Lecture 11

Possible Effects of Contemporary Climate Change (I): Impacts on Ecosystems and Humans

KEY QUESTION:

How will contemporary climate change impact humans?
Will contemporary climate change impact everyone in the same way?

With the completion of this lecture, attached readings and tutorial, you should be able to understand the:

- Changes in temperature and precipitation associated with contemporary climate change
- Impacts of contemporary climate change on aquatic and terrestrial ecosystems
- Impacts of these changes in aquatic and terrestrial ecosystems on humans
- Impacts of contemporary climate change on places
- Variation in negative impacts of contemporary climate change

Lecture Overview

11.1 Changes in Temperature and Precipitation associated with Contemporary Climate Change
  (a) Temperature **(b)** Precipitation

11.2 Impacts of Contemporary Climate Change on Ecosystems
  (a) Terrestrial ecosystem **(b)** Aquatic ecosystem
  Box 1: *Contemporary climate change and its impacts on walruses*

11.3 Impacts of Changes to Ecosystems on Humans

11.4 Positive and Negative Impacts of Contemporary Climate Change on Places
  11.4.1 Melting Ice Sheets and Sea Level Rise (SLR)
  11.4.2 Extreme Weather – (a) Desertification and Drought (b) Storms and Cyclones
  11.4.3 Human Health
  11.4.4 Migration of Populations
  11.4.5 Crop Yields
  11.4.6 Trade Routes
  11.4.7 Tourism

11.5 Variations in Negative Impact of Contemporary Climate Change
  11.5.1 Variations in Negative Impacts of Contemporary Climate Change due to Places
  11.5.2 Variations in Negative Impact of Contemporary Climate Change due to Differences in Vulnerability of Different Groups of People

11.6 Conclusion

Readings – The following are recently published summaries of the impacts observed in world regions most relevant in our syllabus:

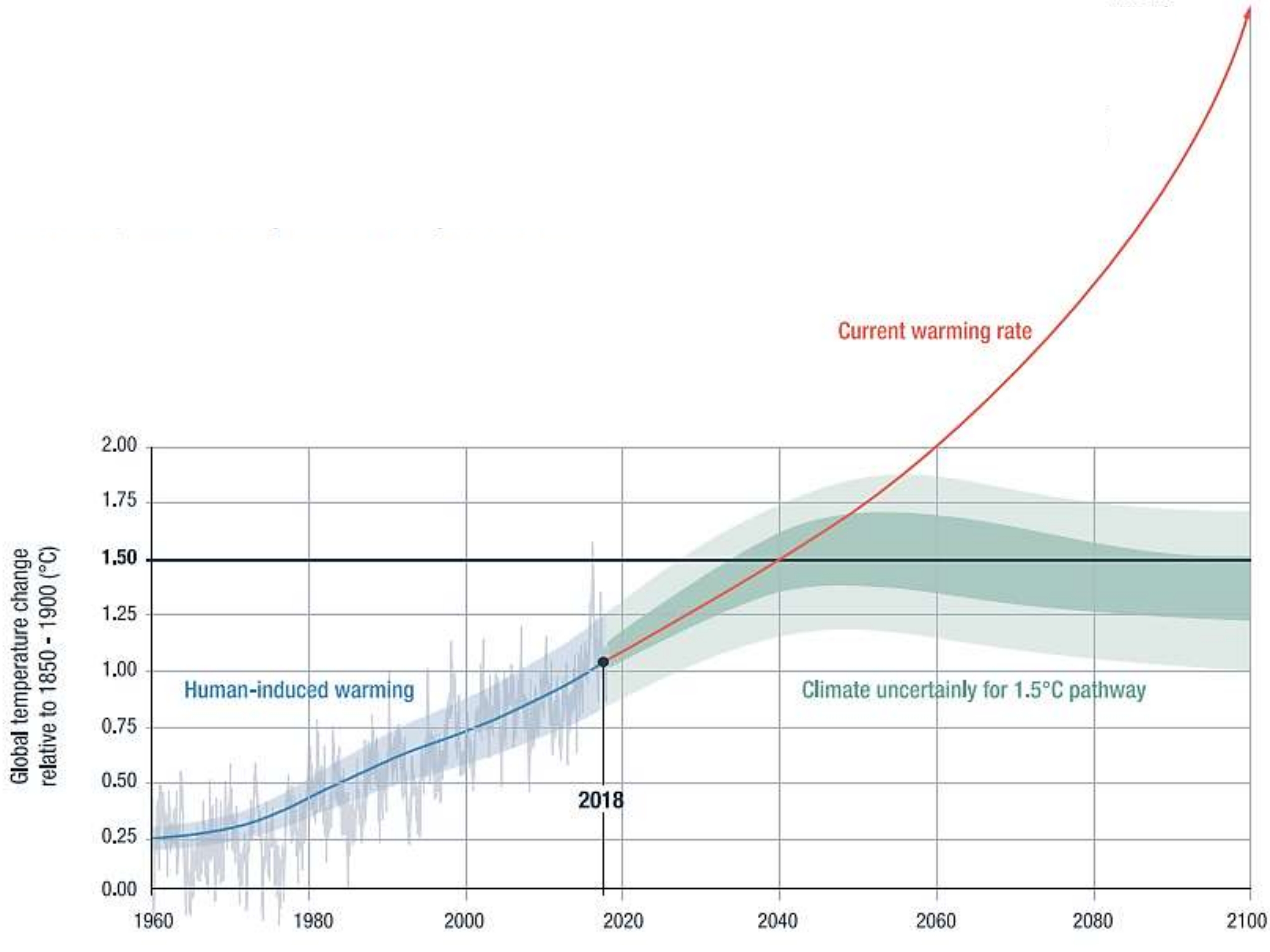
1) Geofile 770, January 2018: See the **Great Barrier Reef** before you die … or before it dies?
2) IPCC AR6 (2022) Factsheet – **Asia**
3) IPCC AR6 (2022) Factsheet – **Africa**
4) IPCC AR6 (2022) Factsheet – **Small Islands**

11.1 Changes in Temperature and Precipitation associated with Contemporary Climate Change

- In **Lecture 10**, we learnt that the enhanced greenhouse effect has led to an increase in heat that is retained on Earth, bringing about an increase in global average temperatures. The rise in temperature influences precipitation. Together, the increase in temperature and precipitation changes are expected to generate potentially devastating impacts on natural systems and humans as a result.

(a) Temperature

- As we have learnt in earlier lectures, the increased amounts of greenhouse gases released by human activities have enhanced the natural greenhouse effect, causing global temperatures to rise.
- To date, human-generated emissions since the start of the Industrial Revolution have led to global warming of 1.0°C.
- If these emissions continue at current rates, we are likely to reach 1.5°C of warming between 2030 and 2052 – an additional warming of 0.5°C from today's level (see **Fig. 1**).



Human-induced warming reached approximately 1°C above pre-industrial levels in 2017. At the present rate, global temperature would reach 1.5°C around 2040.

Adapted from the Special Report on Global Warming of 1.5°C (IPCC)

Fig. 1

(b) Precipitation

- A warmer atmosphere can hold more moisture, and globally water vapour increases by 7% for every degree centigrade of warming. How this will translate into changes in global precipitation is less clear cut, but the **total volume of precipitation is likely to increase by 1-2% per degree of warming**.
  - But this increased moisture **will not fall evenly** across the planet. Some areas will see increased precipitation, while other areas are expected to see less due to shifting weather patterns and other factors.
  - It is also likely that in a warmer climate, heavy rainfall will increase and be produced by fewer more intense events. This could lead to longer dry spells (in between these rainfall events).
- **Fig. 2** below shows projected percentage change in precipitation between the current climate (represented by the 1981-2000 average) and the end of the century (2081-2100) in the average of all of the climate models featured in a recent IPCC report, using the business-as-usual scenario.
- Purple colours show areas where precipitation will increase, while orange areas indicate less future rain and snow. On average, warming is expected to result in dry areas becoming drier and wet areas becoming wetter, especially in mid- and high-latitude areas.

