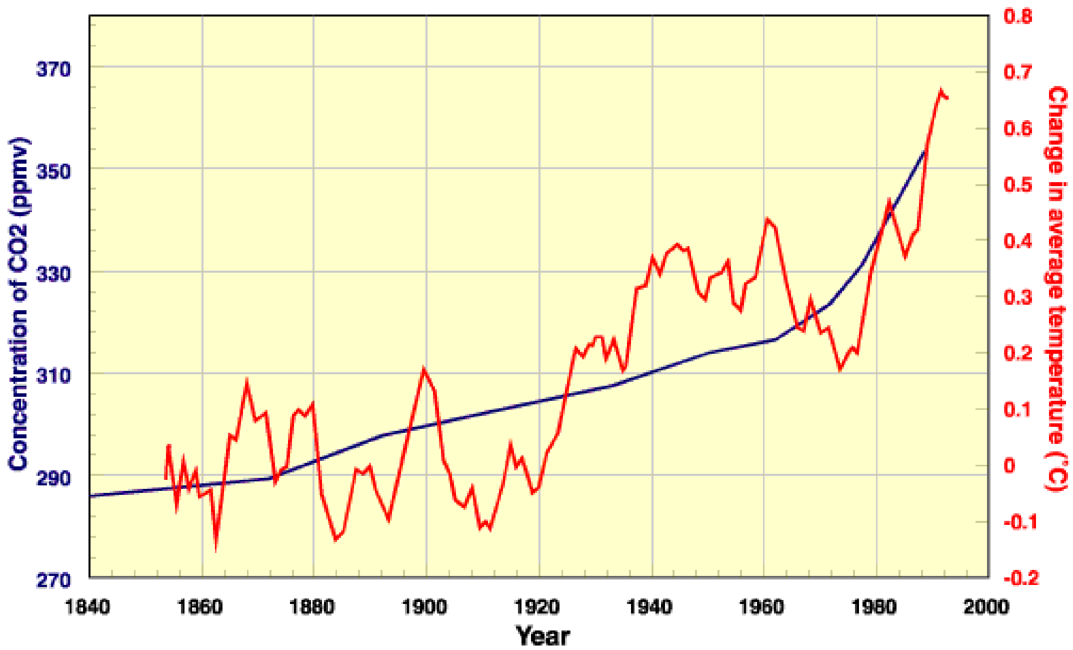
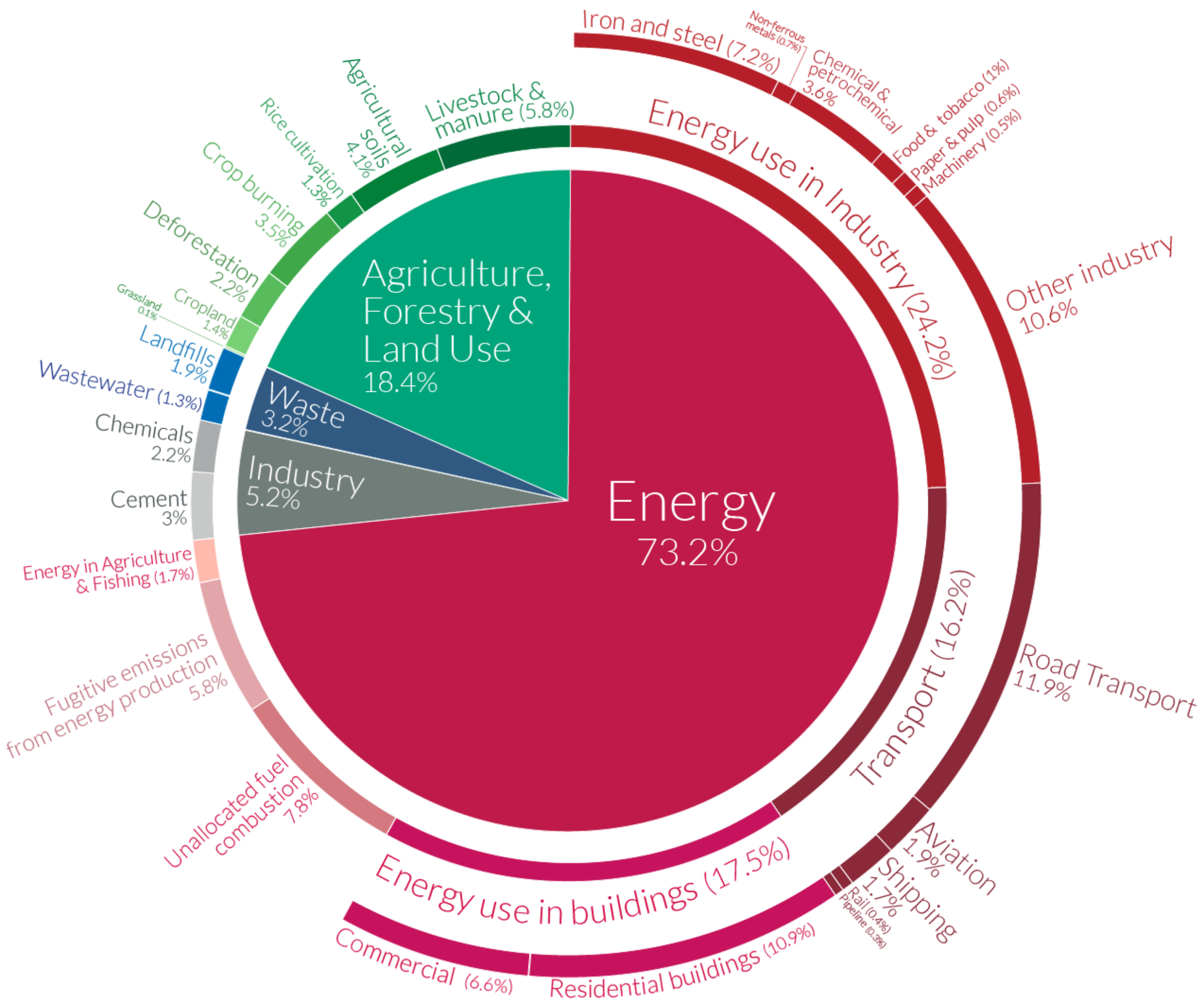


Fig. 1.2 Graphs of CO_2 concentration and change in average temperature

There are many human activities which contribute to increased emission of greenhouse gases. **Burning of fossil fuels for electricity, transportation and industry**, as well as in **agriculture**, contribute to the bulk of greenhouse gas emissions.



OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020).

Fig. 1.3 Global Greenhouse gas emissions by sector for the year 2016

1.1.1 Combustion of Fossil Fuels (coal, natural gas and oil)

- To generate electricity to power lighting, appliances, and heating in commercial and residential buildings
- To power transportation e.g. road transport, aviation, shipping, rail and pipelines transporting fuel and commodities e.g. oil, gas, water or steam

Note: Mining of fossil fuels e.g. coal mining releases methane (CH_4)

1.1.2 Industrial processes

- Production of mineral products e.g. cement for construction
- Production of metals e.g. iron and steel
- Production of chemicals e.g. ammonia for use in water purification

1.1.3 Reduction in carbon sinks due to deforestation

- Trees convert CO_2 in the air to O_2 through the process of photosynthesis. The more trees, the less CO_2 in the atmosphere and the more O_2.
- Some of the CO_2 absorbed by plants is stored as organic matter throughout their lifetime. Soils can also store CO_2, depending on how the soil is managed. This storage of carbon in plants and soils is called **biological carbon sequestration**. Since biological sequestration takes CO_2 out of the atmosphere, it is also called a carbon "sink".
- Humans carry out deforestation to provide land for agricultural expansion e.g. to grow crops, raising livestock or producing bio-fuels for export, as well as to provide timber for domestic fuel or charcoal. Deforestation contributes to increasing carbon dioxide emissions in two ways:
  - **Burning or decomposition of wood** releases carbon dioxide
  - **Absence of trees** to absorb carbon dioxide from the atmosphere

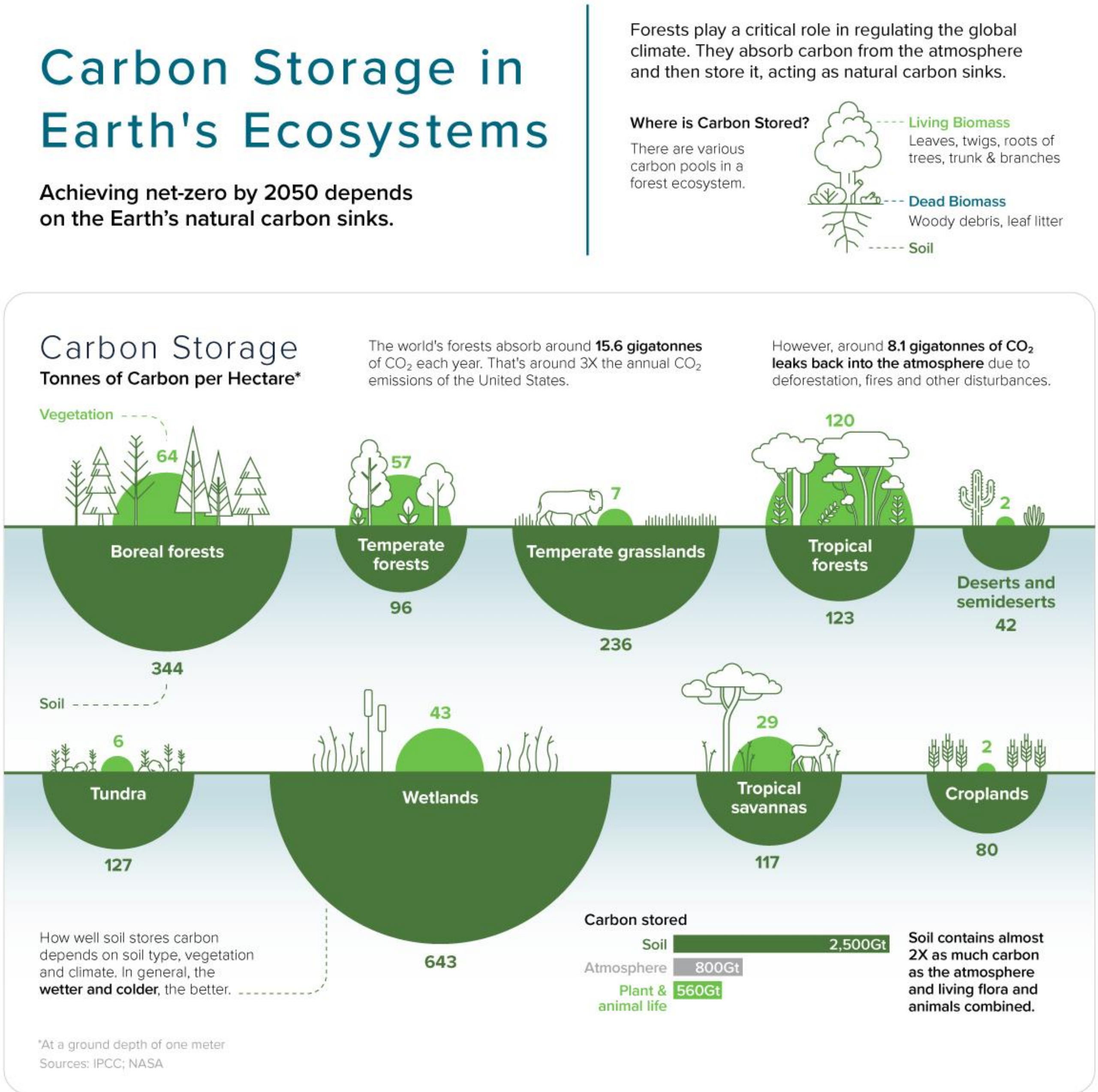


Fig. 1.4 Carbon storage in Earth's ecosystems

1.1.4 Increased livestock production due to higher demand for meat and dairy

- With economic development, industrial style agriculture replaced traditional small-scale farming. The increased efficiency of industrial agriculture has also led to reduced prices for many of our daily products. It helped to nourish large populations, and turned a food that was an occasional meal – meat – into an affordable, everyday product for many.
- The growth in per capita meat consumption is strongly linked to increasing levels of income in many countries of the world.

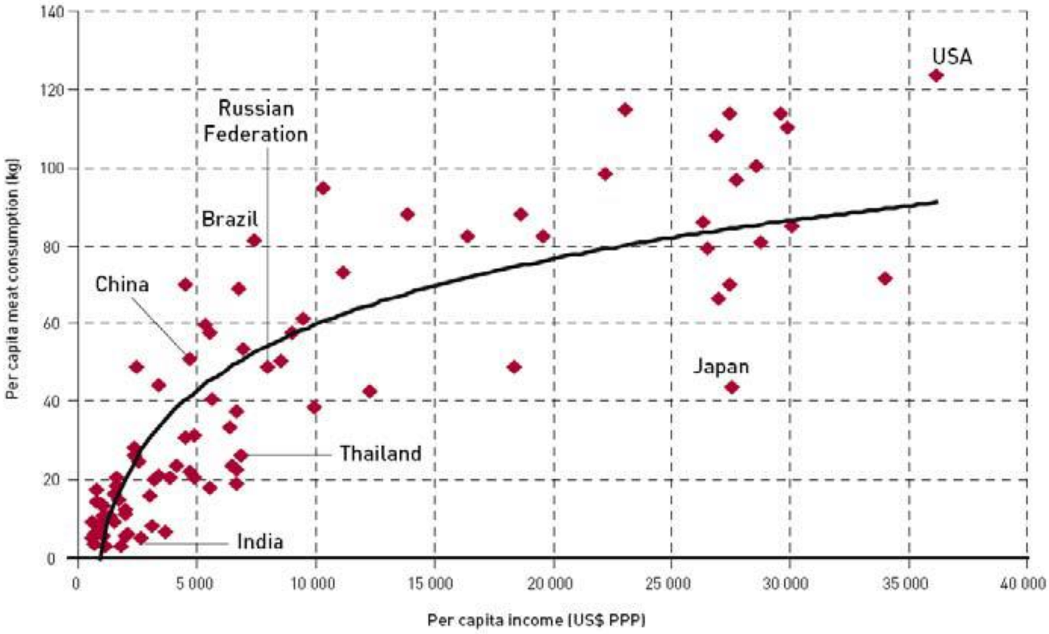


Fig. 1.5 Graph of per capita meat consumption vs per capita income

- Coupled with global human population growth, global meat consumption also increased.

