24 Asia

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Executive Summary

Warming trends and increasing temperature extremes have been observed across most of the Asian region over the past century (*high confidence*). {24.3} Increasing numbers of warm days and decreasing numbers of cold days have been observed, with the warming trend continuing into the new millennium. Precipitation trends including extremes are characterized by strong variability, with both increasing and decreasing trends observed in different parts and seasons of Asia.

Water scarcity is expected to be a major challenge for most of the region as a result of increased water demand and lack of good management (*medium confidence*). {24.4.3} Water resources are important in Asia because of the massive population and vary among regions and seasons. However, there is *low confidence* in future precipitation projections at a sub-regional scale and thus in future freshwater availability in most parts of Asia. Population growth and increasing demand arising from higher standards of living could worsen water security in many parts in Asia and affect many people in the future. Integrated water management strategies could help adapt to climate change, including developing water-saving technologies, increasing water productivity, and water reuse.

The impacts of climate change on food production and food security in Asia will vary by region, with many regions to experience a decline in productivity (*medium confidence*). {24.4.4} This is evident in the case of rice production. Most models, using a range of General Circulation Models (GCMs) and *Special Report on Emission Scenarios* (SRES) scenarios, show that higher temperatures will lead to lower rice yields as a result of shorter growing periods. There are a number of regions that are already near the heat stress limits for rice. However, carbon dioxide (CO_2) fertilization may at least in part offset yield losses in rice and other crops. In Central Asia, some areas could be winners (cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters, and slight increase in winter precipitation), while others could be losers (western Turkmenistan and Uzbekistan, where frequent droughts could negatively affect cotton production, increase water demand for irrigation, and exacerbate desertification). In the Indo-Gangetic Plains of South Asia there could be a decrease of about 50% in the most favorable and high-yielding wheat area as a result of heat stress at 2 times CO_2. Sea level rise will inundate low-lying areas and will especially affect rice growing regions. Many potential adaptation strategies are being practiced and proposed but research studies on their effectiveness are still few.

Terrestrial systems in many parts of Asia have responded to recent climate change with shifts in the phenologies, growth rates, and the distributions of plant species, and with permafrost degradation, and the projected changes in climate during the 21st century will increase these impacts (*high confidence*). {24.4.2} Boreal trees will *likely* invade treeless arctic vegetation, while evergreen conifers will *likely* invade deciduous larch forest. Large changes may also occur in arid and semiarid areas, but uncertainties in precipitation projections make these more difficult to predict. The rates of vegetation change in the more densely populated parts of Asia may be reduced by the impact of habitat fragmentation on seed dispersal, while the impacts of projected climate changes on the vegetation of the lowland tropics are currently poorly understood. Changes in animal distributions have also been projected, in response to both direct impacts of climate change and indirect impacts through changes in the availability of suitable habitats.

Coastal and marine systems in Asia are under increasing stress from both climatic and non-climatic drivers (*high confidence*). {24.4.3} It is *likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels. {WGI AR5 3.7.6} In the Asian Arctic, rising sea levels are expected to interact with projected changes in permafrost and the length of the ice-free season to cause increased rates of coastal erosion (*medium evidence*, *high agreement*). Mangroves, salt marshes, and seagrass beds may decline unless they can move inland, while coastal freshwater swamps and marshes will be vulnerable to saltwater intrusion with rising sea levels. Widespread damage to coral reefs correlated with episodes of high sea surface temperature has been reported in recent decades and there is *high confidence* that damage to reefs will increase during the 21st century as a result of both warming and ocean acidification. Marine biodiversity is expected to increase at temperate latitudes as warmwater species expand their ranges northward (*high confidence*), but may decrease in the tropics if thermal tolerance limits are exceeded (*medium confidence*).

Multiple stresses caused by rapid urbanization, industrialization, and economic development will be compounded by climate change (*high confidence*). {24.4-7} Climate change is expected to adversely affect the sustainable development capabilities of most Asian developing countries by aggravating pressures on natural resources and the environment. Development of sustainable cities in Asia with fewer fossil fuel-driven vehicles and with more trees and greenery would have a number of co-benefits, including improved public health.