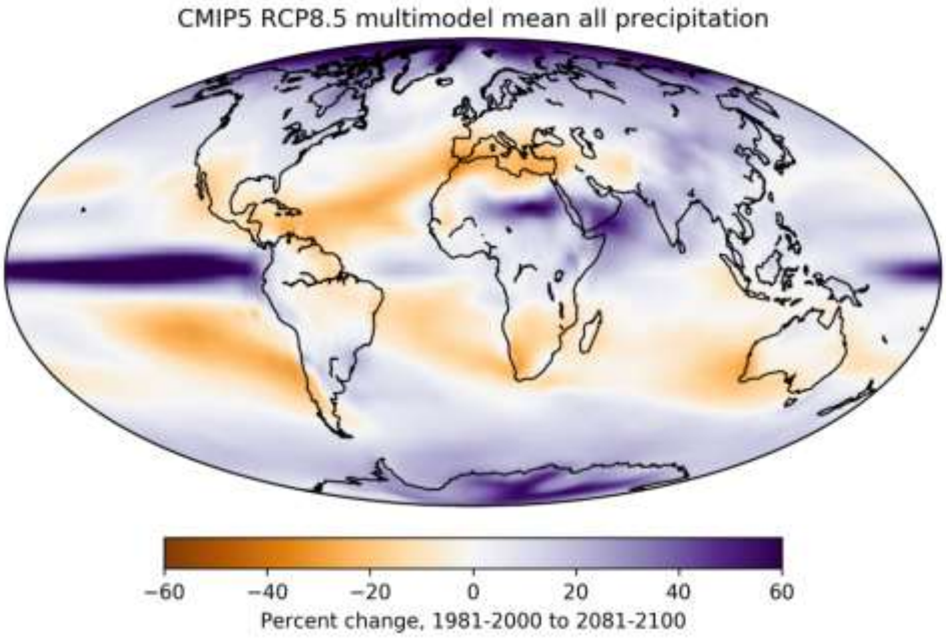
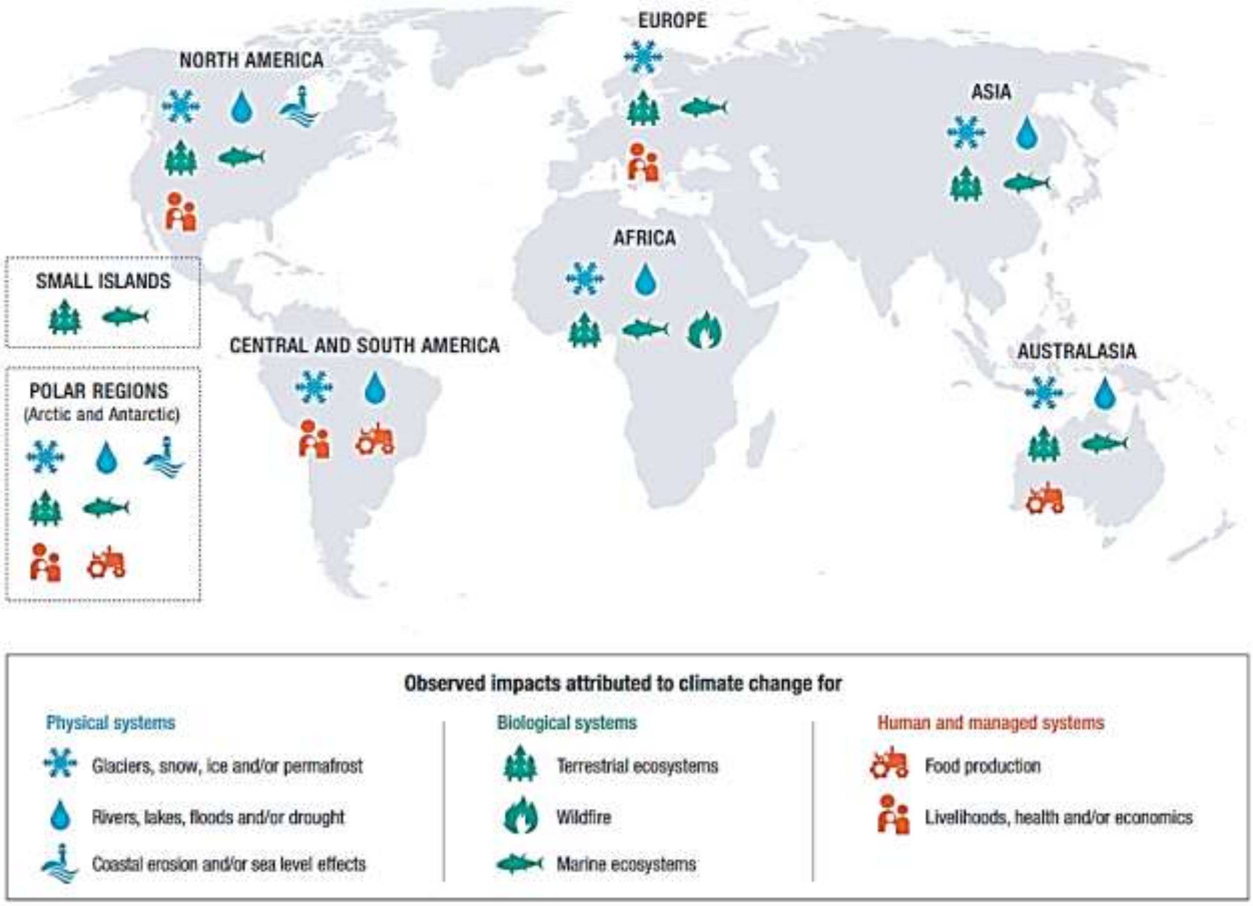


Fig. 2

11.2 Impacts of Contemporary Climate Change on Ecosystems

- Impacts of contemporary climate change can be seen on natural and human systems (see **Fig. 3**). For the purpose of this lecture, we focus on the natural systems, specifically terrestrial and aquatic ecosystems respectively (see **Section 11.2**) and also impact of changes to ecosystems on humans (see **Section 11.3**).
- An ecosystem can be defined as a **dynamic complex of plant, animal and microorganism communities and the non-living environment interacting as a functional unit**. Humans are an integral part of ecosystems.

- Climate is a key element of ecosystems, shaping habitats that support plants and animals. Some plant and animal species will adapt to change, others, more highly specialised or geographically isolated, face decline and ultimately extinction.
- Many terrestrial, freshwater, and marine species have also shifted their geographic ranges, seasonal activities, migration patterns, and species interactions in response to ongoing climate change.



Widespread impacts attributed to climate change based on the available scientific literature.
Adapted from the Special Report on Global Warming of 1.5°C (IPCC).

Fig. 3

(a) Terrestrial ecosystem

- A terrestrial ecosystem is a **land-based** community of organisms and the interactions of biotic and abiotic components in a given area.
- Climate, primarily temperature and precipitation, determine the geographic distribution of major terrestrial ecosystems from deserts to rain forests. Forests and other terrestrial biomes provide habitats for a diversity of plants and animals. If the forest is damaged or removed, habitat loss can endanger the survival of the associated living organisms. Climate change can directly affect many plants and animals by altering the growing season or temperature patterns that trigger life cycle changes.
- The impacts on ecosystems are possibly more apparent in the **tundra** (i.e. the Arctic region where the subsoil is *permafrost*, or permanently frozen) than in any other ecosystems, as temperatures are rising fastest there. Examples of **habitat change** include:

- As the permafrost thaws, wetland areas expand, attracting more migratory birds. Influxes of spring migrants from the south will occur earlier, the breeding season will last longer and higher temperatures will ensure an abundance of insects.
- Meanwhile, the southern fringes of the tundra will lose their open aspect as the tree line advances north. As forests replace tundra, changes in habitat will affect indigenous plant and animal species. Migration patterns among animals such as the caribou (a type of reindeer), which spend the summer on the tundra, will be disrupted. As open tundra habitats shrink, predators such as snowy owls and arctic foxes, which rely on lemming population, will be forced northwards.

- **Phenology**, the study of changes in the timing of spring and other natural seasonal events, is an indicator of global warming. According to IPCC, in the past 30-40 years, spring has occurred earlier by 2.3-5.2 days per decade on average. This creates a loss of synchronisation (**Fig. 4**) between species: animals awaken from hibernation or start to breed before the emergence of food resources such as leaves, insects, larvae and caterpillars.

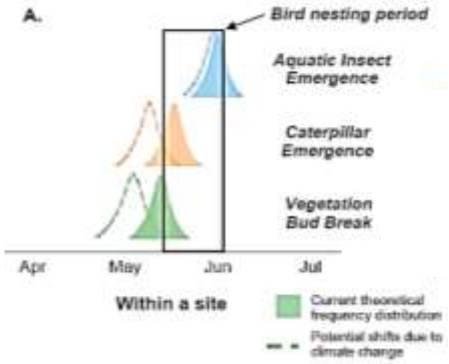


Fig. 4: Potential spring phenology of key trophic levels within a site.
With climate change, desynchronised trophic interactions and reduced food availability for birds could occur.

(b) Aquatic ecosystem

- Aquatic ecosystems include oceans, lakes, rivers, streams, estuaries, and wetlands.

Marine ecosystems

- Global warming affects aquatic ecosystems by ***raising*** **sea surface temperatures** (SSTs).
  - Coral reefs, one of the most biodiverse and productive ecosystems on the planet, are currently threatened by **bleaching**, caused by higher SSTs. Bleaching and the death of corals are possible with only a small rise in water temperature (1-2°C). Coral reefs support some of the most biodiverse ecosystems on the planet. They provide shelter, spawning grounds, and protection to a large variety of marine organisms from predators. They also support organisms at the base of ocean food chains. As reef ecosystems collapse, already at-risk species may face extinction.
  - In Singapore, 44% of corals bleached during the 2024 marine heatwave, with approximately 5% mortality. Deeper reefs (6–8 meters) have declined from ~30% live coral cover in the 1980s to just 5% today due to cumulative stressors, including repeated bleaching events (1998, 2010, 2016, 2024). This reduced biodiversity and habitat complexity, threatening reef-dependent species.
  - Globally, around 70 to 90% of coral reefs are expected to be lost at 1.5°C warming, but 99% at 2°C warming.
- Massive changes to marine ecosystems are currently taking place in the Arctic.

  - Warming of the Arctic Ocean and shrinking of the sea ice have decimated ice algae, which are the base of the marine food chain.
  - Sea ice is also crucial to the survival of marine mammals such as walruses and seals. Walruses use the coastal sea ice as diving platforms for foraging on the seabed and travel long distances on floating ice. (Learn more about the impacts of contemporary climate change on walruses in **Box 1**.) A variety of other species also use sea ice to rest, give birth, raise pups and moult (i.e. shed old feathers, hair, or skin to make way for a new growth).
  - The disappearance of sea ice is the main reason for a projected two-third decline in the polar bear population by mid-century. Their main prey, ringed seals, live under it, and bears hunt from the ice above. As sea ice shrinks, bears have to swim further and further to get to their food source. The harder they have to work, the fewer will survive.
- **Ocean acidification** is another well-known example of how climate change can impact biodiversity. Increasing acidity has a wide range of potentially harmful consequences for marine organisms, shown to impact the immune systems of shellfish and formation of the skeletons of corals and specific plankton.