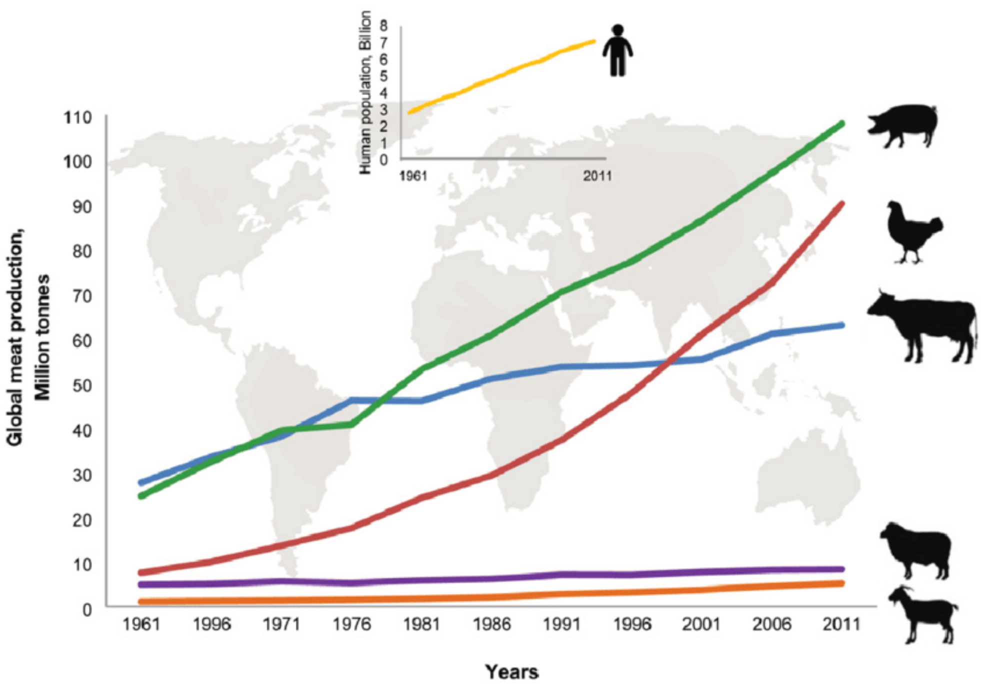


Fig. 1.6 Global meat production increases over the years as global human population increases

- **Increase in populations of ruminants** e.g. cows, goats and sheep.

- **Ruminants produce methane** as part of their normal digestive process and release methane through belching or as flatulence
- **Decomposition of animal manure** under anaerobic conditions release methane
- **Increased production of feed** resulted in an increase in consumption of energy supplied from burning of fossil fuels

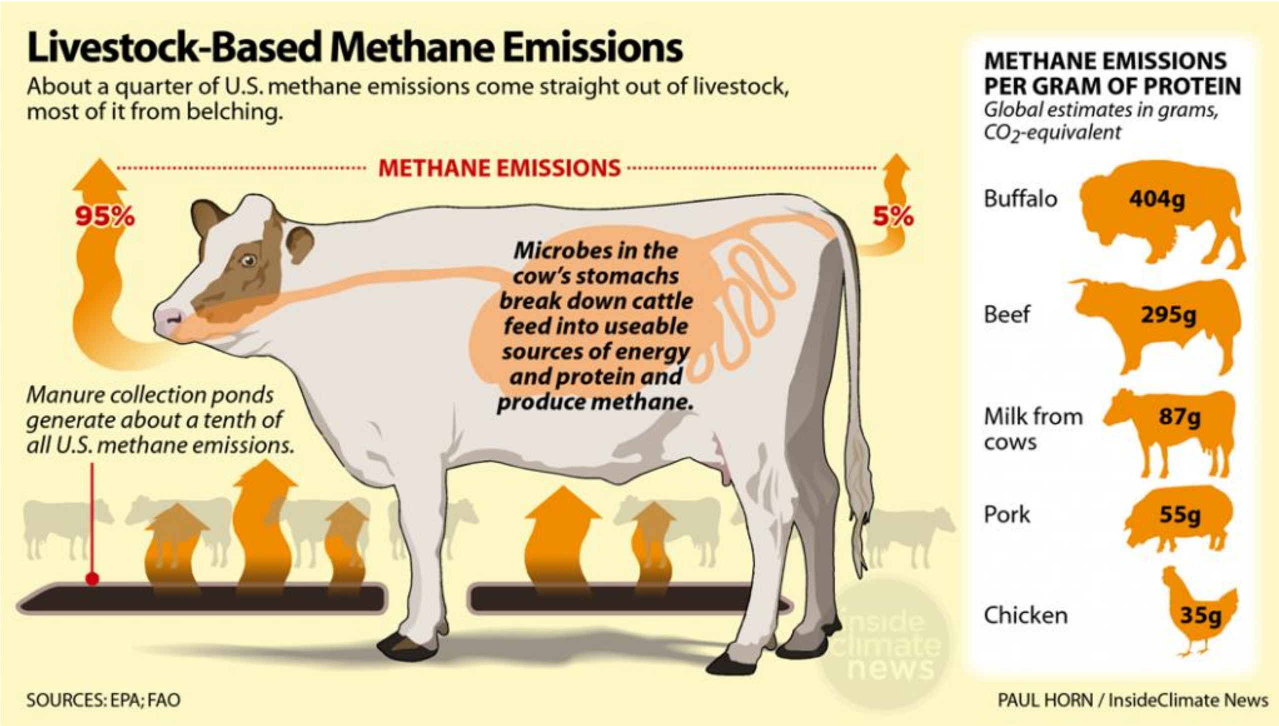


Fig. 1.7 Livestock-based methane emissions

Learning Outcome (b):

Explain the effects of climate change as a result of greenhouse gas 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 and release of greenhouse gases in frozen organic matter.

2 EFFECTS OF CLIMATE CHANGE AS A RESULT OF GREENHOUSE GAS EMISSIONS

As the level of GHGs increases, heat is unable to escape through the atmosphere and consequently leads to global warming, resulting in **climate change**.

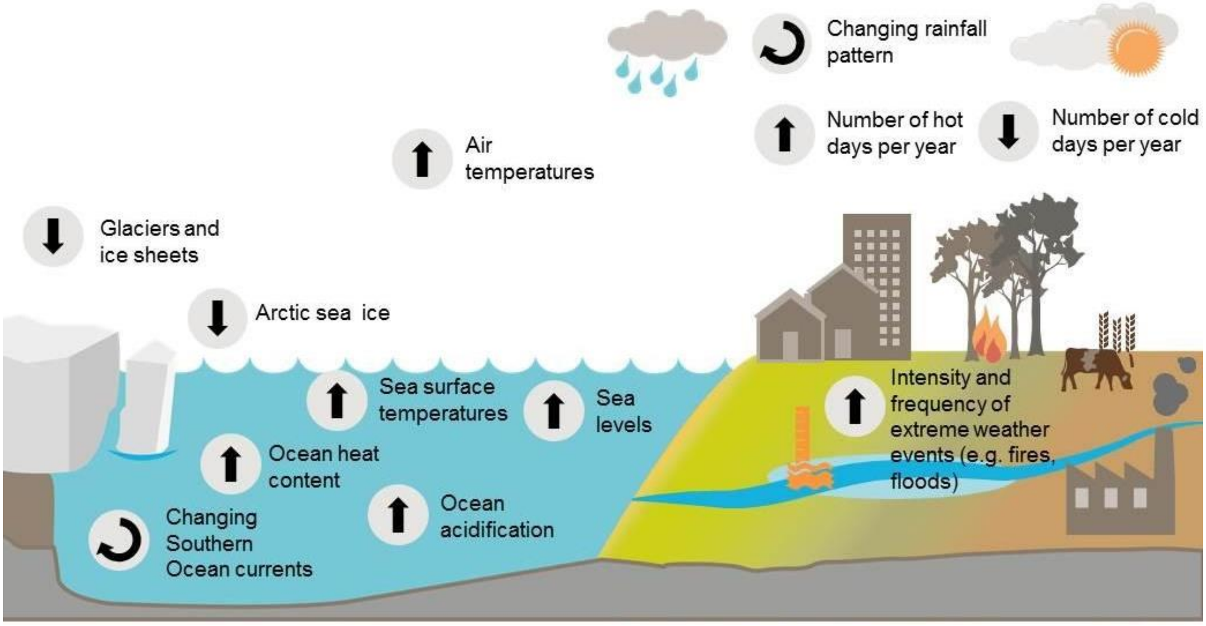


Fig. 2.0 Impact of climate change

Scan this QR code/ click on the link for an overview of the effects of climate change: https://climate.nasa.gov/effects/

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2.1 Melting of Polar Ice Caps

An ice cap is a thick layer of ice and snow that covers large areas of land, usually found in the North and South Poles of the Earth. Ice acts like a protective cover over the Earth and our oceans by **reflecting excess heat back into space** and **keeping the planet cooler**.

As temperature increases,

a) **melting of sea ice** (frozen ocean water) results in:
   - fewer bright surfaces available to reflect sunlight back into space, **more solar energy is absorbed at Earth's surface**, and temperatures rise further
   - changes to the temperature at the poles, hence **disrupting normal ocean circulation** and **affecting global climate**

- depleting available ice for feeding, breeding, growth and survival for animals living at the poles (e.g. seals, polar bears, etc)

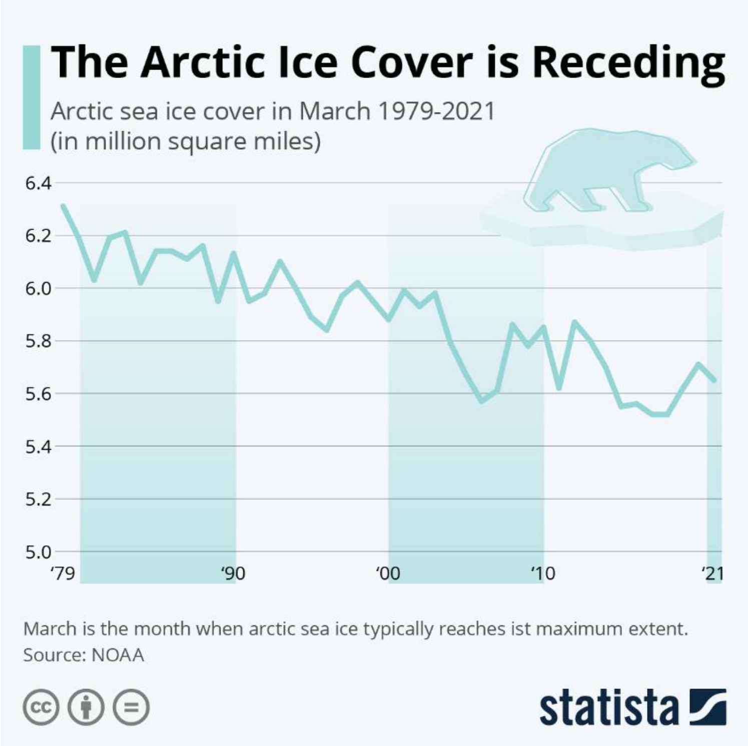

Fig. 2.1.1 Receding sea ice cover

b) **melting of glaciers** (land ice formed from fresh water) which exist in the polar regions (e.g. Greenland, the Canadian Arctic and Antarctica) results in increased volume of water entering the ocean, leading to a **rise in sea level**.