Extreme climate events will have an increasing impact on human health, security, livelihoods, and poverty, with the type and magnitude of impact varying across Asia (*high confidence*). {24.4.6} More frequent and intense heat waves in Asia will increase mortality and morbidity in vulnerable groups. Increases in heavy rain and temperature will increase the risk of diarrheal diseases, dengue fever, and malaria. Increases in floods and droughts will exacerbate rural poverty in parts of Asia as a result of negative impacts on the rice crop and resulting increases in food prices and the cost of living.

Studies of observed climate changes and their impacts are still inadequate for many areas, particularly in North, Central, and West Asia (*high confidence*). {24.8} Improved projections for precipitation, and thus water supply, are most urgently needed. Understanding of climate change impacts on ecosystems in Asia is currently limited by the incompleteness and inaccessibility of biodiversity information. Major research gaps in the tropics include the temperature dependence of carbon fixation by tropical trees and the thermal tolerances and acclimation capacities of both plants and animals. Interactions between climate change and the direct impacts of rising CO_2 on crops and natural ecosystems are also currently poorly understood. More research is needed on impacts, vulnerability, and adaptation in urban settlements, especially cities with populations of less than 500,000. More generally, there is a need to develop low-cost adaptation measures appropriate to the least developed parts of the region.

24.1. Introduction

Asia is defined here as the land and territories of 51 countries/regions (see Figure 24-1). It can be broadly divided into six subregions based on geographical position and coastal peripheries. These are, in alphabetical order, Central Asia (5 countries), East Asia (7 countries/regions), North Asia (2 countries), South Asia (8 countries), Southeast Asia (12 countries), and West Asia (17 countries). The population of Asia was reported to be about 4299 million in 2013, which is about 60% of the world population (UN DESA Population Division, 2013). Population density was reportedly about 134 per square kilometer in 2012 (PRB, 2012). The highest life expectancy at birth is 84 (Japan) and the lowest is 50 (Afghanistan) (CIA, 2013). The gross domestic product (GDP) per capita ranged from US$620 (Afghanistan for 2011) to US$51,709 (Singapore for 2012) (World Bank, 2013).

24.2. Major Conclusions from Previous Assessments

Major highlights from previous assessments for Asia include:

- Warming trends, including higher extremes, are strongest over the continental interiors of Asia, and warming in the period 1979 onward was strongest over China in winter, and northern and eastern Asia in spring and autumn (WGI AR4 Section 3.2.2.7; SREX Section 3.3.1).
- From 1900 to 2005, precipitation increased significantly in northern and central Asia but declined in parts of southern Asia (WGI AR4 SPM).
- Future climate change is *likely* to affect water resource scarcity with enhanced climate variability and more rapid melting of glaciers (WGII AR4 Section 10.4.2).
- Increased risk of extinction for many plant and animal species in Asia is *likely* as a result of the synergistic effects of climate change and habitat fragmentation (WGII AR4 Section 10.4.4).
- Projected sea level rise is *very likely* to result in significant losses of coastal ecosystems (WGII AR4 Sections 10.4.3.2, 10.6.1).
- There will be regional differences within Asia in the impacts of climate change on food production (WGII AR4 Section 10.4.1.1).
- Due to projected sea level rise, a million or so people along the coasts of South and Southeast Asia will likely be at risk from flooding (*high confidence*; WGII AR4 Section 10.4.3.1).
- It is *likely* that climate change will impinge on sustainable development of most developing countries of Asia as it compounds the pressures on natural resources and the environment associated with rapid urbanization, industrialization, and economic development (WGII AR4 Section 10.7).
- Vulnerabilities of industry, infrastructure, settlements, and society to climate change are generally greater in certain high-risk locations, particularly coastal and riverine areas (WGII AR4 Sections 7.3-5).