Freshwater ecosystems

- Increases in water temperatures as a result of climate change will alter fundamental ecological processes and the geographic distribution of aquatic species.
  - For example, cold-water fishes like trout and salmon are projected to disappear from large portions of their current geographic range in the continental United States, when warming causes water temperature to exceed their thermal tolerance limits. In contrast, many fish species that prefer warmer water, such as largemouth bass and carp, will potentially expand their ranges in the United States and Canada as surface waters warm.
- The productivity of inland freshwater and coastal wetland ecosystems also will be significantly altered by increases in water temperatures.
  - Warmer waters are naturally more productive, but the particular species that flourish may be undesirable or even harmful. For example, the blooms of "nuisance" algae that occur in many lakes during warm, nutrient-rich periods can be expected to increase in frequency in the future. Algal blooms can reduce the ability of fish and other aquatic life to find food and can cause entire populations to leave an area or even die.
  - Large fish predators that require cool water may be lost from smaller lakes as surface water temperatures warm, and this may indirectly cause more blooms of nuisance algae, which can reduce water quality for all organisms reliant on it.

11.3 Impacts of Changes to Ecosystems on Humans

- **Ecosystem services** are the *<u>benefits people obtain from ecosystems</u>*. With the terrestrial and aquatic ecosystems adversely impacted by contemporary climate change, the services that humans derive from these ecosystems will also be implicated.

(a) Humans obtain tangible products from ecosystems for basic human needs such as food and fuel.

- An example of this **provisioning service** can be seen in the way the indigenous **Inuit** hunters of the Arctic depend on the **marine** ecosystem. Their economy depends on hunting marine mammals, especially seals, walrus and whales. But thinning and melting of the sea ice makes hunting hazardous. And with more open water in the Arctic, the number of killer whales is increasing. These are natural predators of bowhead whales, narwhals and seals, hence killer whales are in direct competition with Inuit hunters.

- A more general example can be seen in **coral reefs**. These support more species per unit area than any other marine environment, including about 4,000 species of fish. Around half of all federally managed fisheries in the US depend on coral reefs and related habitats for a portion of their life cycles. The commercial value of US fisheries from coral reefs is estimated to be over $100 million. (Read more about coral reef ecosystems in **Reading 1**, and we shall discuss more about them in **Tutorial 11**).
- Similarly, humans depend on terrestrial ecosystems for basic needs such as food and fuel. For example, **tropical forests** are home to 50-90% of Earth's terrestrial species. Their survival will have direct impacts on our ability to derive benefits from the ecosystems.

(b) Humans benefit from the ecosystems' ability to regulate the conditions where humans live and make a living.

- Examples of **regulating services** include:
  - **Pollination**. Animal pollination is an ecosystem service mainly provided by insects but also by some birds and bats. These organisms live in healthy terrestrial ecosystems and usually requires a certain set of conditions to thrive, such as those to do with their life cycles (see **Section 11.2a** on habitat changes and phenology). The yields of more than 70% of the leading global crops are dependent on, or enhanced by, pollination. Pollination not only increases crop yields, but also improves crop quality, particularly in fruits such as strawberries and raspberries that produce misshapen fruits if not adequately pollinated.
  - **Moderation of extreme events**. Coastal aquatic ecosystems, such as mangroves, create buffers against natural disasters such as floods, tropical storms and cyclones. Mangroves, with their dense network of roots, help to break sea waves during storm surges and reduce coastal flooding. Studies show that mangroves can reduce up to 66% of wave energy in the first 100 m of the forest width. Mangroves provide over $65 billion per year in flood protection benefits.

(c) Ecosystems contribute to non-material benefits that arise from interaction between people and ecosystems.

- **Cultural services** are directly experienced in nature and essential to human pursuit of meaning, such as r**ecreation and tourism**. When ecosystems deteriorate, cultural services will also be lost.
- Terrestrial and aquatic ecosystems provide the physical setting for people to interact with the environment and spend their leisure time, through activities such as hiking, mountain biking, snorkelling, scuba diving and whale watching. Many people find beauty or experience a sense of awe in various aspects of ecosystems.

Box 1: **Contemporary climate change and its impacts on walruses**

Contemporary climate change has resulted in substantial loss of sea ice, and consequently, walruses are changing their behaviour.

Walruses feed on the ocean floor in the relatively shallow waters of the continental shelf, where the sea ice itself sustains a rich food web. Females will leave their young on the sea ice while they forage, then haul out to nurse their calves. The accelerating retreat of sea ice puts the newborns' safe haven farther away from the mothers' food—meaning longer, more exhausting swims for the mothers, and more time alone for the calves. Walruses are also seeking haul-outs on beaches, instead of ice, which puts them in closer proximity to sources of human disturbance. Walruses are known to stampede when disturbed. These stampedes can result in mortality.

Researchers first observed large haul-outs off Alaska's Point Lay in 2007, when summer Arctic Sea ice reached its second-lowest minimum extent in recorded history. As the extent of summer sea ice has continued to decline in Arctic waters, the number of walruses coming ashore has grown considerably.

The relationship between shrinking sea ice and walruses was thrown into much media spotlight following an episode in the BBC Earth docuseries in 2019. In it, disturbing scenes of walruses falling to their deaths from cliffs were used with great impact to show what human-induced climate change can do to marine animals. However, there too were opinions that these were exaggerated claims.

Read the attached article from *The Atlantic* for a coverage on the different opinions over this video (such as BBC was accused of manipulating facts) and decide for yourself how much blame you would place on climate change for the walruses' observed behaviour.

Trigger Warning: You may watch the clip at https://www.youtube.com/watch?v=qVJzQc9ELTE but please be warned about how potential discomfort it may cause you.

11.4 Positive and Negative Impact of Contemporary Climate Change on Places

- In **Lecture 10**, we learnt that the enhanced greenhouse effect has led to an increase in heat that is retained on Earth, bringing about an increase in global average temperatures. This is expected to generate potentially devastating impacts on human and natural systems as a result.
- Impacts of contemporary climate change can be seen on natural and human systems. It can refer to impacts on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure. In this section, the **syllabus** also requires you to be able to **identify the positive and negative impact**s. In addition, to demonstrate mastery of this section, you will need to support your answers with **detailed place-based examples**.
- **Fig. 5** and **Table 1** below show some impacts of contemporary climate change as projected by the Intergovernmental Panel on Climate Change (IPCC). We will examine them in greater detail later. Recall from **Lect. 10** that the IPCC is the UN body for assessing the science related to climate change.

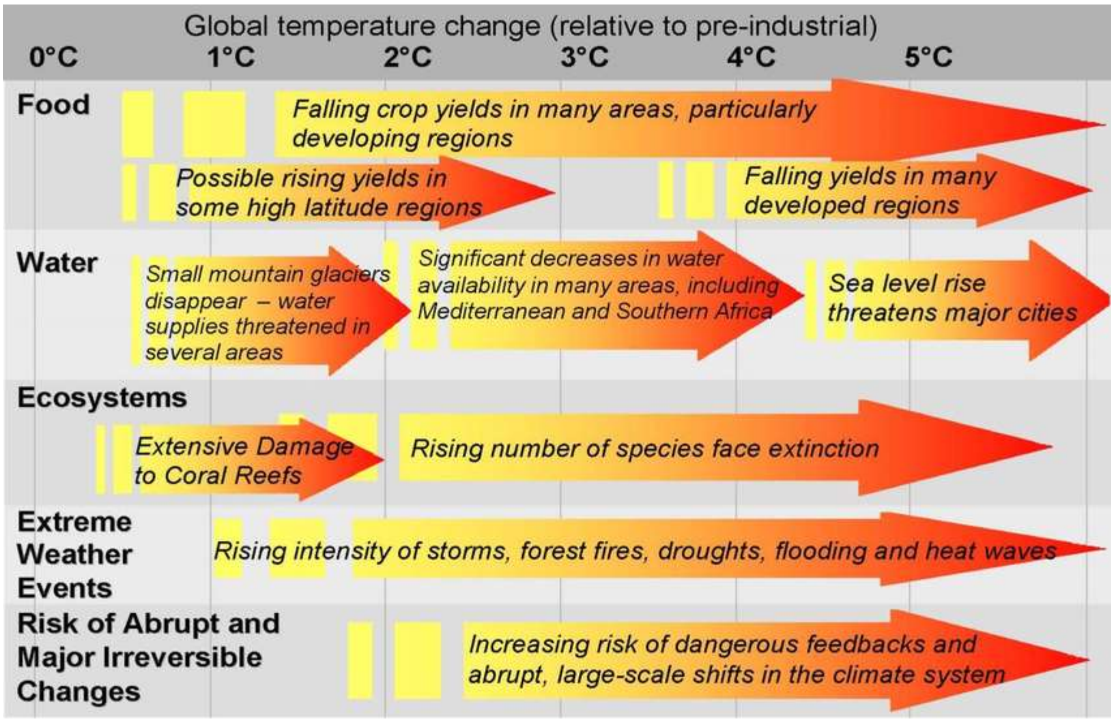


Fig. 5: Projected Impacts of Contemporary Climate Change

🌍 Table 1: Positive and Negative Impacts of Contemporary Climate Change on Places