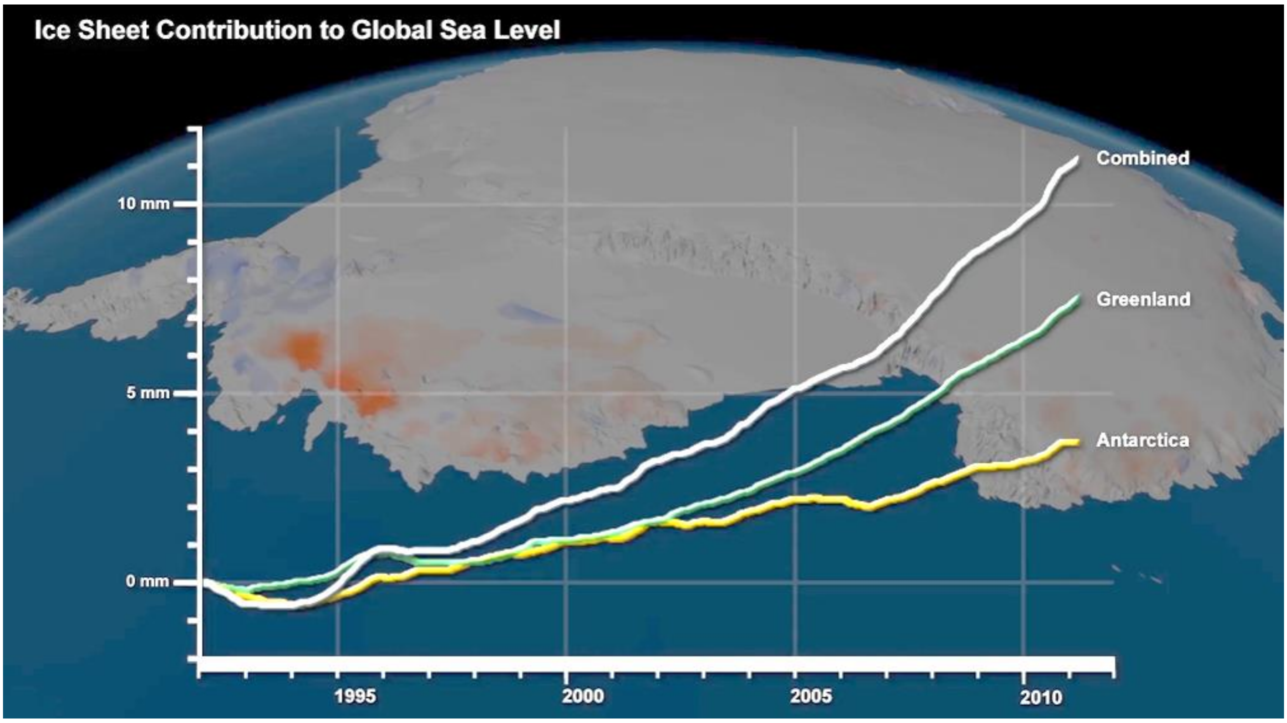

Fig. 2.1.2 Rising sea levels from melting of glaciers

2.2 Rising Sea levels

In addition to the melting of glaciers due to increased temperature, the effects of melting results in the **ice sheet** moving more quickly from the land into the sea, resulting in sea level rising faster.

With increased temperature, the water warms resulting in **thermal expansion** where water expands and occupies more space, resulting in the **rise in sea level**.

When sea levels rise,

a) **coastal flooding** occurs as higher tides move storm surges higher and further inland resulting in more flooding inland.

b) **marshes and wetlands are lost due to flooding by saltwater**, resulting in a loss of habitats for flora and fauna.

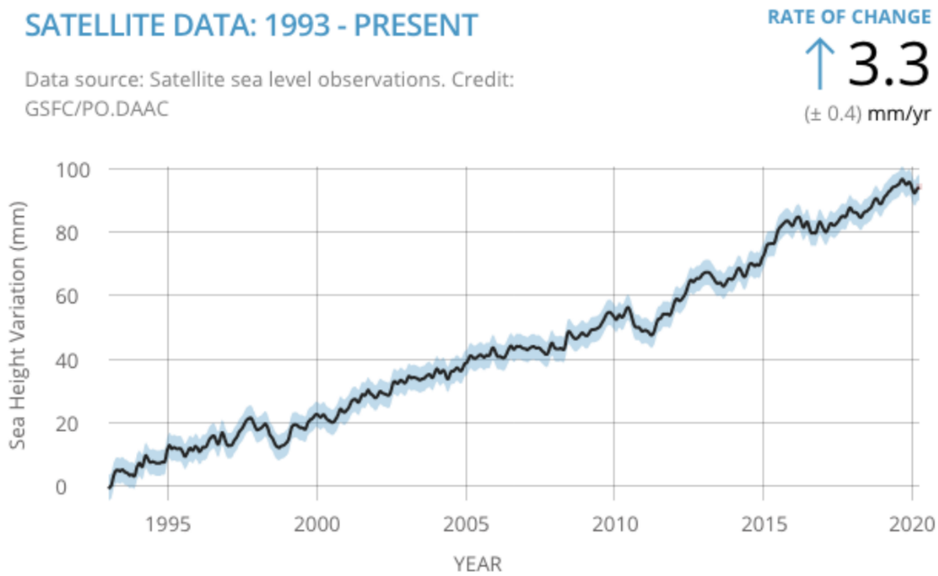

Fig. 2.2.1 Global Mean Sea Level from 1993 to 2020 has been rising about 3.3 millimeters per year

Scan this QR code/ click on the link to learn more about how Singapore may be affected by climate change and rising sea level: [*https://www.straitstimes.com/multimedia/graphics/2022/01/singapore-protect-sea-levels-rise/index.html?shell*](https://www.straitstimes.com/multimedia/graphics/2022/01/singapore-protect-sea-levels-rise/index.html?shell)

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2.3 Stress on Fresh Water Supplies

The ongoing changes to the Earth's climate will have effects on the future availability of freshwater resources. Here are some ways climate change will affect the world's freshwater resources.

a) Stress on fresh water supplies, where **coastal aquifers[1] are contaminated by saltwater** and cause problems for the coastal communities that rely on fresh groundwater supplies for the livelihood.

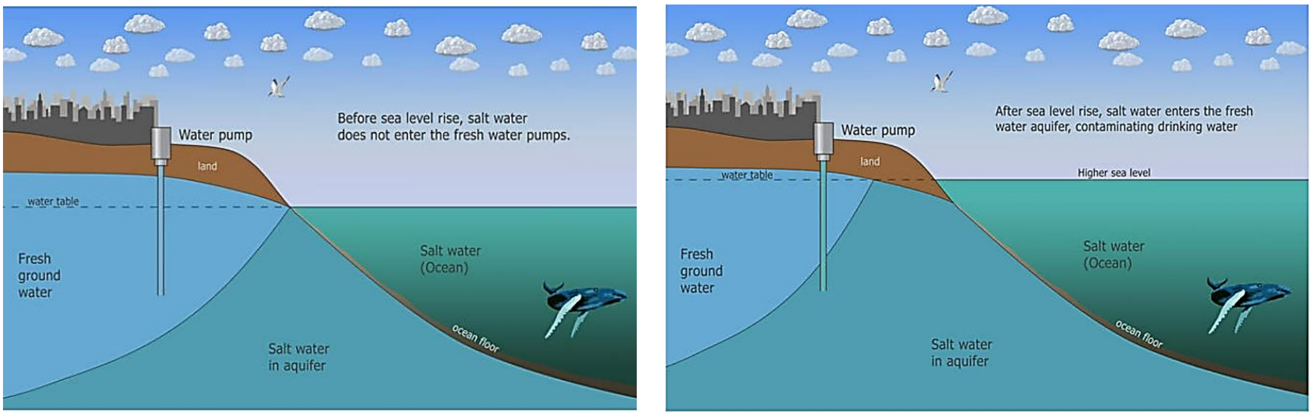

Fig. 2.3.1 Saltwater intrusion into coastal aquifers

b) Intensifying water cycle

Climate change intensifies the water cycle. An intensifying water cycle means that **both wet and dry extremes and the general variability of the water cycle will increase**, although not uniformly around the globe. Rainfall intensity is expected to increase for most land areas, but the largest increases in dryness are expected in the Mediterranean, southwestern South America and western North America.

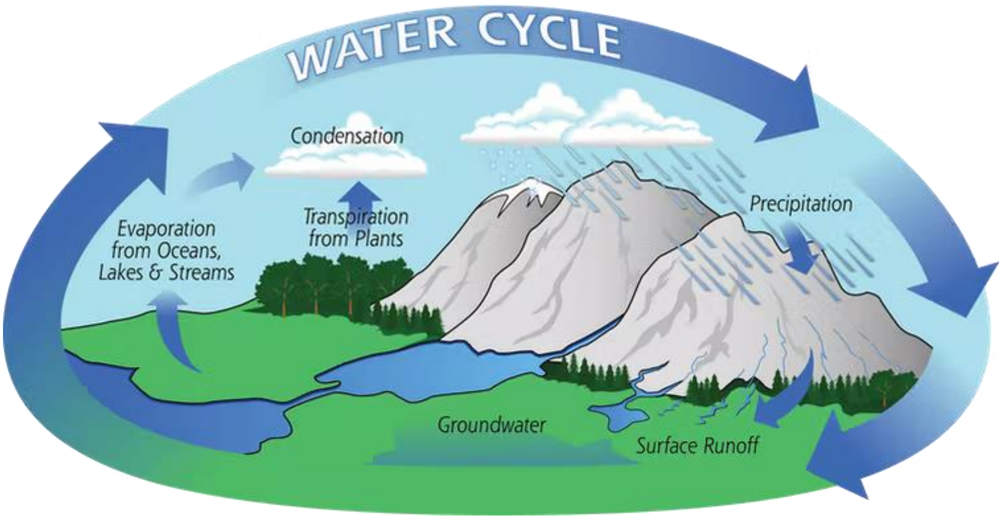

Fig. 2.3.2 The water cycle

[1] An aquifer is a body of rock and/or sediment that holds groundwater.

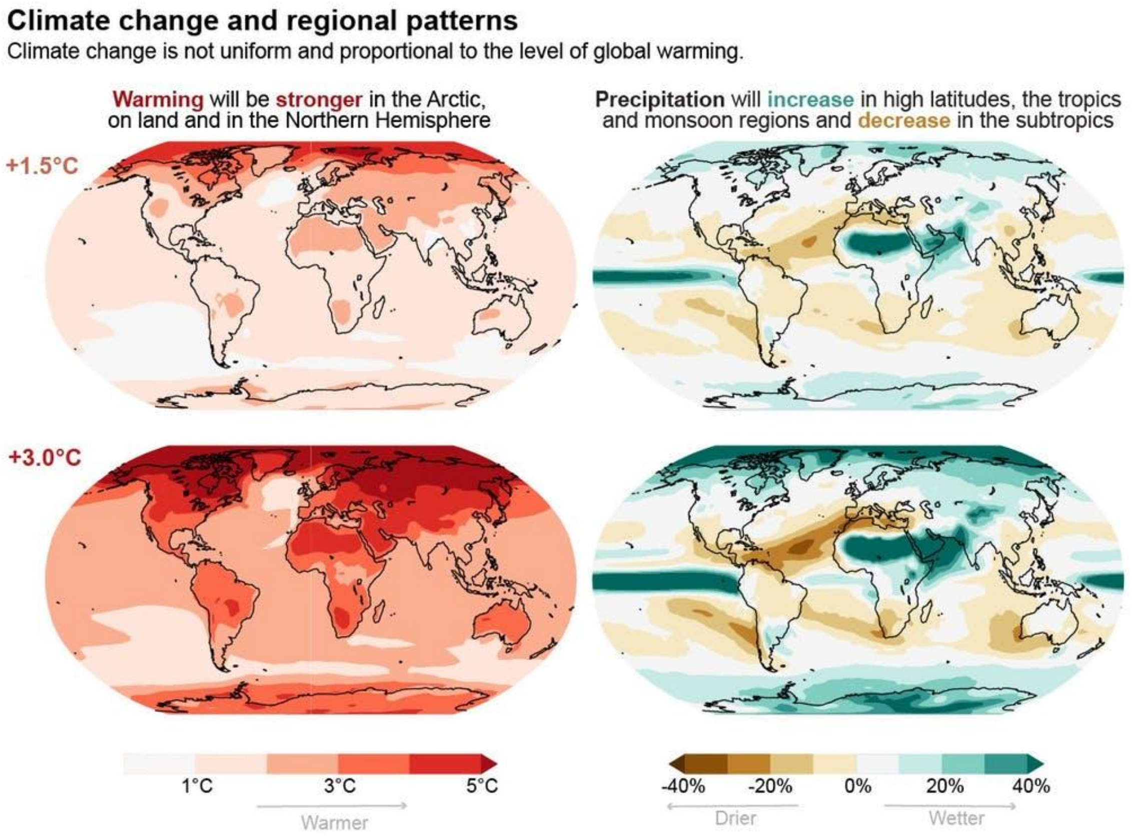

Fig. 2.3.3 Annual average precipitation is projected to increase in many areas as the planet warms, particularly in the higher latitudes.

<u>Changes in precipitation – heavy rainfall</u>

Warmer oceans increase the amount of water that evaporates into the air. Under ideal conditions, rain intensity increases by seven percent for every degree Celsius of temperature rise. This means that theoretically heavy rain should become even heavier in a warmer climate. Hence, when more moisture-laden air moves over land or converges into a storm system, it can produce **more intense precipitation** in the form of heavier rain and snowstorms. This will result in increased **risk of flooding and contamination of freshwater resources.**

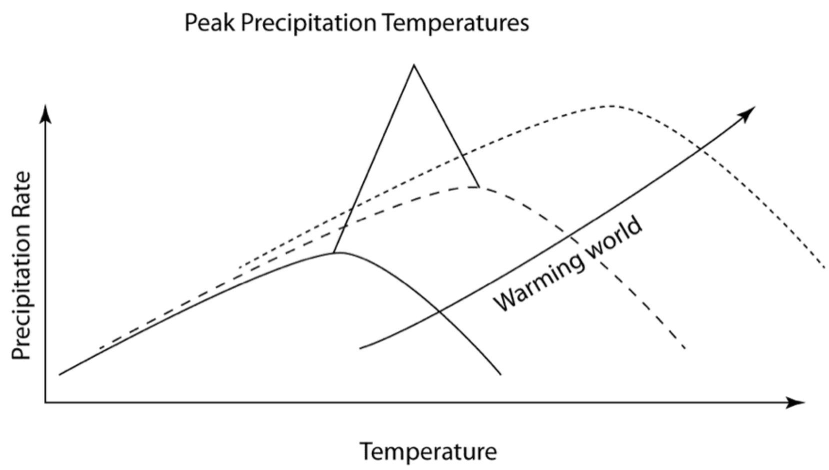

Fig. 2.3.4 Sketch of a temperature/precipitation relationship

Changes in precipitation – droughts

While **rainfall is likely to increase in the tropics, it is likely to decrease in the already dry subtropics**, where warmer temperatures enhance evaporation and reduce surface water, drying out soils and vegetation. It also leads to less precipitation falling as snow and results in a decreased snowpack which adversely affect organisms relying on cold water e.g. salmon and reduce the period in which soil are kept moist as snowpack melts faster and sooner.