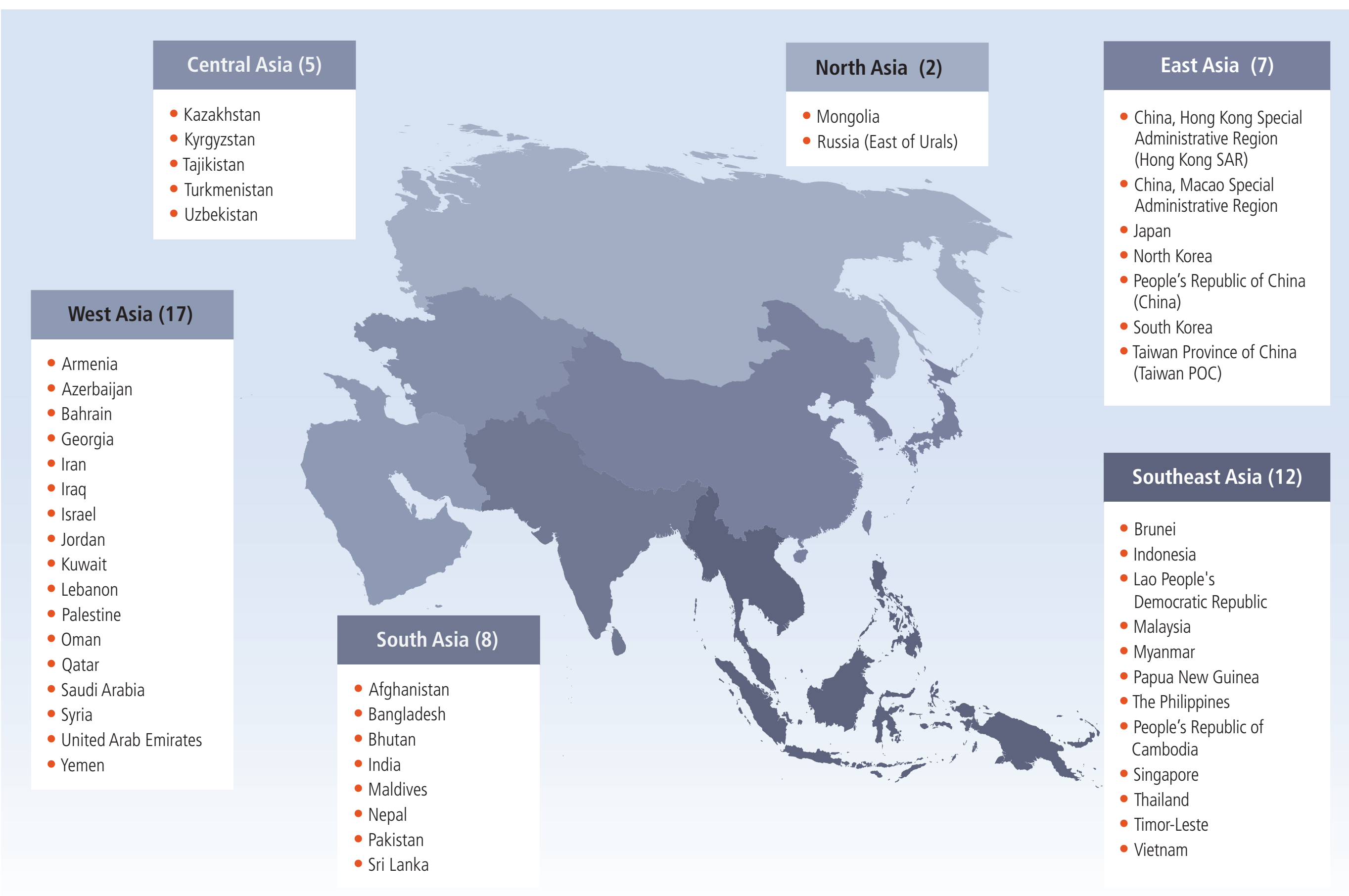


Figure 24-1 | The land and territories of 51 countries/regions in Asia. Maps contained in this report are only for the purpose of geographic information reference.

Box 24-1 | What's New on Asia in AR5?