Region	Negative Impacts	Ecosystem Link	Specific Places	Positive Impacts	Specific Places
Singapore	- Heat stress & rising urban temps - Coastal flooding from sea-level rise - Marine biodiversity loss	- Urban heat island & loss of tree canopy - Decline of mangroves (coastal defence) - Coral bleaching	- East Coast Park (coastal flood risk)- Pulau Ubin (biodiversity shifts)- Sisters' Islands (coral reef bleaching)	- Aquaculture expansion - Urban greening initiatives	- Sembawang (urban farms)- Marina Barrage (green infrastructure)
New South Wales, Australia	- Bushfires & prolonged droughts - Coral reef loss in nearby marine zones - Decline in agriculture	- Collapse of eucalyptus forests - Bleaching in southern GBR - Drying of Murray-Darling basin	- Blue Mountains (fire damage) - South Coast (drought & crop loss) - Batemans Bay (marine change)	- Highland viticulture expansion - Renewables from marine sources	- Orange (new wine regions) - Port Kembla (marine energy)
Mekong Delta, Vietnam	- Saltwater intrusion ruining crops - Inland fish stock decline - Land loss due to subsidence	- Wetland degradation & mangrove loss - Estuarine ecosystem imbalance - River sediment trapped by dams	- Ben Tre, Tra Vinh (salinity) - Can Tho (subsidence & flooding) - An Giang (fishery disruption)	- Aquaculture shift to shrimp/fish - Wetland & mangrove restoration	- Bac Lieu (shrimp zones) - Ca Mau (mangrove regeneration)

Key Observations

- Coastal **and delta regions** (Vietnam, Singapore) are most vulnerable to sea-level rise and saltwater intrusion.
- **Urban centers** (Singapore) experience intense **heat stress**, but are leading on **green infrastructure** adaptation.
- **Mountain and highland regions** (Blue Mountains in New South Wales, Australia) may **benefit agriculturally** from warming, but ecosystems shift.
- **Marine biodiversity** changes are affecting **food security** and **livelihoods** across all regions.

Note: Readings 2, 3 and 4 can be used to supplement the range of places that you can use to discuss positive and negative impacts of CCC on places.

11.4.1 Melting Ice Sheets and Sea Level Rise (SLR)

- Two thirds of the earth's surface is covered by oceans. As it warms, the ocean's volume expands. This expansion, together with additional water from melting glaciers and Greenland and Antarctic ice sheets, raises the sea level. **The relationship between temperature and SLR is clear: a 1°C rise in temperature results in a SLR of approximately 2m.**
- Sea level began to rise in the mid-19th century. Since 1900 the average rise has been 1.0-2.5 mm/year. Recent evidence from satellite altimetry suggests that sea level is currently rising at a faster rate – 3 mm/year – and that this trend will continue throughout the 21st century.
- Just as how the surface of the Earth is not flat, the surface of the ocean is also not flat. Thus, sea level rise will not be uniform globally. Sea level rise at specific locations may be more or less than the global average due to local factors such as land subsidence from natural processes and withdrawal of groundwater and fossil fuels and whether the land is still rebounding from the compressive weight of the Ice Age glaciers which have melted.
- Other areas sensitive to SLR are **low-lying river deltas** and **coastal wetlands**. Examples include the Mississippi, Nile and Ganges deltas. In the United States, a 1m sea level rise would have serious consequences – 30,000 km^2 of coastal area will be inundated and 26-82% of coastal wetlands will be eliminated.
- In brief, the change in sea level will lead to destruction of beaches and wetlands and coastal civilisation because of:
  - Significant erosion along coastline;
  - Severe, permanent inland flooding;
  - Increase the vulnerability of buildings and other structures to waves generated by large storms (see **Fig. 6**); and
  - Saltwater intrusion into groundwater.

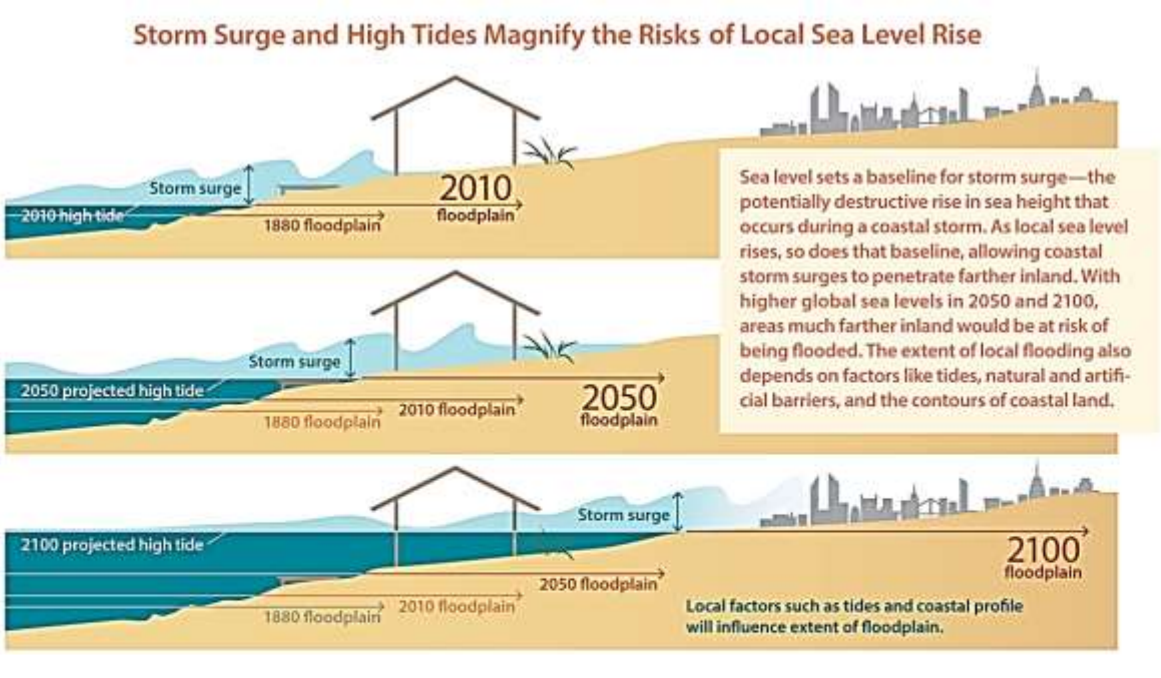


Fig. 6 Impacts of a local sea level rise

Negative Impacts:

Coastal Erosion:

- In **Singapore**, coastal erosion, exacerbated by higher sea levels and more frequent storm surges, could lead to **land value losses** of USD 2 billion by 2100. This will have economic impact. For example, the government estimates it will need to spend USD 75 billion, around 20% of the country's GDP, on coastal protection plans over the coming decades. Moreover, melting ice caps might open alternative sea routes in the Arctic Ocean and challenge Singapore's status as a global sea hub.

Coastal Flooding:

- In **Singapore**, SLR increased **coastal flooding** (**environmental impact**). Low-lying areas like East Coast Park have seen flooding when high tides coincide with heavy rain, according to PUB. Rising sea levels, coupled with storm surges and high tides, contribute to this flooding.
- Rising sea levels and increased rainfall, coupled with subsidence, exacerbate **flood risks**. **Can Tho City in Vietnam** is experiencing **increased flooding** and land subsidence, partly due to climate change and other factors like urbanisation and groundwater extraction. Land subsidence, with the ground sinking by 1.31 cm per year, primarily due to groundwater extraction and sea level rise (4mm sea level rise/year) combine to create a double threat of flooding, making the city more vulnerable to inundation. Land subsidence and flooding can **damage infrastructure**, **contaminate water supplies**, harm agriculture, disrupt businesses, and cause major economic losses.

Damaged Crops and Lack of Fresh Water Supply:

- **Ben Tre** and **Tra Vinh** provinces in the **Mekong Delta** face significant **saltwater intrusion**, particularly during the dry season (March-May). Salinity levels in these coastal areas can reach 25-32 g/l in some locations. This intrusion affects agriculture, particularly rice cultivation, and water availability for human use. Thousands of hectares of crops have been damaged by saltwater that has reached nearly 100 kilometers inland.
- **Ben Tre Province** was severely affected by the most **severe droughts** and **saltwater intrusions** over the last three decades in the Vietnamese Mekong Delta (VMD) in 2016 and 2020. In these years, farmers faced damages caused by saltwater intrusion impacts since intrusions were further inland and remained longer than usual. It was reported that about **40,000 households lacked freshwater**, and **57,000 hectare of paddy, fruit trees, and vegetables were damaged across the province**. The increase in saltwater intrusion in the VMD is mainly from human activities, such as upstream hydropower dams, sand mining, land subsidence, water demand increases, and climate change impacts which have caused significant changes in the hydrologic regime. Saltwater intrusion has also threatened the sustainable water management of Ben Tre Province.

Positive Impacts:

- In **Singapore**, the challenges posed by rising sea levels are driving Singapore to **innovate and explore new approaches to aquaculture**, including land-based and closed-containment systems, which are more resilient to the impacts of climate change. These systems offer more control over water quality, temperature, and other environmental factors, making them more resilient to climate change impacts.

- **Singapore** is exploring the potential of **cultivating a wider range of aquaculture species** that are better adapted to the changing climate.
- Rising sea levels and changing weather patterns are causing more saltwater to seep into the Mekong River, making rice farming increasingly difficult in many areas. The **Mekong Delta in Vietnam** has seen a significant **shift towards shrimp and fish aquaculture**, driven by increased saltwater intrusion. This transition has involved land use changes, with some areas converting rice paddies to shrimp farms and destroying mangrove forests. Shrimp aquaculture has also boosted Vietnam's seafood exports and contributed to the economic development of the Mekong Delta. While aquaculture has brought economic benefits, it also poses challenges to the environment, including habitat loss and pollution.