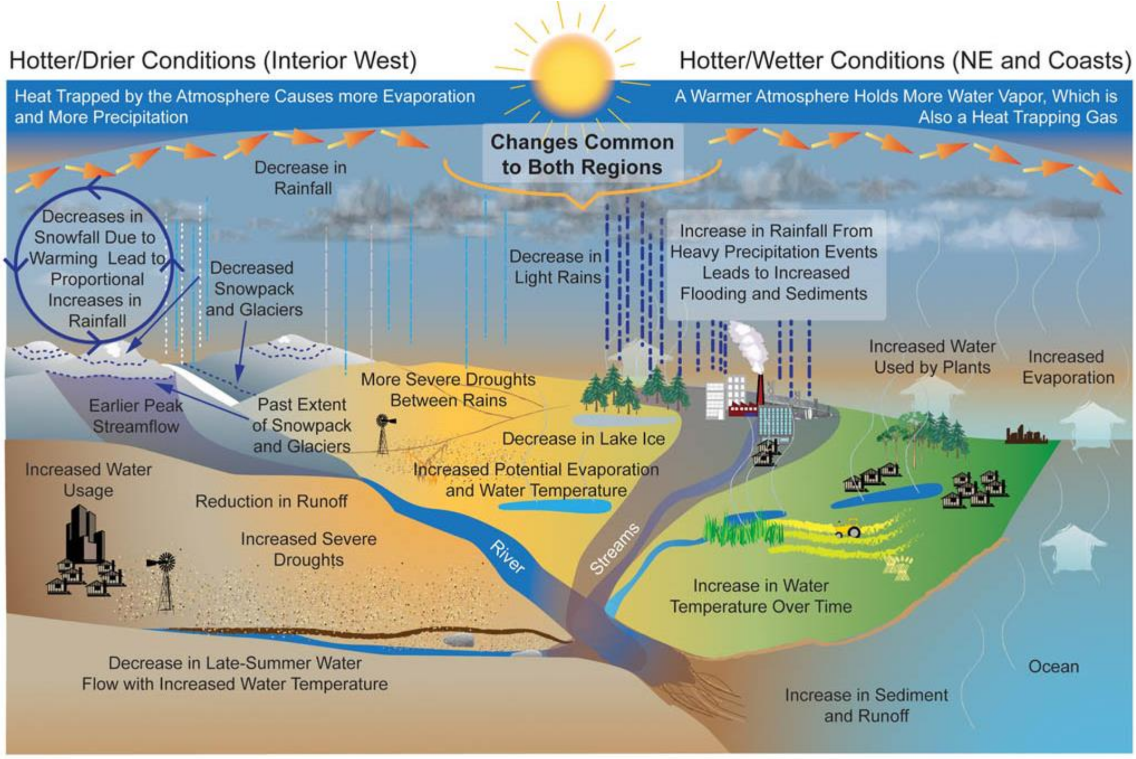

Fig. 2.3.5 Impact due to changes in the water cycle

2.4 Heat Waves

A heat wave is defined as a **period of abnormally hot and usually humid weather**.

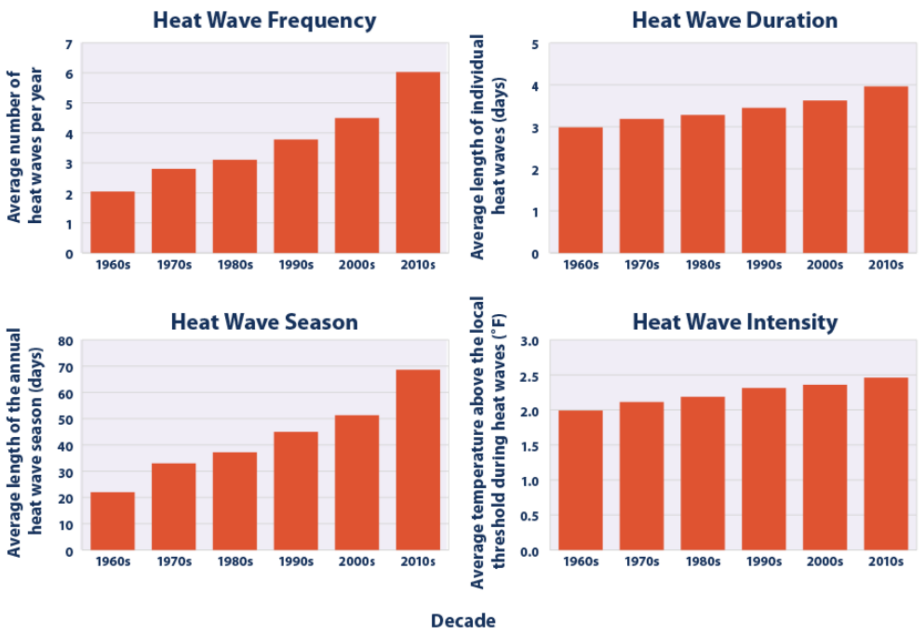

Fig. 2.4.1 Heat Wave Characteristics in the United States by Decade, 1961–2019

Heat can exacerbate drought, and **hot, dry conditions can in turn create wildfire conditions**. Urban areas and cities will experience prolonged heat as the infrastructure releases heat absorbed during the day slower. Hot days are also associated with **increases in heat-related illnesses**, including cardiovascular and respiratory complications and kidney disease.

In extreme temperatures, **air quality is also affected**. Hot and sunny days can increase the production of ground-level ozone, a harmful pollutant that is the main component of smog, which can damage the respiratory system and is particularly harmful for those with asthma.

Marine heat waves can result in **coral bleaching**.

<u>Coral Bleaching</u>

Corals are marine invertebrates that belong to a large group of animals called Cnidaria. They are colonial organisms, meaning many individuals live and grow while connected to one another. Corals have a symbiotic relationship with the **photosynthetic algae, zooxanthellae**. These algae live inside the coral polyp's body where they photosynthesise to produce energy for themselves and the polyps. The polyps, in turn, provide a home and carbon dioxide for the algae. Additionally, the zooxanthellae provide the coral with their lively colours — most coral polyp bodies are clear and colourless without zooxanthellae.

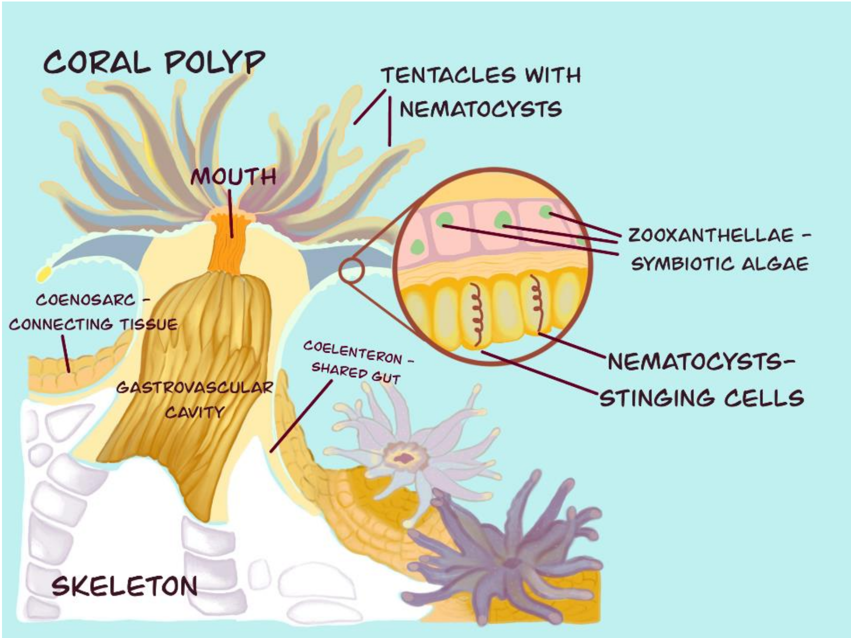

Fig. 2.4.2 Anatomy of a coral

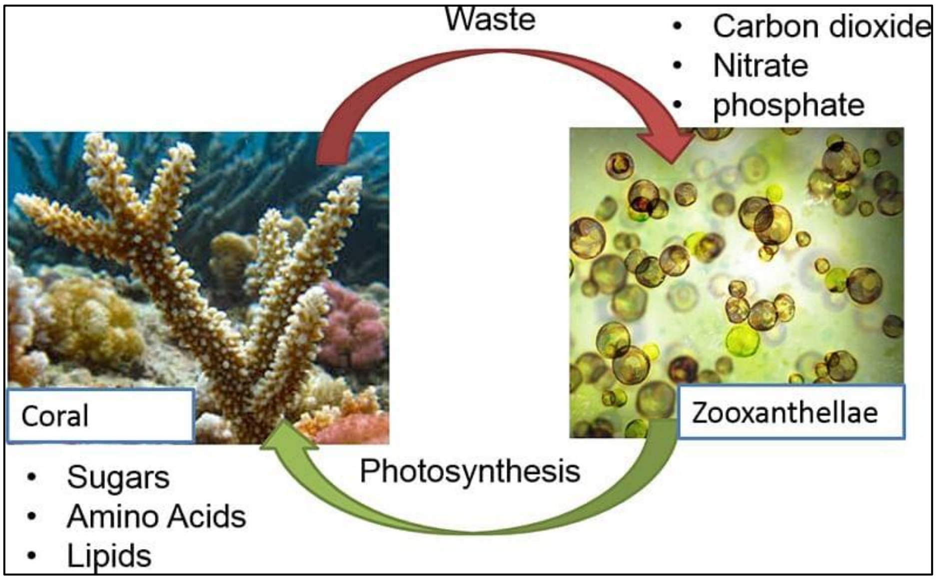

Fig. 2.4.3 Symbiotic relationship between coral and zooxanthellae

Coral bleaching occurs when the close symbiotic relationship between the zooxanthellae and their coral hosts breaks down due to stressors such as **rising sea temperatures**, causing the **corals to expel the zooxanthellae.** Without zooxanthellae, corals turn white because zooxanthellae give corals their colour. **White, unhealthy corals are called bleached corals**. Bleached corals are weak and less able to combat disease. If favourable conditions return to the waters, zooxanthellae may also return to the corals. Otherwise, the **bleached corals will eventually die due to starvation and disease**.

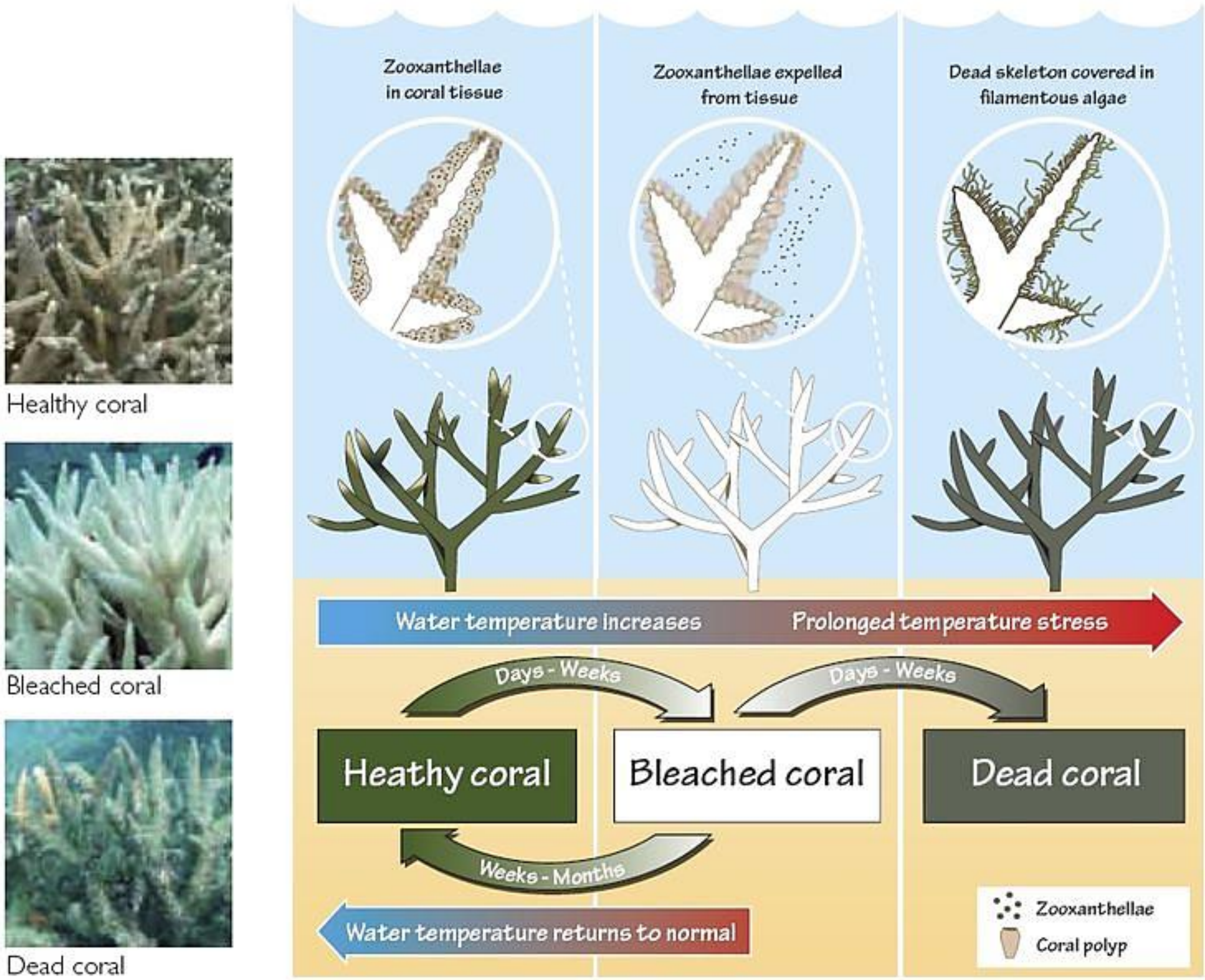

Fig. 2.4.4 Coral bleaching

Apart from bleaching events, **ocean acidification** due to increased carbon dioxide emissions affects reef structures. With the lowered pH, **hard corals cannot absorb the calcium carbonate they need to maintain their skeletons and reefs will dissolve**. Hence ocean acidification limits coral growth by corroding pre-existing coral skeletons while slowing the growth of new ones, making the reefs more vulnerable to erosion. In addition, **changes in storm patterns can directly destroy coral reefs** when increased precipitation results in increased runoff of freshwater, sediment, and land-based pollutants, contributing to algal blooms. Such murky water conditions reduce the amount of light reaching zooxanthellae, resulting in coral death indirectly.