- There is improved country coverage on observed and future impacts of climate change.
- There is an increase in the number of studies reflecting advances in research tools (e.g., more use of remote sensing and modeling of impacts), with an evaluation of detection and attribution where feasible.
- More conclusions have confidence statements, while confidence levels have changed in both directions since AR4.
- Expanded coverage of issues—for example, discussion of the Himalayas has been expanded to cover observed and projected impacts (Box 3-2), including those on tourism (see Section 10.6.2); livelihood assets such as water and food (Sections 9.3.3.1, 13.3.1.1, 18.5.3, 19.6.3); poverty (Section 13.3.2.3); culture (Section 12.3.2); flood risks (Sections 18.3.1.1, 24.2.1); health risks (Section 24.4.6.2); and ecosystems (Section 24.4.2.2).

24.3. Observed and Projected Climate Change

24.3.1. Observed Climate Change

24.3.1.1. Temperature

It is *very likely* that mean annual temperature has increased over the past century over most of the Asia region, but there are areas of the interior and at high latitudes where the monitoring coverage is insufficient for the assessment of trends (see WGI AR5 Chapter 2; Figure 24-2). New analyses continue to support the Fourth Assessment Report (AR4) and IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) conclusions that it is *likely* that the numbers of cold days and nights have decreased and the numbers of warm days and nights have increased across most of Asia since about 1950, and heat wave frequency has increased since the middle of the 20th century in large parts of Asia (see WGI AR5 Section 2.6.1).

As a part of the polar amplification, large warming trends (>2°C per 50 years) in the second half of the 20th century were observed in the northern Asian sector (see WGI AR5 Section 14.8.8). Over the period 1901–2009, the warming trend was particularly strong in the cold season between November and March, with an increase of 2.4°C in the mid-latitude semiarid area of Asia (see WGI AR5 Section 14.8.8). Increasing annual mean temperature trends at the country scale in East and South Asia have been observed during the 20th century (Table SM24-1). In West Asia, upward temperature trends are notable and robust in recent decades (WGI AR5 Section 14.8.10). Across Southeast Asia, temperature has been increasing at a rate of 0.14°C to 0.20°C per decade since the 1960s, coupled with a rising number of hot days and warm nights, and a decline in cooler weather (see WGI AR5 Section 14.8.12).

24.3.1.2. Precipitation and Monsoons

Most areas of the Asian region lack sufficient observational records to draw conclusions about trends in annual precipitation over the past century (see WGI AR5 Chapter 2; Figure 24-2; Table SM24-2). Precipitation trends, including extremes, are characterized by strong variability, with both increasing and decreasing trends observed in different parts and seasons of Asia (see WGI AR5 Chapter 14; Table SM24-2). In northern Asia, the observations indicate some increasing trends of heavy precipitation events, but in central Asia, no spatially coherent trends were found (see WGI AR5 Section 14.8.8). Both the East Asian summer and winter monsoon circulations have experienced an inter-decadal scale weakening after the 1970s, due to natural variability of the coupled climate system, leading to enhanced mean and extreme precipitation along the Yangtze River valley (30°N), but deficient mean precipitation in North China in summer (see WGI AR5 Section 14.8.9). A weakening of the East Asian summer monsoon since the 1920s was also found in sea level pressure gradients (*low confidence*; see WGI AR5 Section 2.7.4). In West Asia, a weak but non-significant downward trend in mean precipitation was observed in recent decades, although with an increase in intense weather events (see WGI AR5 Section 14.8.10). In South Asia, seasonal mean rainfall shows inter-decadal variability, noticeably a declining trend with more frequent deficit monsoons under regional inhomogeneities (see WGI AR5 Section 14.8.11). Over India, the increase in the number of monsoon break days and the decline in the number of monsoon depressions are consistent with the overall decrease in seasonal mean rainfall (see WGI AR5 Section 14.8.11). But an increase in extreme rainfall events occurred at the expense of weaker rainfall events over the central Indian region and in many other areas (see WGI AR5 Section 14.2.2.1). In South Asia, the frequency of heavy precipitation events is increasing, while light rain events are decreasing (see WGI AR5 Section 14.8.11). In Southeast Asia, annual total wet-day rainfall has increased by 22 mm per decade, while rainfall from extreme rain days has increased by 10 mm per decade, but climate variability and trends differ vastly across the region and between seasons (see WGI AR5 Sections 14.4.12, 14.8.12). In Southeast Asia, between 1955 and 2005 the ratio of rainfall in the wet to the dry seasons increased. While an increasing frequency of extreme events has been reported in the northern parts of Southeast Asia, decreasing trends in such events are reported in Myanmar (see WGI AR5 Section 14.4.12). In Peninsular Malaya during the southwest monsoon season, total rainfall and the frequency of wet days decreased, but rainfall intensity increased in much of the region. On the other hand, during the northeast monsoon, total rainfall, the frequency of extreme rainfall events, and rainfall intensity all increased over the peninsula (see WGI AR5 Section 14.4.12).