11.4.2 Extreme Weather

- Global warming is predicted to disrupt regional weather patterns. Extreme weather events such as storms, droughts and heatwaves (**Table 2**) are forecast to occur with greater frequency and intensity.
- The connection between global warming and more extreme weather is complex and not fully understood. However, rising temperatures are known to disrupt the atmospheric system.
- Although extreme weather is part of the natural variability of climate, there is mounting evidence that the trend towards more extreme weather is driven by climate change.

Table 2 Nature and distribution of extreme weather phenomena

Extreme weather event	Nature	Distribution
Tropical cyclones (hurricanes, typhoons)	Large, violent revolving storms generating hurricane-force winds and torrential rain.	The tropics and sub-tropics, mainly in the North Atlantic and North Pacific Oceans, and the western Pacific.
Mid-latitude depressions	Large, mobile low-pressure systems which form on the jet stream and bring spells of heavy rain and gale force winds.	Middle to high latitudes, between 35° and 70°, e.g. northwest Europe, South Island New Zealand.
Tornadoes	Violent, rotating, funnel-shaped columns of air in contact with the ground.	Continental interiors in mid-latitudes, e.g. Midwest USA between the Rockies and the Gulf of Mexico.
Heavy rainfall	Either intense, short-lived thunderstorms or prolonged periods of rainfall associated with cyclones and depressions. The outcome is often river floods or groundwater flooding.	Widespread and most extreme in climates with wet and dry seasons, e.g. monsoon Asia.
Blizzards	Heavy snowfall driven by strong winds.	High latitudes and mountainous regions.
Severe cold spells	Prolonged spells of abnormally low temperature and/or snow cover, e.g. below zero.	Middle to high latitudes. Continental rather than oceanic locations.
Heatwaves	Prolonged spells of abnormally high temperature, e.g. > 30°C.	Middle latitudes in summer.
Droughts	Prolonged spells of abnormally low rainfall.	Widespread but most common in the sub-tropics (e.g. the Sahel), continental interiors (e.g. Midwest USA) and the Mediterranean.

(a) Desertification and Droughts

- An increase in **drought** events (i.e. prolonged spells of abnormally low rainfall) may also result from contemporary climate change. Some of the arid areas become drier and warmer from contemporary climate change and are likely to have more droughts.
- It is likely that areas with no significant history of droughts will have to cope with them. These areas may be ill-equipped to accurately predict and deal with droughts, further compounding the problem.
- Drought can be observed in both developed and developing countries.
  - The Sahel region of Africa has endured numerous droughts in the past 40 years, which have accelerated desertification while in 2015 California entered its fourth successive year of drought.
- Droughts can be confused with two other related terms. **Table 3** below provides the differences between *drought*, *aridity* and *desertification*.
- **Desertification** refers to a phenomenon of conversion of land to that *resembling* desert will increase. Full desert-like conditions are rare, but *agricultural productivity is greatly reduced* in affected areas.
  - Desertification is the outcome of persistent land degradation, most often in dryland environments, frequently caused by deforestation, overgrazing and overcultivation.
  - Although desertification is a human-induced phenomenon, climate change will likely exacerbate the problem in areas that are already becoming warmer and drier. The effects related to desertification are long-term and chronic.
- Note about Table 3: While desertification and droughts are problems that can be connected to contemporary climate change, aridity is an expected climatic condition in places such as tropical deserts, characterised by very low rainfall. While contemporary climate change may make living conditions less conducive here, it is difficult to claim that contemporary climate change *created* such places as they were formed even before contemporary climate change took place.

Table 3 Drought, Aridity and Desertification

Drought **A temporary phenomenon**	**Aridity** **A permanent condition**	**Desertification** **A human-induced condition**
Can occur in any climate Unpredictable occurrence Uncertain frequency Uncertain duration Uncertain severity Long period of lower-than-average precipitation Diminished water resources Diminished productivity of natural ecosystems Diminished productivity and deterioration of farms and rangeland	Climate state associated with global circulation patterns Low annual precipitation normal Rainfall highly variable in both time and space High evaporation normal High solar energy input Large annual temperature variations normal Low productivity of natural ecosystems normal Low productivity of farms and rangeland normal Sparse human settlement normal	*Resulting from:* Groundwater abstraction Overgrazing and unwise cultivation Attempts to extract from land more than natural productivity allows Unwise irrigation practices leading to salinisation *and producing symptoms of:* Reduction of perennial vegetation cover Aquifer depletion, land subsidence Damaged surface soil and subsoil, loss of soil nutrients Increase in soil temperature Compaction and salinisation of soils Oxidisation of soil organic matter Reduction of water-holding capacity of soil Increased propensity for flash flooding and further erosion Loss of productivity of natural ecosystems and of farms and rangeland Raised surface albedo (tends to diminish rainfall) Invasion of former farms and rangeland by woody weeds

Negative Impacts:

Drought and Bushfire:

- Climate change in **New South Wales** (NSW) is impacting the state with increased risks of drought and bushfires due to extreme rise in temperatures and decrease in rainfall patterns.
- The **Black Summer bushfires** in New South Wales significantly impacted **eucalyptus forests**, resulting in widespread damage and, in some cases, **complete forest collapse**. While eucalypts are adapted to fire, the unprecedented severity and extent of the fires led to a higher level of damage, particularly in areas with **prolonged drought** conditions.
- The 2019-20 Australian bushfires, severely impacted the **Blue Mountains**, causing significant environmental and economic damage. The fires burned through large areas of the Blue Mountains National Park, affecting tourism, agriculture, and infrastructure.
- The **fires burned** through approximately **55,000 hectares of land** in the Blue Mountains, including significant portions of the World Heritage-listed Blue Mountains National Park and Gondwana Rainforests. This resulted in the destruction of vast tracts of forest, including sensitive rainforest ecosystems.
- Drought and upstream hydropower dams have reduced floodwater in **An Giang**, drying wetlands, devastating fish stocks, and threatening local livelihoods. An Giang may have seen the sharpest drop in fish catch, with 4 in 10 fish in 2000 to less than 1 in 10 fish in 2001. All other five inland provinces in the Mekong Delta experienced annual decline rates of 1 to 9 per cent in the 2001-2020 period.

Positive Impacts:

- Since 2012, An Giang has organised annual fish release events to regenerate aquatic resources in natural waters. These efforts have significantly contributed to improving fish stocks and supporting ecosystem recovery. The province aims to achieve 5 per cent growth in fisheries output every year from 2021 until 2030.
- The province targets seafood exports of US$500 million in 2030, double the 2020 figure.

(b) Storms and Cyclones

- A warmer atmosphere can hold more moisture. The IPCC reports that the atmosphere is 0.75°C warmer than at the start of the century, which allows it to hold 5-6% more moisture, and moisture is the fuel for storms that bring with them torrential rains.
- Tropical cyclones which are large, violent storms. There are suggestions in the scientific community that the raised SSTs (Sea Surface Temperatures) encourage more occurrences of tropical cyclones, or hurricanes, and at higher intensities.

Negative Impacts:

- In September 2024, **Hurricane Helene** destroyed whole communities across six states in the **south-eastern US** and claimed more than 100 lives.
- Helene first hit the US as a hurricane, the most powerful on record to hit Florida's Big Bend, before moving toward Georgia, the Carolinas and Tennessee. **More than six months' worth of**

rain landed in parts of North Carolina as Helene passed through. Helene brought historic **flooding** and a **storm surge of more than 4.5m** as it barrelled across the southeast of the US.

- Initial analysis of the storm already suggests that human induced climate change played a significant role in the amount of rainfall dumped by Helene. Studies claim that climate change caused over 50% more rainfall during Hurricane Helene in some parts of Georgia and the Carolinas. Another study found that cyclones similar to Hurricane Helene are up to 20% wetter over the south-east of the US and up to 7% windier in Florida's Gulf today compared to the past. It is well understood that a warming climate means a wetter world. That is because a warmer atmosphere holds more moisture, which produces more intense rainfall.

(c) Heat Stress and Rising Urban Temperature

Urban centres have been found to be warmer than surrounding natural or less urbanised areas, usually due to higher levels of anthropogenic heat, reduced vegetation, and densely built environments restricting airflow. This phenomenon is well-known as the **urban heat island** (UHI) effect.

Negative Impacts:

- **Singapore** experiences an **urban heat island** (UHI) effect, where built-up areas are hotter than surrounding areas, due to the impact of climate change and rapid urban development. This is exacerbated by factors like reduced vegetation and heat-absorbing surfaces in densely built environments. The UHI effect, coupled with rising global temperatures, leads to increased heat stress for residents and impacts on public health and the environment.
- **Urban areas in Singapore can be significantly hotter than surrounding areas**, potentially experiencing **differences of up to 7°Celsius**. The UHI effect can affect native plant and animal species, leading to changes in ecosystems.
- Higher temperatures can lead to **heat exhaustion**, heatstroke, and other heat-related health problems. In Singapore, hospital admissions for heat-related illnesses, including heat exhaustion and heatstroke, have been observed between 71 and 124 cases annually from 2010 to 2020. As Singapore's temperature increases faster than the global average, these numbers are expected to rise, particularly affecting outdoor workers, the elderly, and children.
- Moreover, people rely more on air-conditioning to cope with the heat, leading to increased energy demand and potentially higher carbon emissions which in turn worsen the situation.

Positive Impacts:

- Singapore is actively implementing **urban greening initiatives**, including expanding nature parks and tree planting, as well as incorporating greenery into buildings through skyrise greenery, to reduce the impacts of UHI and increase greenery. Singapore's urban greenery policies broadly support two activities: i) expanding nature parks and tree planting in open areas and ii) covering building walls and roofs with vegetation.
- **Sembawang** was one of the pilot areas for converting carpark rooftops to urban farms to increase greenery and reduce heat absorption by buildings.