Coral death impacts the building of coral reefs which are underwater structures composed of the skeletons of coral. This will adversely **impact marine animals and plants which depend on coral reefs** as their habitat, which in turn have downstream effects on the fishing and tourism industries.

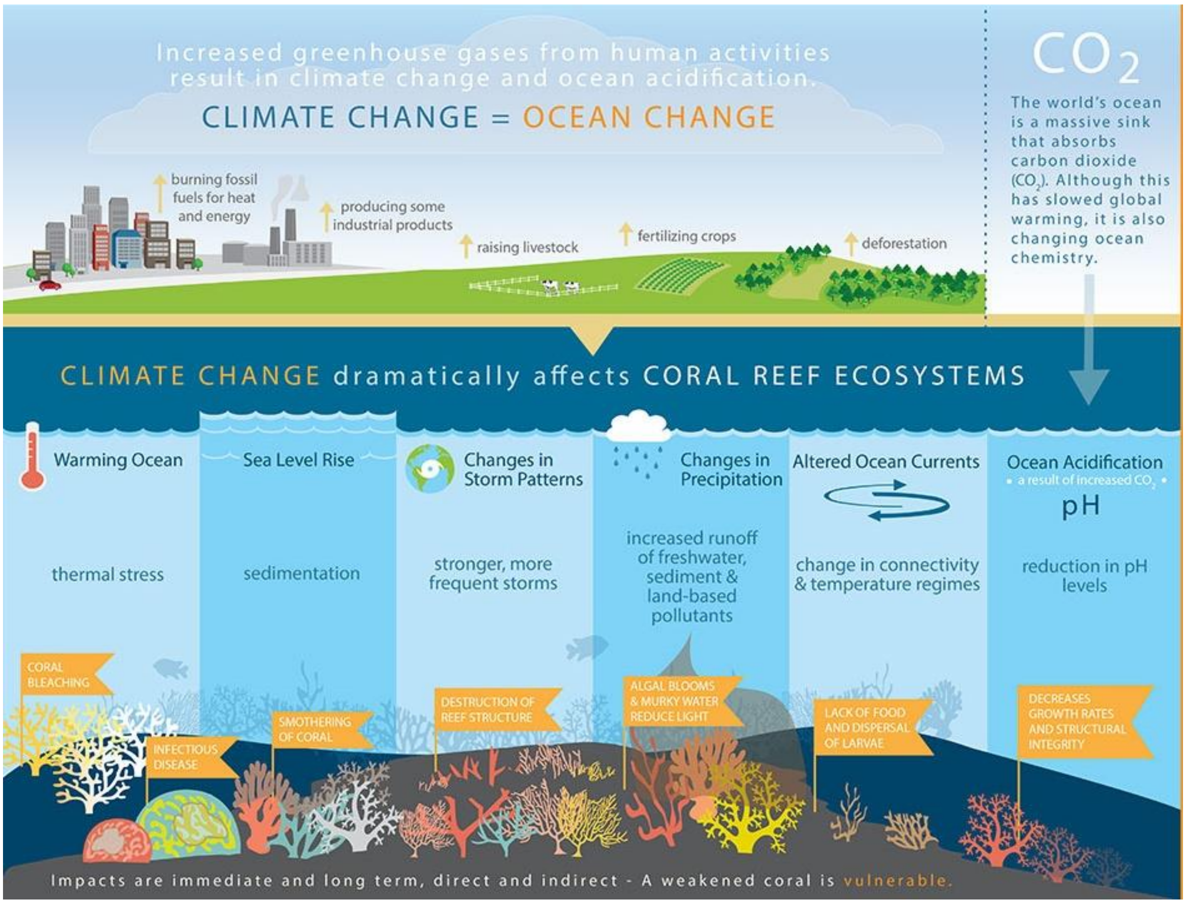

Fig. 2.4.5 Climate change impacts on coral reef ecosystems

Scan this QR code/ click on the link to learn more about how Singapore researchers study colonies of corals at Sentosa for sea level data: *https://www.youtube.com/watch?v=n0sWb_1U2OQ*

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Scan this QR code/ click on the link to learn more about how coral bleaching occurs: *https://www.barrierreef.org/the-reef/threats/coral-bleaching*

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2.5 Migration of Fishes and Insects

Fishes

As oceans warm, **tropical fishes are moving towards the earth's poles** in search of cooler water with better oxygenation, since colder waters can hold more dissolved oxygen than warmer ones. Expansion of range towards the north **increases the competition with native species for food and shelter** which may lead to the native species being outcompeted. While tropical fishes expanded their range, temperate fishes contract theirs.

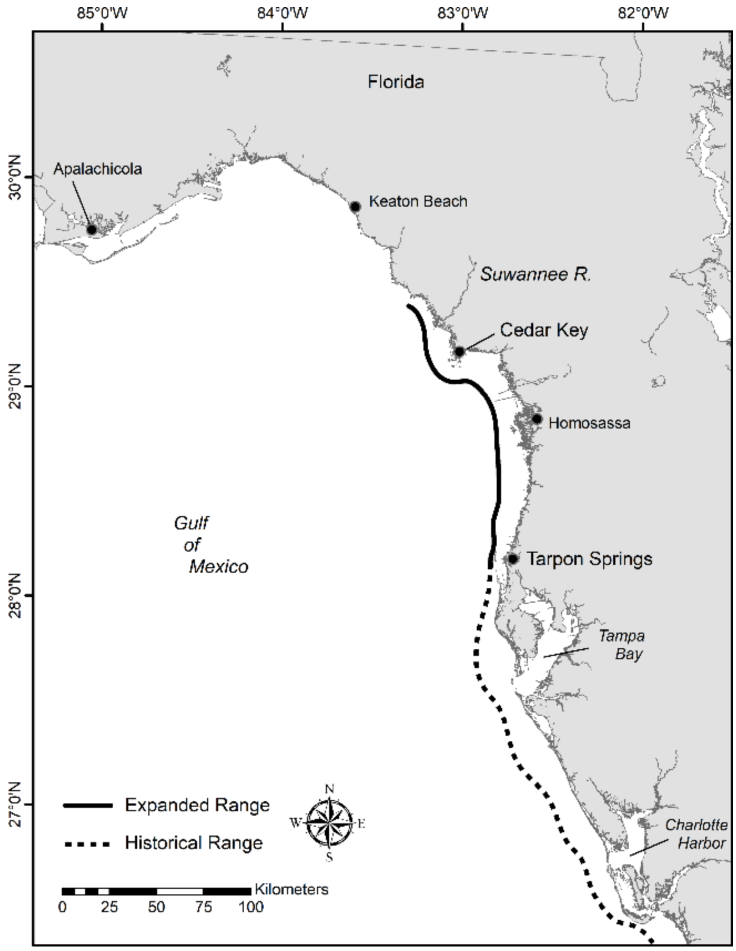


Fig. 2.5.1 Map of historic and expanded ranges of snook on the Gulf coast of Florida.

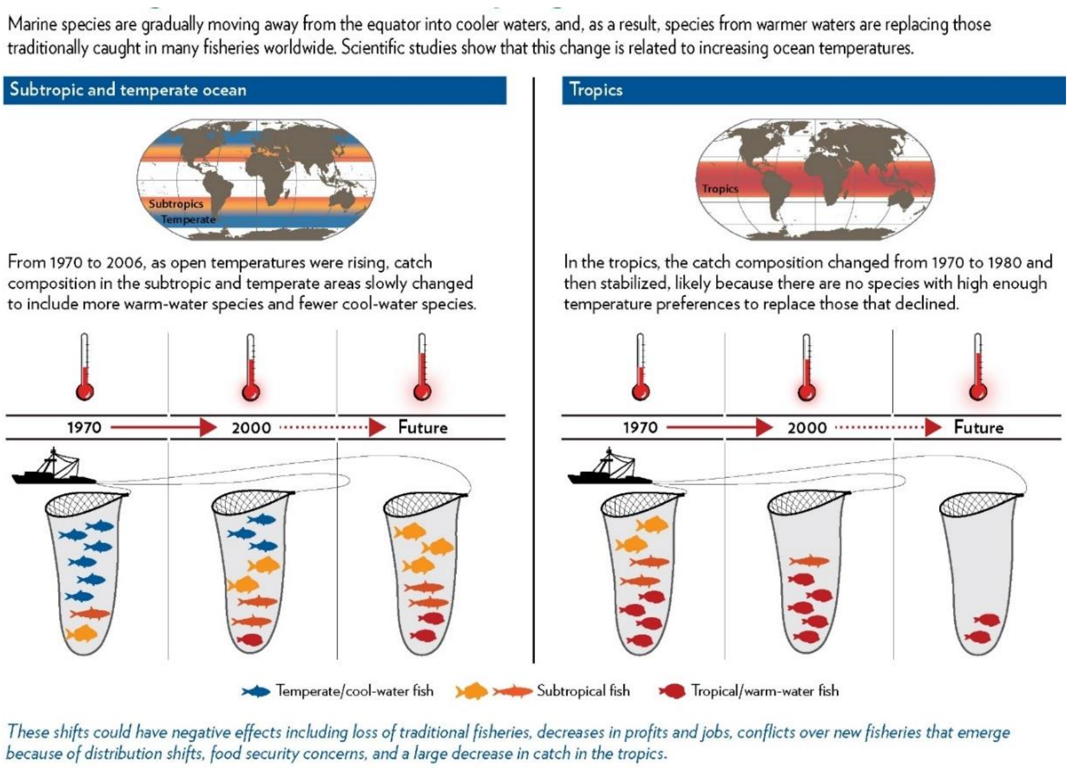


Fig. 2.5.2 Shifts in fish populations in the tropics and temperate regions

Insects

Temperature is the most important environmental factor affecting insect population dynamics. Global climate warming could trigger an **expansion of their geographic range towards the poles**, increased overwintering survival due to higher winter temperatures, increased number of generations, increased risk of invasive insect species and insect-transmitted plant diseases, as well as changes in their interaction with host plants and natural enemies.

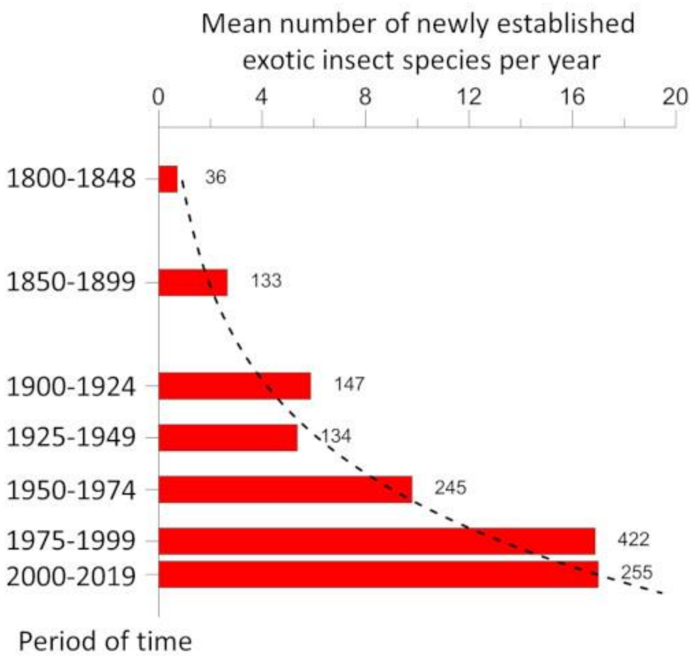


Fig. 2.5.3 Temporal changes in the establishment of non-native insect species in Europe between 1800 and 2019. The numbers next to the bars correspond to the total number of newly reported non-native species established during the reporting period

2.6 Release of GHGs in frozen organic matter

One-third of the Earth's soil carbon is stored **as frozen organic matter in permafrost.** Permafrost occurs in areas where the temperature of the ground remains below the freezing mark for two years or more. Most of the world's permafrost is found in northern Russia, Canada, Alaska, Iceland, and Scandinavia. Much of it underlies peat ecosystems. But like peat, permafrost is also found in the Rocky Mountains of Canada and Alaska, the Alps, the Himalayas, the high-altitude Patagonia region of South America, and the high country of New Zealand.