24.3.1.3. Tropical and Extratropical Cyclones

Significant trends in tropical cyclones making landfall are not found on shorter timescales. Time series of cyclone indices show weak upward trends in the western North Pacific since the late 1970s, but interpretation of longer term trends is constrained by data quality concerns (see WGI AR5 Section 2.6.3). A decrease in extratropical cyclone activity and intensity over the last 50 years has been reported for northern Eurasia (60°N to 40°N), including lower latitudes in East Asia (see WGI AR5 Section 2.6.4).

24.3.1.4. Surface Wind Speeds

Over land in China, including the Tibetan region, a weakening of the seasonal and annual mean winds, as well as the maximums, is reported from around the 1960s or 1970s to the early 2000s (*low confidence*; see WGI AR5 Section 2.7.2).

24.3.1.5. Oceans

A warming maximum is observed at 25°N to 65°N with signals extending to 700 m depth and is consistent with poleward displacement of the mean temperature field (WGI AR5 Section 3.2.2). The pH measurements between 1983 and 2008 in the western North Pacific showed a –0.0018 ± 0.0002 yr^{-1} decline in winter and –0.0013 ± 0.0005 yr^{-1} decline in summer (see WGI AR5 Section 3.8.2). Over the period 1993–2010, large rates of sea level rise in the western tropical Pacific were reported, corresponding to an increase in the strength of the trade winds in the central and eastern tropical Pacific (see WGI AR5 Section 13.6.1). Spatial variation in trends in Asian regional sea level may also be specific to a particular sea or ocean basin. For example, a rise of 5.4 ± 0.3 mm yr^{-1} in the Sea of Japan from 1993 to 2001 is nearly two times the global mean sea level (GMSL) trend, with more than 80% of this rise being thermosteric, and regional changes of sea level in the Indian Ocean that have emerged since the 1960s are driven by changing surface winds associated with a combined enhancement of Hadley and Walker cells (see WGI AR5 Section 13.6.1).

24.3.2. Projected Climate Change

The AR4 assessed that warming is *very likely* in the 21st century (Christensen et al., 2007), and that assessment still holds for all land areas of Asia in the mid- and late-21st century, based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations under all four Representative Concentration Pathway (RCP) scenarios (Figures 24-2, SM24-1; Table SM24-3). Ensemble-mean changes in mean annual temperature exceed 2°C above the late-20th-century baseline over most land areas in the mid-21st century under RCP8.5, and range from greater than 3°C over South and Southeast Asia to greater than 6°C over high latitudes in the late-21st century. The ensemble-mean changes are less than 2°C above the late-20th-century baseline in both the mid- and late-21st century under RCP2.6, with the exception of changes between 2°C and 3°C over the highest latitudes.

Projections of future annual precipitation change are qualitatively similar to those assessed in the AR4 (Christensen et al., 2007; see Figure 24-2). Precipitation increases are *very likely* at higher latitudes by the mid-21st century under the RCP8.5 scenario, and over eastern and southern areas by the late-21st century. Under the RCP2.6 scenario, increases are *likely* at high latitudes by the mid-21st century, while it is *likely* that changes at low latitudes will not substantially exceed natural variability.

24.3.2.1. Tropical and Extratropical Cyclones

The future influence of climate change on tropical cyclones is *likely* to vary by region, but there is *low confidence* in region-specific projections of frequency and intensity. However, better process understanding and model agreement in specific regions indicate that precipitation will *likely* be more extreme near the centers of tropical cyclones making landfall in West, East, South, and Southeast Asia (see WGI AR5 Sections 14.6, 14.8.9-12). There is *medium confidence* that a projected poleward shift in the North Pacific storm track of extratropical cyclones is *more likely than not*. There is *low confidence* in the magnitude of regional storm track changes and the impact of such changes on regional surface climate (see WGI AR5 Section 14.6).