- The **Marina Barrage in Singapore** has a large rooftop garden which provides natural heat insulation for the building. The grass and soil shield the building from the sun and reduces maximum surface temperature by 3˚C.

(d) Marine Biodiversity Loss

Negative Impacts:

- In 2026, 40% of corals at **Sisters' Islands Marine Park** and **Pulau Hantu** in **Singapore** were bleached, impacting the health of the reef ecosystems and potentially leading to reduced biodiversity. Coral bleaching, caused by rising sea temperatures, causes corals to expel the algae that provide them with colour and food, weakening them and making them more susceptible to disease and mortality. A significant portion of reef life depends on healthy corals, so bleaching can negatively impact the diversity of species that live there.
- Bleached corals may have difficulty reproducing, potentially leading to a decrease in the number of corals over time. While some corals may recover, the effects of bleaching can be long-lasting, especially if bleaching events are frequent or prolonged.
- The 2024 bleaching event, which was also a global phenomenon, saw **30-55% of corals in some areas like Pulau Hantu and Sisters' Islands bleached**, with some corals showing signs of recovery by November 2024.
- The **Great Barrier Reef** in Australia has experienced **seven mass bleaching events** between 1998 and 2024, all attributed to rising ocean temperatures. The 2024 bleaching event was particularly severe, 66% of colonies bleached by February 2024, rising to 80% by April. By July 2024, 44% of bleached corals had died, with Acropora (a key reef-building genus) suffering 95% mortality.
- When **reefs degrade**, their tourist appeal declines. Bleached, dead or damaged corals lose their vibrancy and natural beauty, **discouraging visitors**. Studies estimate that the degradation of the Great Barrier Reef has already led to a decline in tourist numbers, putting at **risk** an industry that generates **$6.4 billion a year in Australia alone**.

(e) Wetland Degradation and Mangrove Loss

Negative Impacts:

- Wetland degradation and mangrove loss in **Ca Mau, Vietnam**, result from a combination of climate change impacts and human activities, exacerbated by unsustainable resource management.
- Rising seas intensify coastal erosion and saltwater intrusion, **damaging freshwater ecosystems and agricultural land**. Ca Mau has **lost approximately 90 km² of coastal forest** since 2007 due to erosion.

Positive Impacts:

- Recent restoration efforts in **Ca Mau** have shown measurable progress, combining ecological, economic, and community benefits.

- Between 2015 and 2020, Ca Mau and neighbouring provinces in the Mekong Delta saw an **increase of 11,184 hectares of mangrove forest**, with **27,322 hectares restored or newly planted** through state and NGO-funded projects.
- The integration of **mangrove conservation with shrimp aquaculture** is unique to Ca Mau and has proven effective in maintaining stable mangrove cover while supporting local livelihoods. Farmers have reported **reduced impacts from typhoons and improved ecosystem services**, such as soil retention and saltwater intrusion prevention.

11.4.3 Human Health

- Overall, contemporary climate change is likely to have negative effects on human health. The World Health Organisation (WHO) forecasts an additional 250,000 deaths a year worldwide between 2030 and 2050 linked to contemporary climate change causing an increase in heat related diseases, water-borne diseases and vector-borne diseases.
  - In New South Wales, extreme heat days (≥99th percentile) **raised emergency hospital admissions for dehydration** (+1.3% per 1°C). Bushfire smoke worsened PM2.5 levels, **exacerbating asthma and heart conditions**.
  - In **Mekong delta**, a 1°C increase in temperature led to a 1.5% **rise in diarrhoea cases**. Wet seasons saw a higher incidence (2.8/10,000 person-weeks).

11.4.4 Migration of Populations

- Contemporary climate change will alter regional agricultural and industrial potential and could trigger large scale migrations and redistributions of people. Such population displacements can result in serious socioeconomic disruptions, negative health impacts, and increased human suffering.

Negative Impacts:

- Studies suggest that climate change is the dominant factor for **14.5% of migrants leaving the Mekong Delta, translating to approximately 24,000 people per year directly migrating due to climate impacts** such as flooding, saltwater intrusion, drought, and coastal erosion. By 2050, the lower Mekong subregion is expected to see between 3.3 million and 6.3 million new climate migrants, representing 1.4% to 2.7% of the population. **Older residents and those whose livelihoods depend on agriculture are most vulnerable**, with deteriorating land and water shortages forcing many to relocate to urban areas.

11.4.5 Crop Yields

- Based on many studies covering a wide range of regions and crops, negative impacts of contemporary climate change on crop yields have been more common than positive impacts.

Positive Impacts:

- Global warming will probably shift growing areas by several hundred kilometres per degree increase in temperature, increasing agricultural productivity in some areas of the world, while drastically decreasing it in others. The smaller number of studies showing positive impacts relate mainly to high latitude regions.

- There is clear evidence that crop cultivation-especially winter crops-has increased in New South Wales (NSW) alongside changes in temperature and rainfall:
  - NSW saw a **surge in winter crop production** with an estimated 11,360 kilotons, in the financial year 2024. For 2025, production is forecast to jump to over 20,000 kilotons, nearly doubling in just one year. This includes wheat, barley, canola, chickpeas, faba beans, field peas, lentils, lupins, oats, triticale, and wheat.
  - Wheat production alone in NSW is forecast to reach 11,000 kilotons in 2025.
  - The 2025 Winter Crop Variety Sowing Guide highlights the **release of new, higher-yielding and more resilient varieties** of wheat, barley, oats, and canola-many specifically bred for better performance under variable and sometimes wetter conditions. Increased and more variable rainfall, along with new crop varieties, have contributed to a **marked increase in winter crop cultivation and yields in NSW in recent years**.

Negative Impacts:

- Changes in atmospheric $C0_2$, temperature, precipitation, and soil moisture, individually or together, could alter crop production. Also, as crops are stressed by contemporary climate change, they become more vulnerable to damaging pests and diseases.
  - **Rice, the Mekong Delta's staple crop**, has seen **significant decreases in both cultivation and yield** due to flooding, drought, and especially saltwater intrusion. The region's food supply capacity has decreased by 10% as a result of these climate impacts. The World Bank forecasts **Vietnam's rice production** could **decline by 8.3% in 2040 and 9.6% in 2050** due to climate change.
  - In 2024, saltwater intrusion affected 29,260 hectares of rice in areas not zoned for the crop, with salinity reaching 50–60 km up major rivers, far exceeding the 1 g/L tolerance for most crops. In some districts, farmers reported **production losses of over 50% after being forced to irrigate with saline water during droughts.** Over 1,000 hectares of rice were damaged by lack of freshwater in the 2023–2024 winter-spring season, with some farmers losing entire fields or seeing yield drops of 50–70%. The combination of extreme weather, sea-level rise, and changing rainfall patterns is projected to further reduce the region's agricultural output and threaten livelihoods.
  - The Mekong Delta is Vietnam's "rice basket," producing over 55% of the country's rice and supporting millions of small-scale farmers. **Declines in rice yield and arable land directly threaten food security and rural incomes.**
- In general, studies have shown that changes in agricultural economies will be detrimental in equatorial regions, beneficial at high latitudes and mixed at temperate latitudes. Hence contemporary climate change will have serious impacts on world food supplies, especially in less developed countries found at lower latitudes.

11.4.6 Trade Routes

- Melting sea ice in the Arctic could impact trade routes, globally. Sea ice in the Arctic covers the largest area at the end of winter in March and thaws to an annual minimum in September. Continual melting of the sea ice with contemporary climate change, together with better technology (such as ships that can break through thick sea ice), means that the **Northern Sea Route** (NSR) could become an **economically viable cargo shipping route all year round**.

Fig. 7: NSR versus the existing shipping route via the Suez Canal

Positive Impacts:

- The NSR is the **shortest route between Europe and Asia** (see **Fig. 7**). For example, a ship travelling from South Korea to Germany would take roughly 34 days via the current route passing through the Suez Canal and **23 via the Northern Sea Route**.
- Russia has plans to invest millions of dollars to boost its northern economy by developing port infrastructure along the NSR, and China also has ambitious plans to develop shipping lanes along the NSR to form a "Polar Silk Road."

Negative Impacts:

- Melting Arctic ice **opens new shipping routes**, especially the Northern Sea Route, which could shorten travel between Europe and Northeast Asia by 2–3 weeks. This could **divert some shipping traffic away from Singapore's port**, potentially reducing its role as a global maritime hub and affecting the maritime sector, which accounts for 7% of Singapore's GDP and 170,000 jobs. However, the impact on Singapore's port might not be severe since the Arctic route is only seasonally navigable, and Southeast Asian goods would still need to pass through Singapore.

11.4.7 Tourism

- In some parts of the world, the climate itself is the main feature promoting tourism, and for further development of tourism it is important that climate remains favorable for particular pleasurable activities.

Positive Impacts:

- **Despite climate challenges, Singapore's tourism is booming.** International arrivals are projected to reach nearly 16 million in 2025, 9.6% above pre-pandemic levels, with tourism contributing $66.1 billion to the economy (9.8% of GDP) and supporting 570,000 jobs. There is a shift in traveler preferences as 77% of Singapore-based travelers prioritise **sustainable travel**, and 91% want to make more **eco-friendly choices**. The sector's greenhouse gas emissions have dropped 4.1% per year since 2019, reflecting a **move toward greener tourism**.