Under low temperature, the frozen organic matter remains stable. However, with global warming, **permafrost is thawing rapidly**.

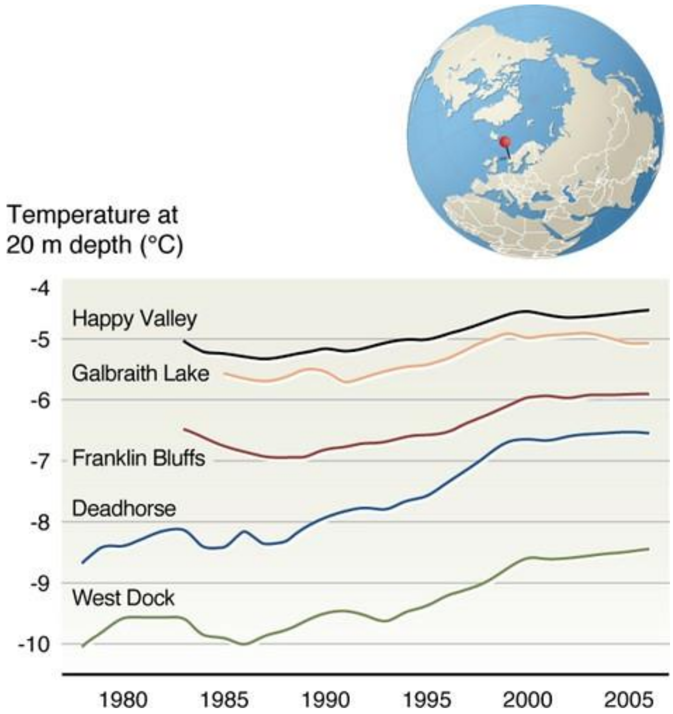


Fig. 2.6.1 Trends in permafrost temperatures during the last 23 to 28 years in northern Alaska

As permafrost thaws, once-dormant microorganisms become active and **break down organic matter, allowing methane and carbon to be released** in the atmosphere. Thawing can also open pathways for methane to rise up from reservoirs deep in the earth.

When permafrost disintegrates, buried ice melts too. As water drains, it transports heat that spreads the thawing, and it leaves behind tunnels and air pockets. The ground sinks to fill those cavities, creating surface depressions that fill with rain and meltwater. The water deepens the pools and chews through their icy banks, until puddles grow to ponds and ponds become lakes. This causes more ground to warm and more ice to melt.

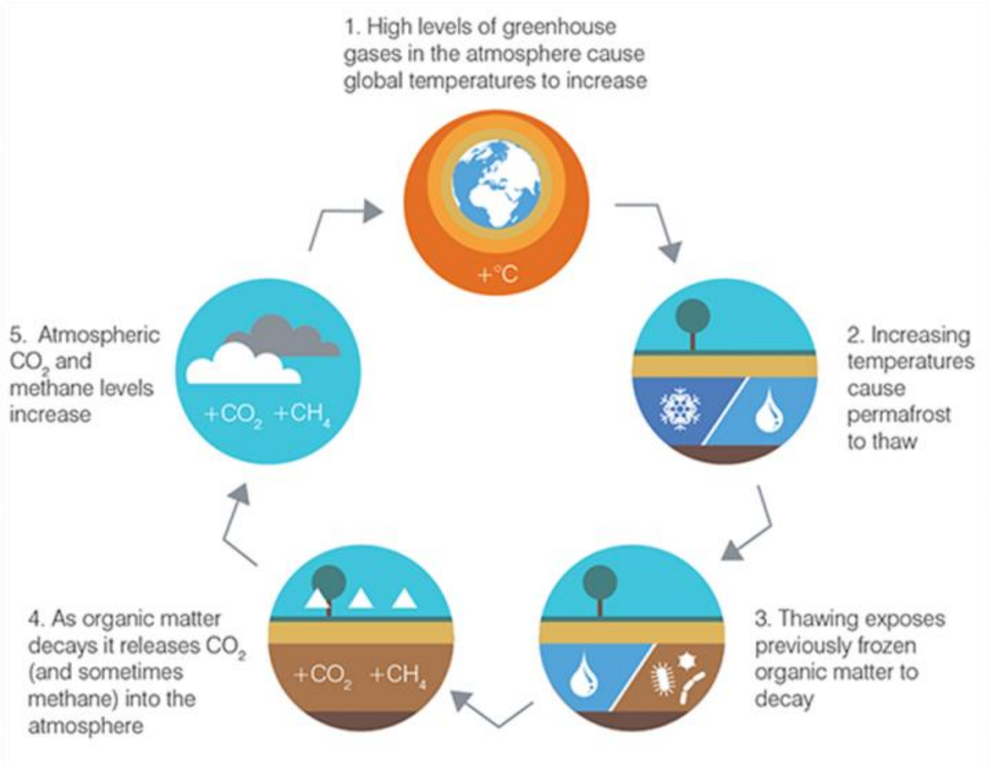


Fig. 2.6.2 Positive feedback loop in the thawing of permafrost

Learning Outcome (c):

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

3 EFFECTS OF CLIMATE CHANGE ON PLANTS

Recent climate change has become one of the main drivers of shifts in the geographical distributions of plant species. There are several ways in which species can respond to climate change: **adapt**, **move to track suitable climates** (i.e. towards higher latitudes and elevations, or to the east and west), or **go extinct** – locally, regionally or globally.

Responses of plant species will depend on their genetic diversity and ability to adapt to the magnitude and rate of climate change, as well as availability of space for species to move into local microclimates (climate of a very small or restricted area).

Increased temperature, frost-free period, snow line, and occurrence of severe drought **increase plant stress over the years**. This would decrease a species' ability to survive in the drier, warmer, lower parts of its range and increase its competitive ability and tolerance in the wetter, cooler, upper parts of its range.

3.1 Changes in Plant Distribution

As global temperature rise, plant populations – as well as animal populations – are projected to **gradually shift upward to higher elevation** and **towards northern latitudes** where temperatures are cooler, in order to stay within their ideal range of environmental conditions.

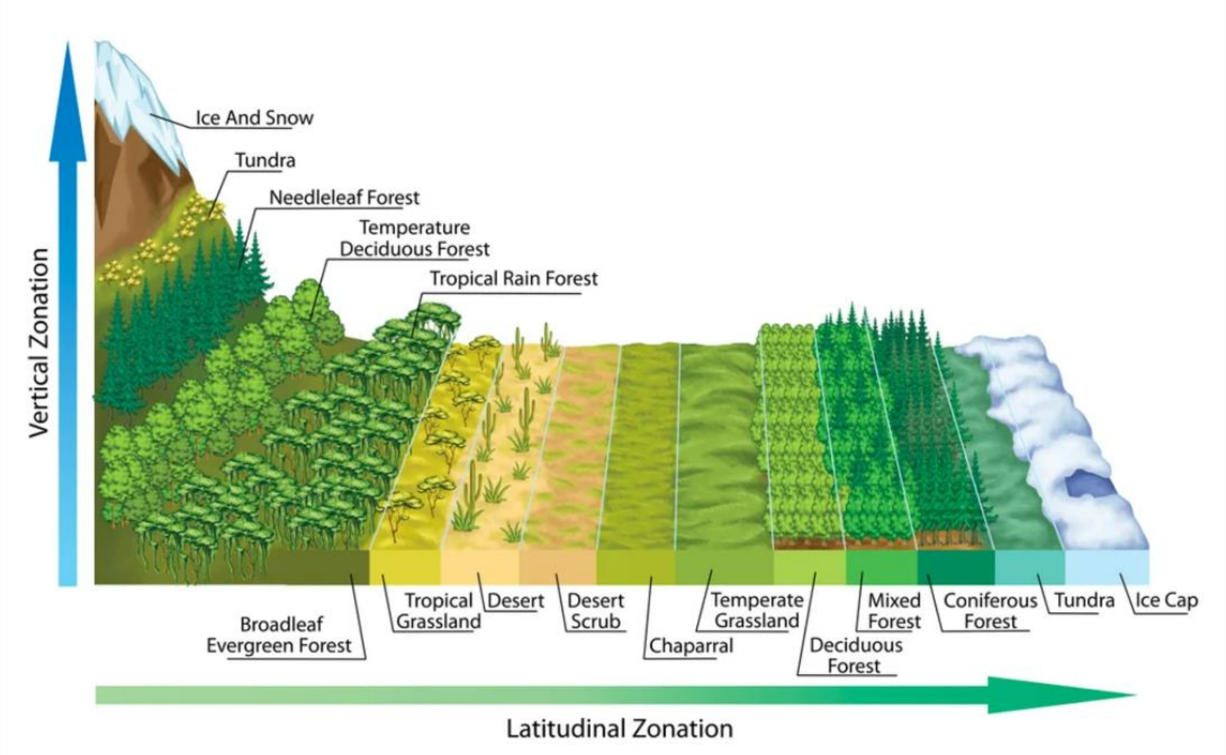


Fig. 3.1.1 Vertical and latitudinal zonation of plants

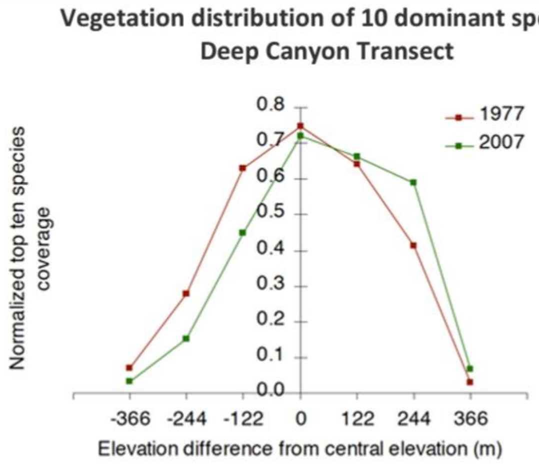
Case Study of plant distribution in Southern California's Santa Rosa Mountains

Surveys of plant cover were made in 1977 and 2006–2007 in Southern California's Santa Rosa Mountains. As Southern California's climate warmed at the surface, the precipitation variability increased, and the amount of snow decreased during the 30-year period preceding the second survey. Scientists found that the average elevation of the dominant plant species rose by 65m between the surveys. At the Deep Canyon Transect, dominant plant species shifted their distributions upslope in a relatively short period due to warmer temperatures.

Species	Mean elevation, m		Change, m
	1977	2006–2007	
Abies concolor (evergreen needleleaf tree)	2,421	2,518	96
Pinus jeffreyi (evergreen needleleaf tree)	2,240	2,267	28
Quercus chrysolepis (evergreen broadleaf tree or shrub)	1,987	2,033	47
Rhus ovata (evergreen shrub)	1,457	1,518	61
Ceanothus greggii var. *perplexans* (evergreen shrub)	1,602	1,671	70
Quercus cornelius-mulleri (evergreen shrub)	1,485	1,522	37
Larrea tridentata (evergreen shrub)	317	459	142
Ambrosia dumosa (drought deciduous shrub)	630	748	118
Encelia farinosa (drought deciduous shrub)	574	674	100
Agave deserti (evergreen succulent)	693	643	−50

Mean change in elevation, 65 m; 95% confidence interval, 34 m.

Fig. 3.1.2 Change in elevation of the ten most widely distributed species in the Deep Canyon Transect



Sources: Kelly and Goulden 2008 (left);
Breshears et al. 2009 (right)

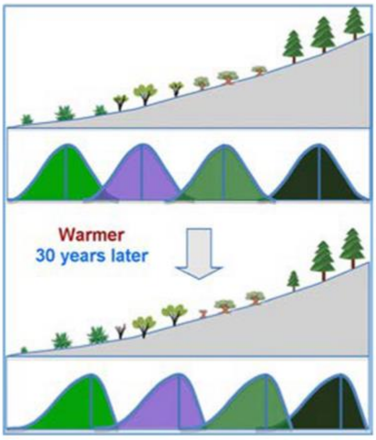


Diagram illustrates shifts along an elevation gradient over a 30-year span. Notice how the graphs in the lower row slant to the right. This indicates that the overall distribution of each species is shifting upslope.

Fig. 3.1.3 Change in elevation of the ten most widely distributed species in the Deep Canyon Transect

Due to climate change, plants which require colder temperatures will move towards the poles. **Plants which can tolerate higher temperatures will expand their range while plants which can only grow in cold temperatures will be lost due to contraction in range**. Such changes in plant species distribution can disrupt ecological relationships, affecting the availability of food and habitat for other species. With increasing habitat loss, **biodiversity is expected to decline** due to fragmentation.