24.3.2.2. Monsoons

Future increases in precipitation extremes related to the monsoon are *very likely* in East, South, and Southeast Asia (see WGI AR5 Sections 14.2.1, 14.8.9, 14.8.11-12). More than 85% of CMIP5 models show an increase in mean precipitation in the East Asian summer monsoons, while more than 95% of models project an increase in heavy precipitation events (see WGI AR5 Section 14.2.2, Figure 14.4). All models and all scenarios project an increase in both the mean and extreme precipitation in the Indian summer monsoon (see WGI AR5 Section 14.2.2 and Southern Asia (SAS) in Figure 14.4). In these two regions, the interannual standard deviation of seasonal mean precipitation also increases (see WGI AR5 Section 14.2.2).

24.3.2.3. Oceans

The ocean in subtropical and tropical regions will warm in all RCP scenarios and will show the strongest warming signal at the surface (WGI AR5 Section 12.4.7, Figure 12.12). Negligible change or a decrease in mean significant wave heights are projected for the trade and monsoon wind regions of the Indian Ocean (see WGI AR5 Section 13.7.3).

24.4. Observed and Projected Impacts, Vulnerabilities, and Adaptation

Key observed and projected climate change impacts are summarized in Tables 24-1, SM24-4, and SM24-5 (based on Sections 24.4.1-6).

24.4.1. Freshwater Resources

24.4.1.1. Sub-regional Diversity

Freshwater resources are very important in Asia because of the massive population and heavy economic dependence on agriculture, but water

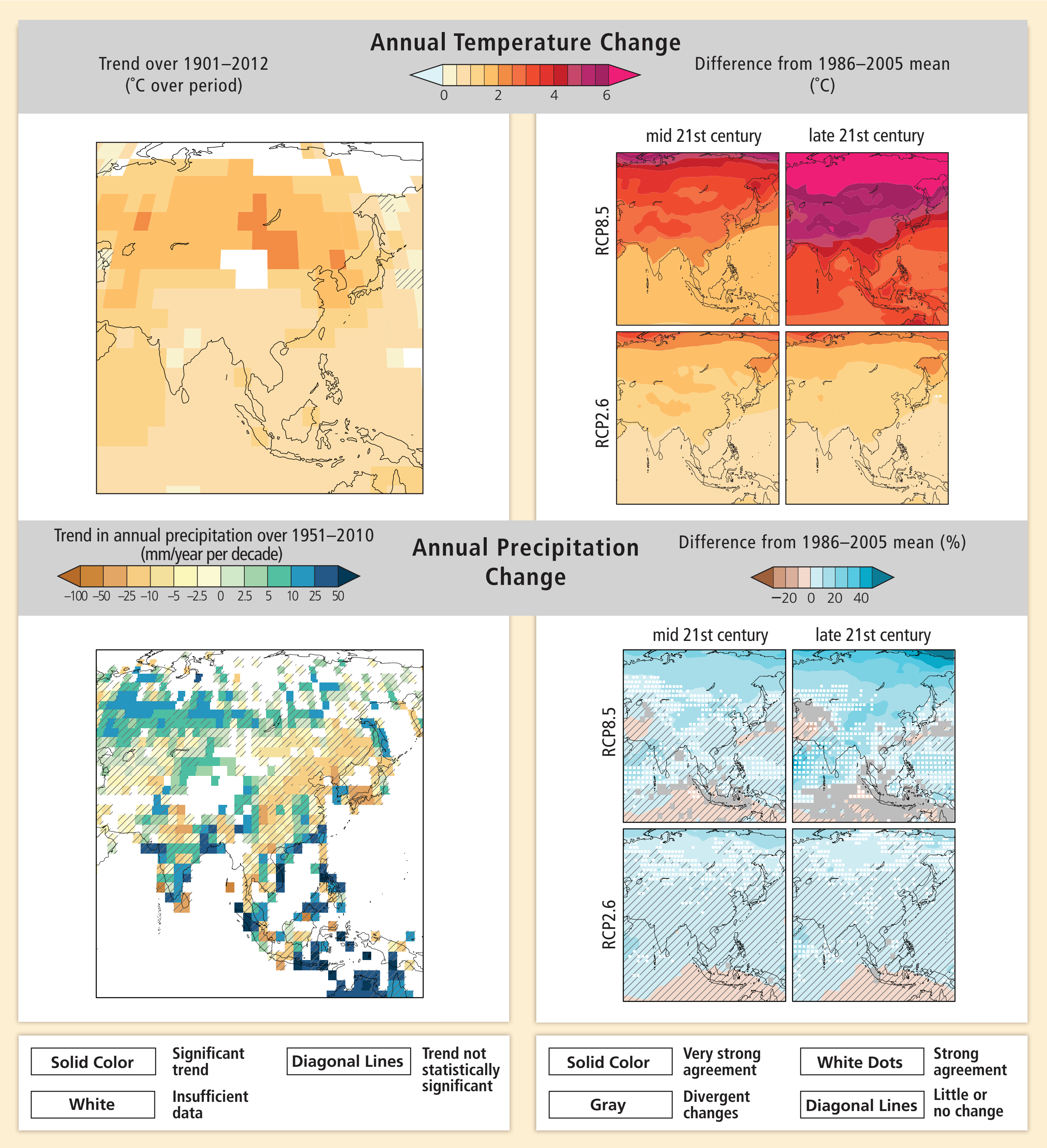
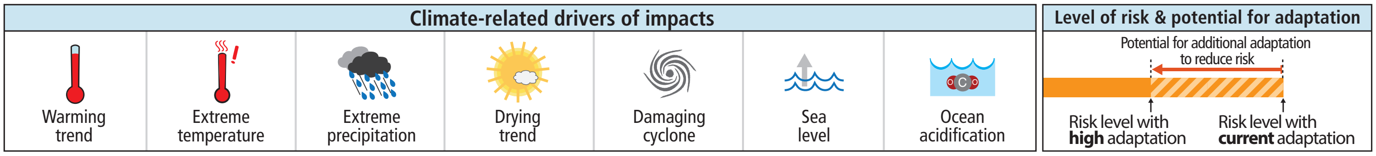