Negative Impacts:

- Global warming has led to **more frequent bushfires**, heatwaves, and floods in **NSW**. The 2019–2020 bushfire season (the "Black Summer") caused widespread destruction, resulting in a 21% drop in international visitors and a 17% drop in domestic overnight trips to affected regions. Major tourist destinations like the Blue Mountains and South Coast saw cancellations and closures due to smoke and fire risk.
- Recent years have also brought **severe floods**, disrupting travel infrastructure, damaging attractions, and prompting event cancellations. Coastal erosion and rising sea levels threaten popular beaches and waterfront destinations, potentially **reducing their appeal and accessibility**.
- The **tourism industry in NSW** is highly sensitive to climate extremes, with **direct losses from the 2019–2020 bushfires estimated at over AUD 2 billion**. Recovery efforts have focused on marketing, rebuilding, and promoting sustainable tourism, but **repeated climate shocks pose ongoing risks to visitor numbers and regional economies.**

To sum up this section, remember that the learning outcome pertains to the **impact on humans**. Therefore, it is important that you can **identify how the impact of climate change affects humans**. Furthermore, you are required to make a **distinction between positive and negative impacts**. **Fig. 8** shows how the impacts of contemporary climate change can be **either positive or negative** for humans and different places.

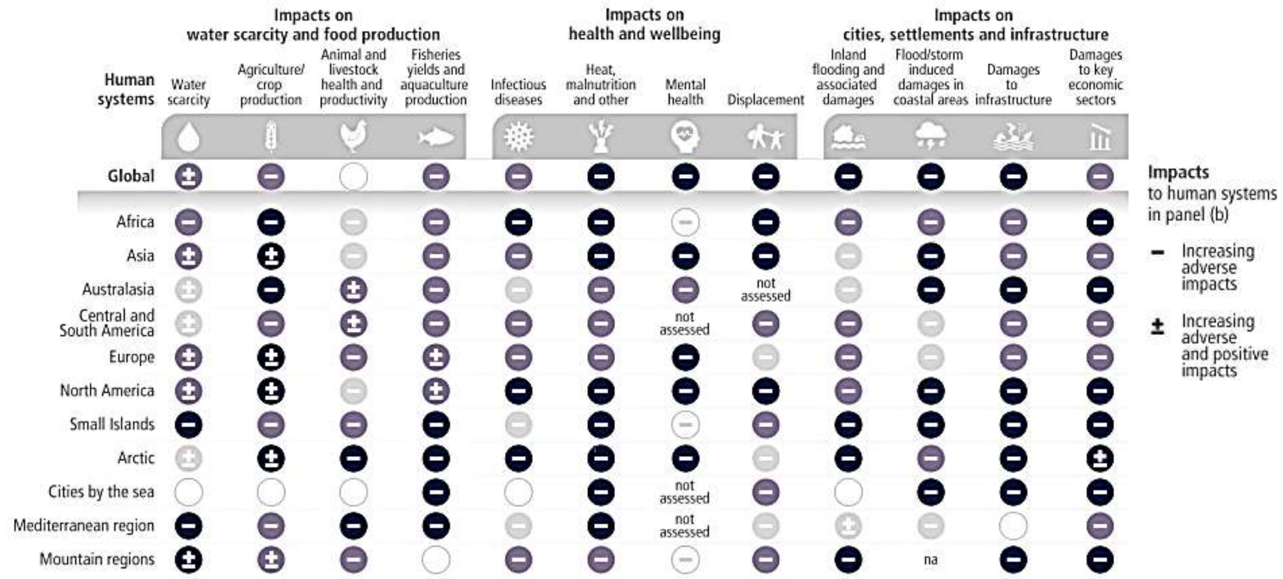


Fig. 8: Observed Uneven Impacts of Contemporary Climate Change on Places

11.5 Variations in Negative Impacts of Contemporary Climate Change

- Climate impacts seem to be *geographically uneven*, on people and places.
  - Note**:** To demonstrate mastery of this learning outcome, case studies and examples are crucial. You must be able to discuss the negative impact of climate change on **at least two places**. The two places should be comparable, i.e., be at the **same scale**, i.e., they should both be regions, countries, or cities. The two places should also allow you to illustrate the variations in negative impacts due to varying degrees of climate change experienced around the world and variations in negative impacts due to differences in vulnerability of different groups of people. You may use **Readings 2, 3 and 4** to supplement out main discussion on Singapore, the Mekong River Delta and New South Wales, Australia.

11.5.1 Variations in Negative Impacts of Contemporary Climate Change due to Places

- Impacts of contemporary climate change could vary *geographically* due to regional differences in the alteration of temperature and precipitation pattern.
  - **Singapore** is steadily getting hotter and wetter, with both temperature and rainfall rising. The increase is fairly consistent, but the wet and dry seasons are becoming more extreme, and heavy rain events are happening more often.

  - **New South Wales** is experiencing the most uneven changes: the coast is warming less and still gets plenty of rain, while inland areas are heating up much more and getting drier. The mountains remain the coolest and wettest. This means some parts will face more droughts and heatwaves, while others may see more floods making the impacts very uneven across the state.

  - **Mekong Delta** is warming at a moderate rate, but future rainfall is highly uncertain. Some scenarios predict much more rain, while others predict less, so the region could swing between severe floods and droughts. This makes planning for the future especially challenging, as the changes will not be the same every year or everywhere in the delta.

  - Climate change is **affecting all three regions**, but the size, geography, and weather patterns mean that the changes in temperature and rainfall are happening at different rates and in different ways.

Region	Temperature Change (1950–2000)	Recent Observed Temperature (2020s)	Projected Temperature Change by 2100	Precipitation Change (1950–2000)	Recent Observed Ppt (2020s)	Projected Ppt Change by 2100	Notes on Variability
Singapore	+1°C since 1950s	28.2°C (2023)	+1.5°C to +4.6°C	+83 mm/decade since 1980	2,411 mm (2023); avg 2,113 mm	More intense rainfall, wetter wet seasons, drier dry seasons	Warming and rainfall increases are steady but not extreme; rainfall is rising, and heavy rain events are becoming more frequent. Seasonal contrasts (wet/dry) are growing.
New South Wales	+0.84°C (by 1990–2009)	18.68°C (2019; 1.95°C above avg.)	+2°C to +4°C (higher inland)	Coast: 800–3,000 mm/yr; Inland: 150–500 mm/yr; Mountains: 600–1,600+ mm/yr	Highly variable by region	More dry spells, fewer rainy days, heavier rainfall events when they occur	Temperature and rainfall changes are very uneven: coastal areas warm less and stay wetter, inland heats up more and becomes drier, mountains stay coolest and wettest. Droughts and floods are both becoming more common.
Mekong Delta	+0.5–1.5°C (1950–2000)	27.6°C (2014–2020)	+0.4°C to +3.3°C by 2060	Slight increase, more variable	~1,600–2,000 mm/year	Rainfall could fall by 16% (dry scenario) or rise by 17% (wet scenario) by 2060	Temperature rise is moderate, but rainfall change is highly uncertain: some years could be much wetter, others much drier. Floods and droughts are both expected to worsen.

11.5.2 Variations in Negative Impact of Contemporary Climate Change due to Differences in Vulnerability of Different Groups of People

- Impacts of contemporary climate change could also vary because of different communities and their respective *vulnerabilities*. **Vulnerability is a possible future state that implies (a) high risk combined with (b) an inability to cope.**

(a) The risk depends largely on two factors: (i) **the type and severity of climate change impact present where they live** and (ii) **the extent humans are affected by the impacts of climate change**.

- (i) the type and severity of climate change impact varies from place to place. As mentioned, precipitation and temperature changes differ from place to place, this will result in different types and severity of climate hazards in different places.
  - **Sea-Level Rise**
    - Singapore: Projects a 0.2–1.0m rise by 2100.
    - Vietnam: Most vulnerable, with 0.9m rise by 2050 potentially submerging 47% of Mekong Delta land.
    - NSW: Predicts 27cm rise by 2050, with $38B coastal assets at risk from storm surges.

  - **Extreme Events**
    - Singapore: Prone to urban flash floods.
    - Vietnam: Hit by typhoons and fluvial floods.
    - NSW: Has experienced disastrous wildfires ("Black Summer") and major floods ("Great Deluge"), highlighting vulnerability to compounding natural disasters.

- In terms of (ii), the extent humans are affected by the impacts will be determined by **how sensitive an area is** to the impacts of climate change.
  - <u>*Sensitivity of an area to the impact of climate change*</u>: Different areas have different levels and types of sensitivity to the impacts of climate change.
    - **Economic Losses**
      <u>Vietnam</u> is projected to suffer the most severe economic impacts, with GDP losses reaching 12–14.5% by 2050 and a staggering 30.2% by 2070, indicating a profound threat to national development and poverty reduction goals. The country's long coastline, low-lying river deltas (especially the Mekong Delta), and densely populated coastal cities make it particularly exposed to flooding, saltwater intrusion, and storm surges. These impacts threaten key sectors like agriculture, fisheries, and manufacturing, which are vital for national development and poverty reduction. <u>New South Wales (NSW)</u> faces serious but less quantified losses; while fire days are expected to double by 2050, and coastal erosion poses a substantial economic threat, these losses remain harder to calculate. <u>Singapore</u>, in contrast, is primarily exposed through systemic import chain risks, reflecting its dependence on global trade rather than direct domestic production losses. Therefore, while

Vietnam's economy faces the most direct structural decline, NSW may face costly but localised disasters, and Singapore's vulnerability is indirect yet significant due to its reliance on global stability.

- **Human Displacement**
  Vietnam again stands out as the most critically affected, with projections of 5 million climate migrants from the Mekong Delta by 2100, underscoring both the scale and urgency of social and infrastructure challenges. NSW faces growing inland relocation pressures, especially from rising sea levels and coastal vulnerability, but lacks the same concentrated population risk as Vietnam. Singapore appears least impacted in this category, with tightly-regulated migration systems suggesting high institutional capacity to control population movements. Thus, while all three regions are facing population mobility pressures, Vietnam's situation is by far the most acute, with displacement numbers posing long-term societal destabilisation risks.