Scan this QR code/ click on the link to learn more about how the world's climate zones are shifting : https://e360.yale.edu/features/redrawing-the-map-how-the-worlds-climate-zones-are-shifting

SCAN ME

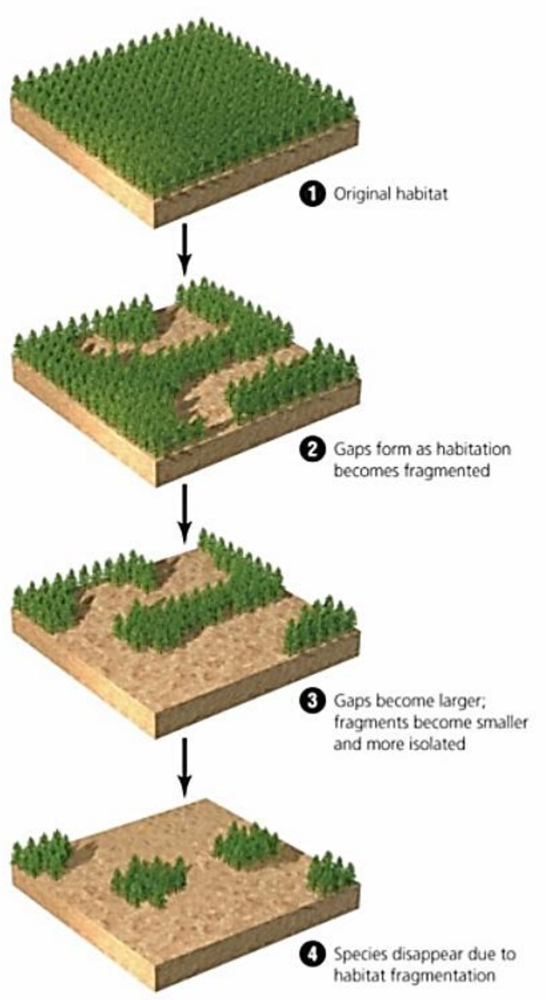


Fig. 3.1.4 Habitat fragmentation resulting in disappearance of species

3.2 Changes in Plant Adaptations

Changes to CO_2 levels, temperature and rain cycles can directly impact biological processes such as photosynthesis, respiration, growth and composition of plant tissues.

Water availability is a major rate limiting factor for plant growth. Under drought conditions and/or high temperatures, plants may experience water stress and exhibit the following physiological and morphological changes:

- reduction of water content and turgor, causing cell expansion to slow down or cease
- reduction in levels of photosynthetic pigments
- increasing ratio of roots to shoots, since plant needs to access more water
- reducing leaf number and leaf size to reduce transpiration
- stomatal closure or reduction in stomatal density to reduce transpiration

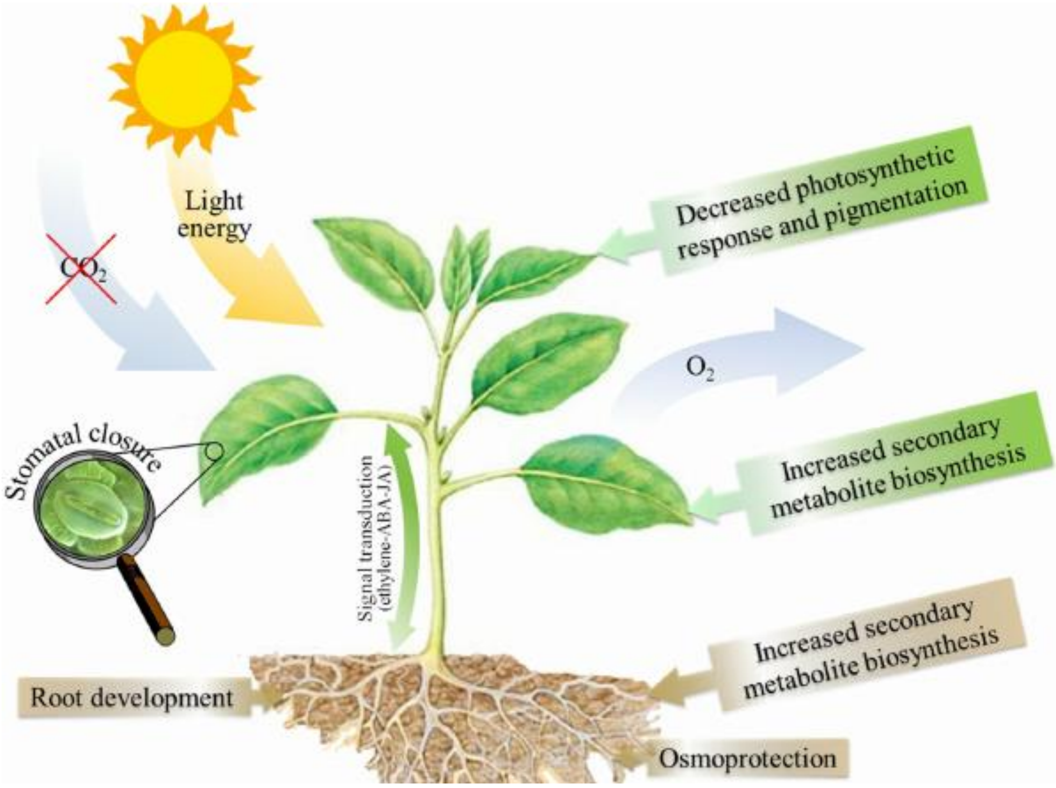


Fig. 3.2.1 Effects of water deficit and high temperature on plants

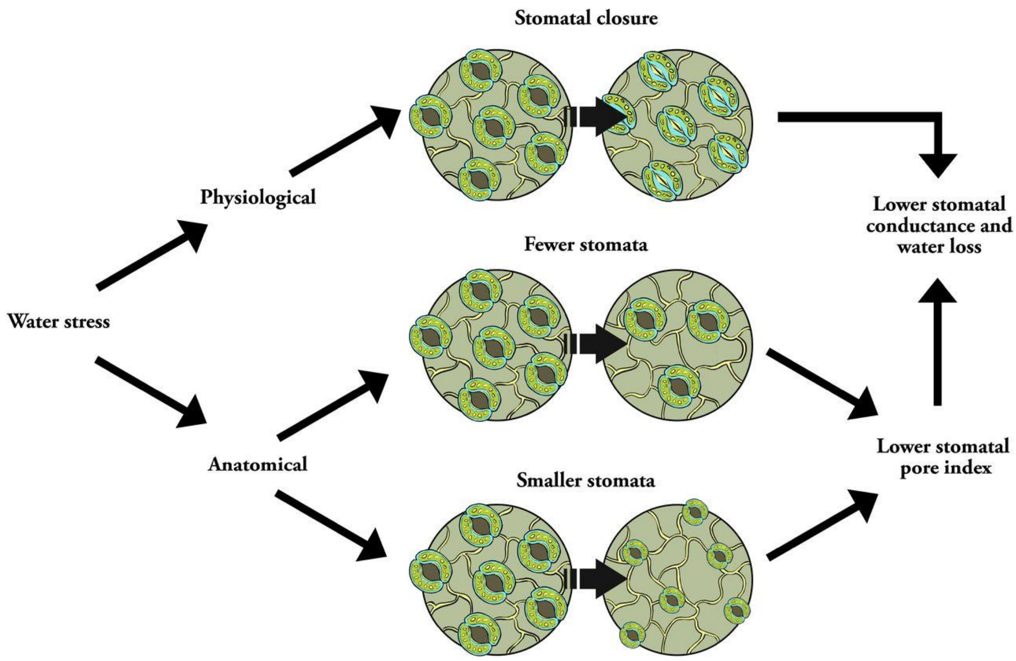


Fig. 3.2.2 Changes in stomata in response to water stress

As a result of the above physiological responses, **photosynthetic rates in plants decrease** and **plant growth is retarded**. Under prolonged drought conditions, many plants dehydrate and die.

Global warming can also affect plant reproduction in the following ways:
- high temperature at flowering time reduces pollen viability in cereals
- earlier flowering season in response to a shorter winter and adaption of the timing of flowering to different winter conditions

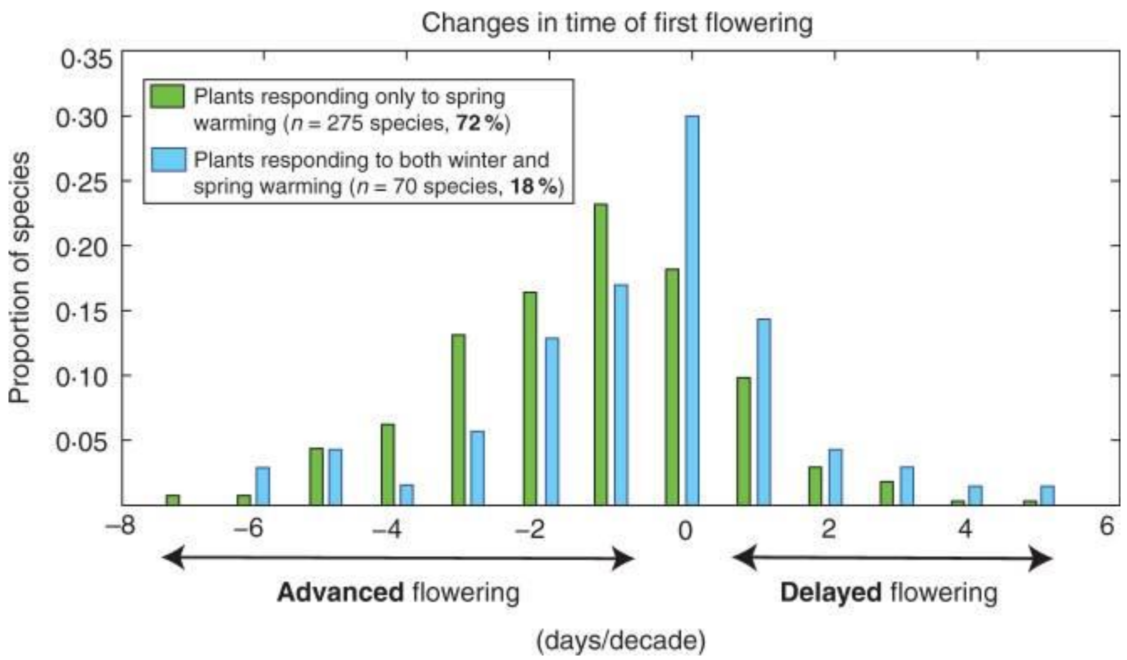


Fig. 3.2.3 Changes in timing of first flowering from 1954 to 2000 for plant species in northern England.

Learning Outcome (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.

4 EFFECTS OF CLIMATE CHANGE ON GLOBAL FOOD SUPPLY

Climate change will **accelerate the danger of severe food shortages**. As a warming atmosphere intensifies the world's droughts, flooding, heat waves, wildfires and other weather patterns, it is **speeding up the rate of soil loss and land degradation thus affecting agriculture**. Food shortages are likely to affect poorer parts of the world far more than richer ones.

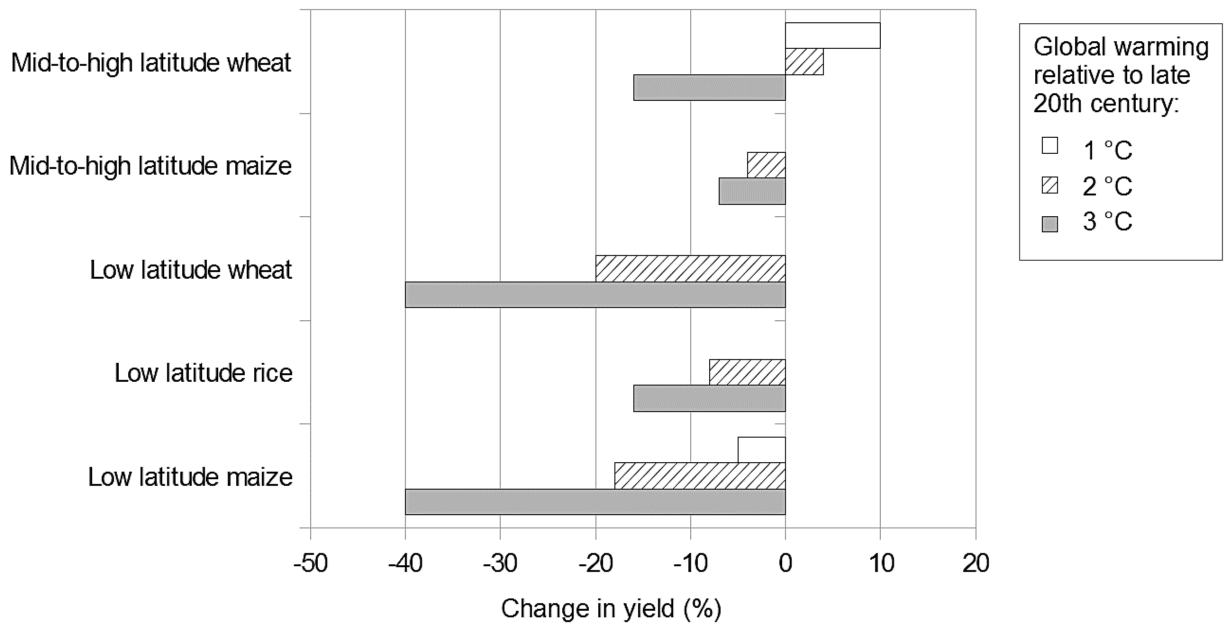


Fig. 4.1 Projected changes in crop yields at different latitudes with global warming

Here are some ways that **climate change affects agriculture and livestock**:

- **Unconducive weather** that is too hot, too cold, too wet or too dry:
    - Droughts reduces the amount of quality forage available to grazing livestock, thus affecting quality of livestock.
    - Heat stress results in the inability of animals to cool down their body temperature effectively, leading to impaired productivity e.g. lower milk yield in cattle.
    - Unusually heavy spring rains may result in sodden fields that are too wet to plant, affecting food crops e.g. soy and corn.
    - Increasing extreme weather events can lead to prolonged droughts and frequent storms resulting in crop failure.
    - Shorter winters result in insufficient time for environmental cues for spring flowering and result in low fruit yields e.g apples. Flowers in the temperate regions may be destroyed by frost during periods of cold spell preceded by warm temperatures.
    - Warmer temperatures affect the growth, survival of pollinators e.g. bats, hummingbird, bees and butterflies. In addition, there could be a mismatch between the timing of flower blooming and active period of pollinators, thus affecting pollination efficiency and leading to a reduction in crop yield.