- **Biodiversity Threats**
  NSW experiences some of the most biologically significant losses, with iconic species such as koalas, ancient Gondwana rainforests, and alpine ecosystems at high risk, marking an irreplaceable loss of global ecological heritage. Vietnam's threat is more ecosystem-specific, with the collapse of Mekong fisheries potentially devastating both biodiversity and food security. Singapore, with its limited terrestrial ecosystems, faces relatively less biodiversity loss but has fewer natural buffers to begin with. In summary, NSW holds the greatest concentration of globally significant biodiversity at risk, Vietnam faces critical ecosystem service collapse, and Singapore's limited biodiversity base reduces its losses but also its ecological resilience.

(b) It is to be expected that **the less able a community can withstand the impacts of contemporary climate change, the less able it is also in attaining sustainable development**. (Sustainable development is examined in **H1 Cluster 1 Topic 1.1**)

- *Ability to cope with the impact on humans*: Inequality and poverty at a global scale mean those at greatest risk are concentrated in the world's poorest countries, even though these countries contribute the least to greenhouse gas emissions which led to global warming. **People in poverty have fewest entitlements to protect themselves and their families against natural climatic hazards and to cope with losses of crops, property and steep rises in food prices.**
- Singapore, New South Wales (NSW), and the Mekong River Delta each approach climate change adaptation with strategies shaped by their governance structures, resources, vulnerabilities, and the readiness of their populations.

Singapore

- Singapore's ability to cope with climate change is underpinned by a highly centralised, well-coordinated national planning framework, supported by substantial and targeted funding. The government sets clear, ambitious targets-such as reducing emissions to 45–50 $MtCO_2e$ by 2035 and achieving net zero by 2050-through its Nationally Determined Contributions (NDCs) and the Singapore Green Plan 2030. These targets are regularly updated and integrated into national policy, ensuring alignment across ministries and agencies.
- A dedicated Inter-Ministerial Committee on Climate Change (IMCCC) oversees climate policy, with the Resilience Working Group (RWG) coordinating long-term adaptation strategies. These include ongoing studies on physical vulnerabilities and the incorporation of the latest climate science into planning, such as risk mapping for infrastructure and coastal protection.
- Singapore backs its plans with significant funding. For example, the government has committed S$100 billion over the next century to protect against sea-level rise, starting with an initial S$5 billion Coastal and Flood Protection Fund. Additionally, the Future Energy Fund received a S$5 billion top-up in 2024 to accelerate the energy transition, and public sector green bonds of up to S$35 billion by 2030 will finance projects in renewable energy, green buildings, and climate adaptation.
- This centralised approach ensures that climate adaptation is mainstreamed into all aspects of national planning, from urban development and transport to water management and biodiversity. The government's strong fiscal position, robust regulatory oversight, and ability to mobilize both public and private sector resources enable Singapore to implement large-scale, long-term climate resilience measures efficiently and effectively.
- Singapore's population is generally well-prepared for climate adaptation, supported by high levels of education, government-led public awareness campaigns, and active engagement through national movements like Go Green SG. These initiatives, which saw participation from tens of thousands in 2024, foster collective action and behavioral change toward sustainability. The government's clear communication and frequent policy updates help ensure that the public is informed and responsive to climate challenges. However, as an urbanized and affluent society, Singaporeans may be less directly exposed to some climate risks compared to agrarian populations, but their readiness is bolstered by robust infrastructure and high trust in government-led adaptation.

New South Wales (NSW), Australia

- NSW adopts a broad, collaborative model grounded in state legislation. The NSW Climate Change Adaptation Action Plan 2025-2029 outlines 46 actions across seven themes, including advancing policy, building capability, and expanding knowledge. Adaptation is mainstreamed into all government decision-making, ensuring risks are systematically addressed across sectors like land-use planning, health, water management, and infrastructure. Multiple agencies share responsibility for delivering these actions, and the plan is reviewed regularly to incorporate new risk assessments and scientific knowledge. The approach is proactive and designed to be flexible, with regular updates and cross-agency collaboration to build resilience statewide.

- In terms of financing, NSW's ability to cope with climate change is strong, but not as centralized or singularly resourced as Singapore's. The state government allocates significant funding for climate adaptation through dedicated programs such as the Climate Change Fund, which has invested over A$1.4 billion since its inception in 2007 to support energy efficiency, renewable energy, and adaptation initiatives. NSW also leverages federal funding, public-private partnerships, and grants for local governments and communities to implement adaptation projects. However, the scale of funding is distributed across multiple agencies and programs, and while substantial, it must be balanced with other state budget priorities. NSW's robust economy and established financial mechanisms provide a solid foundation for adaptation, but the decentralized approach means that financing is more diffused and dependent on ongoing political and budgetary support.
- The population of NSW has experienced significant climate impacts firsthand, including bushfires, floods, and heatwaves in recent years. This direct exposure has increased public awareness and urgency around climate adaptation. The government recognizes that adaptation requires action from all sectors of society-not just government, but also business, communities, and individuals. There are ongoing efforts to build capability and expand knowledge through education, communication, and stakeholder engagement. However, readiness can vary between urban and rural communities, with some areas better resourced and informed than others. Overall, there is growing societal recognition of the need for resilience, but challenges remain in ensuring equitable readiness across diverse regions and populations.

Mekong River Delta

- The Mekong River Delta faces acute climate risks-sea-level rise, salinisation, and ecosystem degradation-exacerbated by limited resources and complex environmental pressures. Adaptation efforts in the Delta are increasingly sophisticated, involving a range of regional coordination mechanisms, technical projects, and master plans developed with international support.
- A key example of regional coordination is the Cambodia-Mekong Delta Aquifer (CMDA) project, a transboundary initiative spanning Vietnam and Cambodia. Launched in 2023 and funded by the Global Environment Facility, the project brings together governments, scientists, and local communities to safeguard groundwater resources vital for agriculture, drinking water, and biodiversity. UNESCO and the FAO are leading efforts to apply science-based assessments and innovative groundwater management approaches, with a strong focus on inclusive stakeholder engagement and gender equity.

  - Technical projects addressing sediment management and sustainable sand mining are also central. The "Drifting Sands" project, implemented by WWF and funded by the International Climate Initiative, works with Vietnamese ministries and the Mekong River Commission to develop a comprehensive sand and gravel budget for the Lower Mekong catchment. The project promotes improved regulations, sustainable mining practices, and dialogue between public and private sectors to mitigate the impacts of unsustainable sand extraction, which is a major driver of erosion and land subsidence in the delta. Complementing this, the Sustainable Sand Management Project (IKI SMP) uses advanced monitoring and modeling (such as the Delft3D Flexible Mesh Suite) to track sand movement, estimate stocks, and inform policy for sustainable extraction.
  - Master planning is another pillar of adaptation. The Mekong Delta Regional Masterplan, developed with international consultancy and based on Vietnam's Law on Planning, integrates "building with nature" principles and aims to coordinate sectoral and provincial planning for climate-resilient development through 2030 and beyond. This plan addresses challenges such as sea-level rise, salinization, and ecosystem degradation by promoting smart investment choices and balancing environmental, economic, and social priorities. In parallel, scientific collaborations like the GEMMES Vietnam project (a partnership between Vietnam's Ministry of Natural Resources and Environment and the French Development Agency) assess the consistency of adaptation plans with the latest climate science, propose new options, and explore governance innovations to steer the delta's transformation sustainably.
  - These initiatives are complemented by basin-wide strategies such as the Mekong Climate Change Adaptation Strategy and Action Plan (MASAP), which sets out shared priorities for transboundary adaptation across the Mekong Basin. Large infrastructure projects, such as the Central Mekong Delta Region Connectivity Project, also integrate climate risk and vulnerability assessments to ensure that new investments are resilient to future climate impacts.
  - However, governance is fragmented across multiple levels, and institutional capacity is often insufficient to match the scale of the challenges. Financing for adaptation in the Mekong Delta relies heavily on international aid, development bank loans, and limited national government funding, making it difficult to sustain large-scale, long-term resilience projects.
  - The population of the Mekong River Delta is highly vulnerable to climate impacts, with many dependent on agriculture and fisheries that are directly threatened by environmental changes. While there is growing awareness of climate risks-often driven by direct experience with floods, salinization, and crop failures-adaptive capacity is limited by lower income levels, less access to education, and fewer resources for relocation or livelihood diversification. Community-based adaptation and international NGO support play crucial roles in building local resilience, but readiness is uneven and often constrained by poverty, limited infrastructure, and governance challenges.
- In summary, Singapore leverages centralised planning, deep resources, and a highly engaged, well-informed population for integrated, future-proof adaptation. NSW employs a whole-of-government, legislated strategy with solid but more distributed financing and a population

whose readiness is growing through direct experience and government engagement, though with some disparities. The Mekong River Delta, despite innovative projects and international support, remains constrained by fragmented governance, high vulnerability, limited financial capacity, and a population whose readiness is challenged by socio-economic and infrastructural limitations.

11.6 Conclusion

- Contemporary climate change today is the **accumulated result of two centuries of unsustainable development** – unsustainable industrialisation, unsustainable energy production using fossil fuels, unsustainable land use (e.g. deforestation), unsustainable lifestyles and consumption patterns. Hence, managing climate change is a **crucial driving force for** moving away from unsustainable production and consumption and **making sustainable development a reality**, for the costs of not doing so are too high.