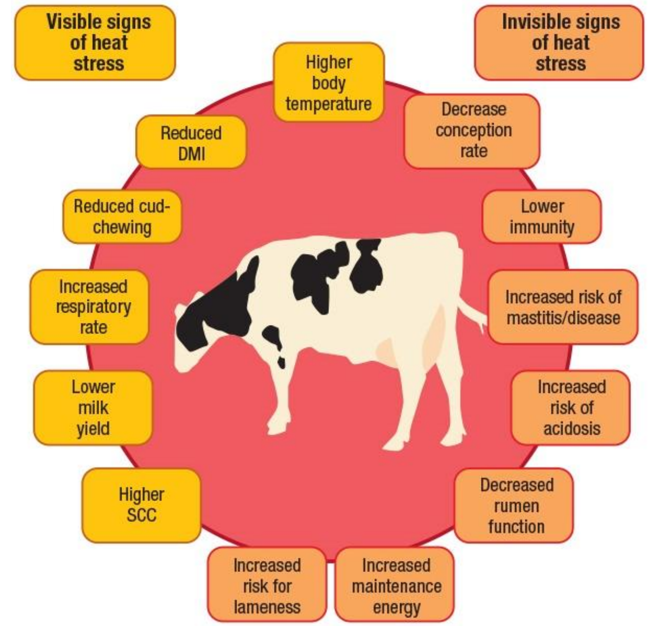


Fig. 4.2 Impact of heat stress on dairy cows

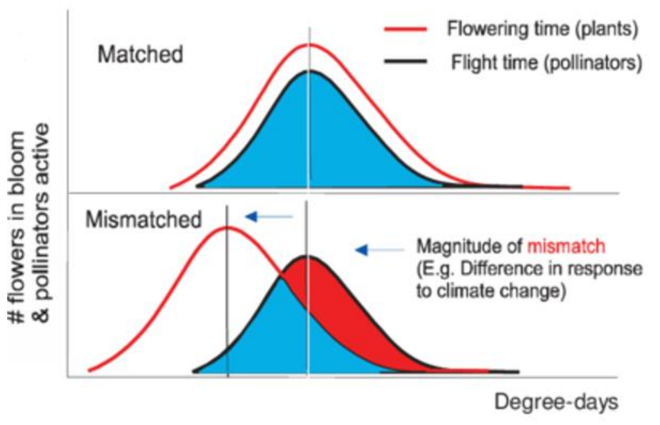


Fig. 4.3 Phenological mismatches between pollinators flight time and plant flowering time

- **Growth in population of crop pests**:
  - Climate change creates new ecological niches that provide opportunities for crop pests to establish and spread in new geographic regions and shift from one region to another.
  - Warmer weather increases the numbers and appetites of the pests, resulting in widespread destruction of the crops e.g. desert locust swarms decimating rice, maize plantations.

Fig. 4.4 Swarming locusts on maize

- **High concentrations of carbon dioxide** in the atmosphere and oceans:
  - Elevated CO_2 levels alters the mineral content of crops thereby **reducing their nutritional quality**, which has implications on human health.
  - Increased ocean acidification could lead to the weakening of shells in the shellfish. Reduction in the size and abundance of shellfish leads to decreased harvest.

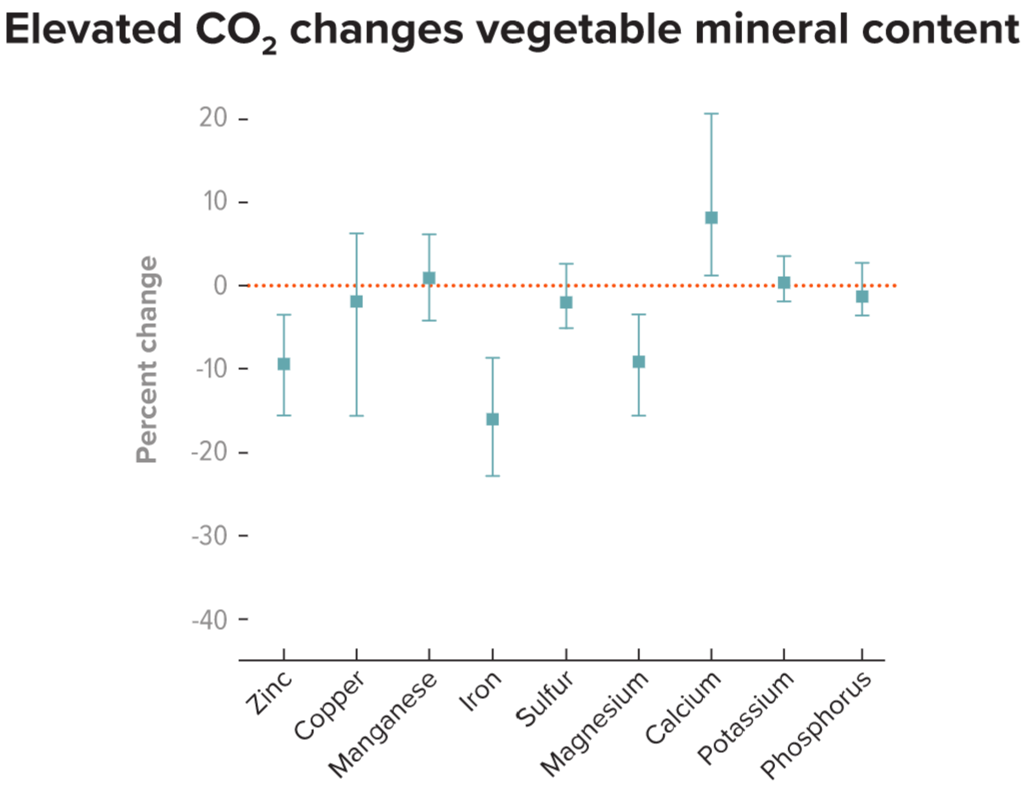


Fig. 4.5 Effect of high CO_2 levels on mineral content of crops

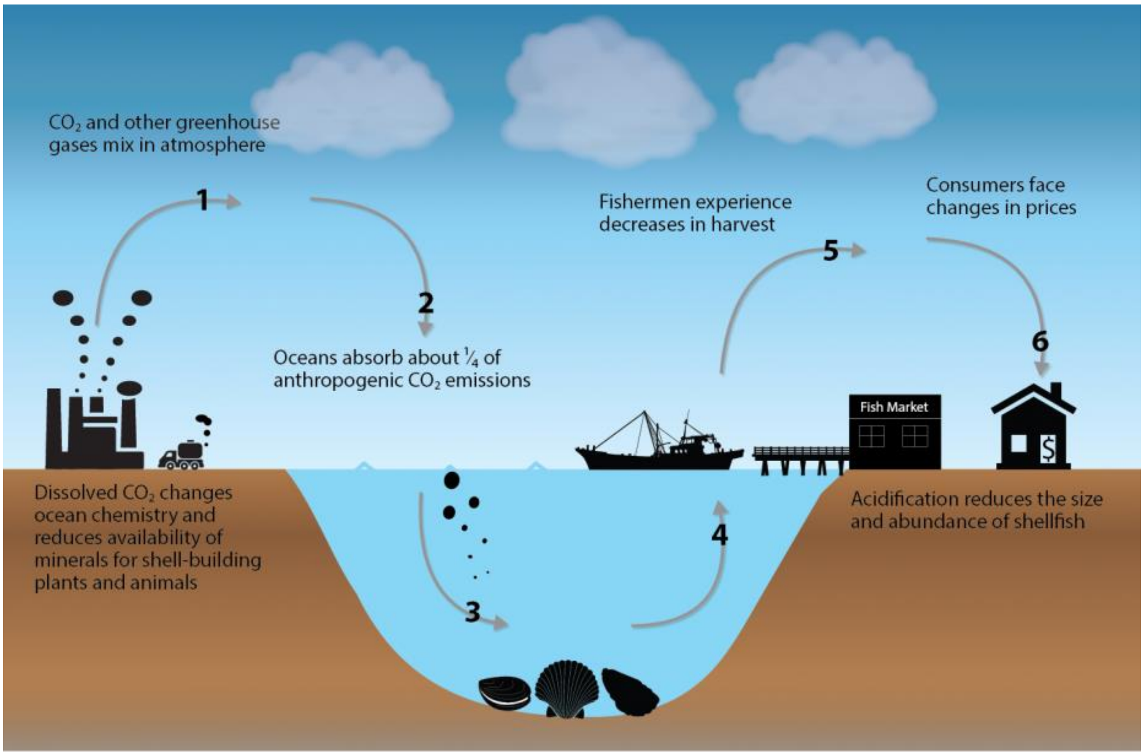


Fig. 4.6 Ocean acidification leading to decrease in shellfish harvest

- **Contamination of freshwater supplies**:
    - Rising sea levels results in saltwater intrusion into freshwater supplies, contaminating freshwater meant for agriculture thereby leading to reduced yield.

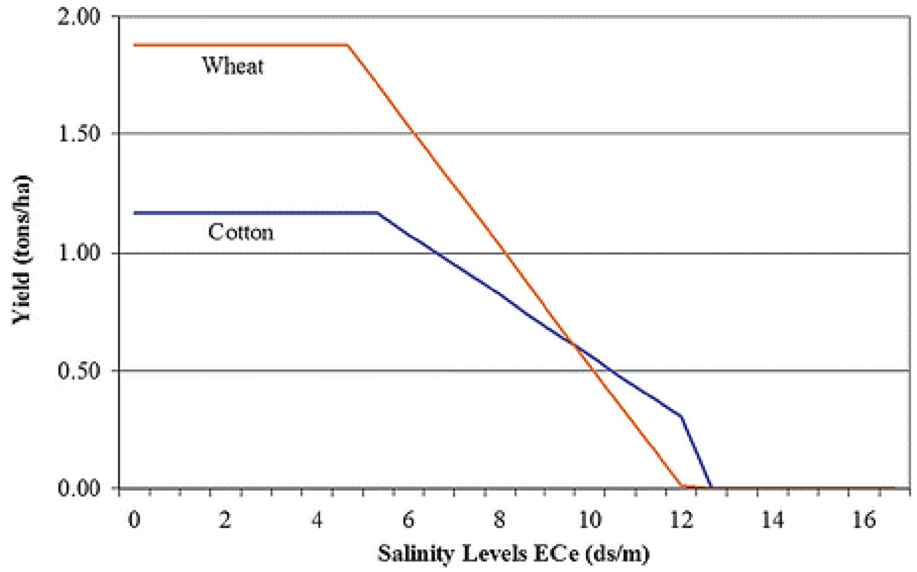


Fig. 4.7 Effect of salinity on crop yield

- **Migration of fish and shellfish**:
    - Fish and shellfish species are expected to move poleward to find colder habitats because of increased sea temperatures.
    - This intensifies competition between the invading species and local species. This could lead to the reduction in population of economically important fish and shellfish, potentially resulting in the collapse of fisheries.

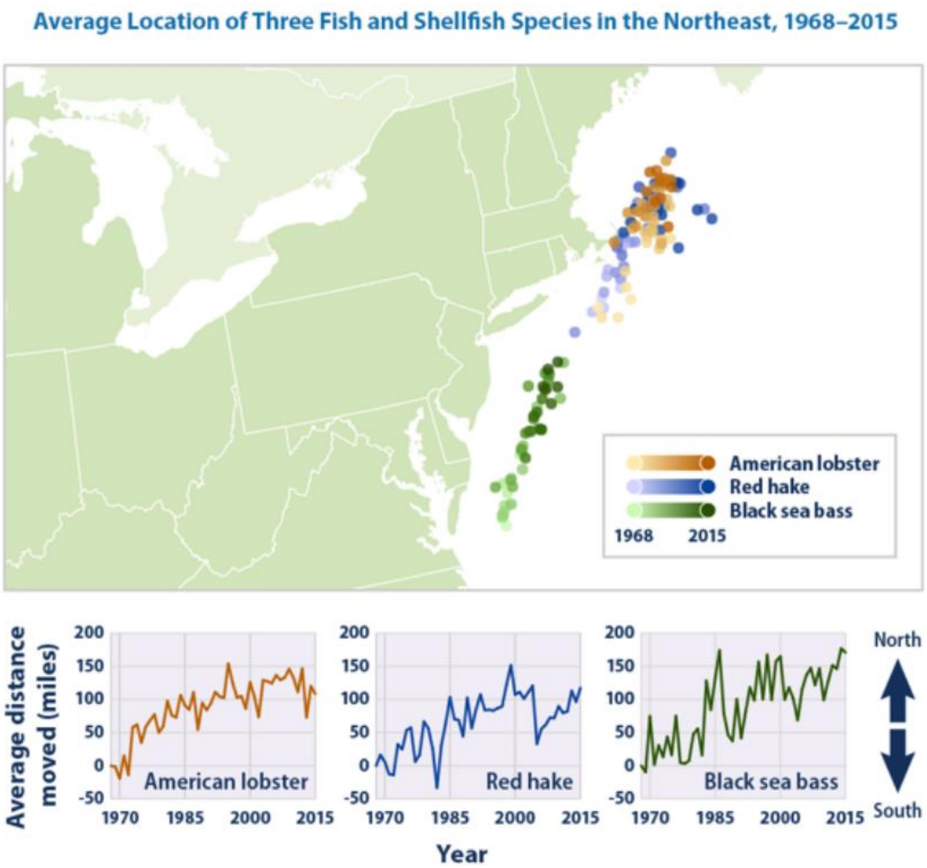


Fig. 4.8 Poleward movement of fish and shellfish