Figure 24-2 | Observed and projected changes in annual average temperature and precipitation in Asia. (Top panel, left) Map of observed annual average temperature change from 1901–2012, derived from a linear trend. [WGI AR5 Figures SPM.1 and 2.21] (Bottom panel, left) Map of observed annual precipitation change from 1951–2010, derived from a linear trend. [WGI AR5 Figures SPM.2 and 2.29] For observed temperature and precipitation, trends have been calculated where sufficient data permit a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where trends are significant at the 10% level. Diagonal lines indicate areas where trends are not significant. (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent changes in annual mean precipitation for 2046–2065 and 2081–2100 under RCP2.6 and 8.5, relative to 1986–2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability (natural internal variability in 20-yr means) and ≥90% of models agree on sign of change. Colors with white dots indicate areas with strong agreement, where ≥66% of models show change greater than the baseline variability and ≥66% of models agree on sign of change. Gray indicates areas with divergent changes, where ≥66% of models show change greater than the baseline variability, but <66% agree on sign of change. Colors with diagonal lines indicate areas with little or no change, where <66% of models show change greater than the baseline variability, although there may be significant change at shorter timescales such as seasons, months, or days. Analysis uses model data and methods building from WGI AR5 Figure SPM.8. See also Annex I of WGI AR5. [Boxes 21-2 and CC-RC]

Table 24-1 | Key risks from climate change and the potential for risk reduction through mitigation and adaptation in Asia. Key risks are identified based on assessment of the literature and expert judgments, with supporting evaluation of evidence and agreement in the referenced chapter sections. Each key risk is characterized as very low, low, medium, high, or very high. Risk levels are presented for the near-term era of committed climate change (here, for 2030–2040), in which projected levels of global mean temperature increase do not diverge substantially across emissions scenarios. Risk levels are also presented for the longer term era of climate options (here, for 2080–2100), for global mean temperature increase of 2°C and 4°C above pre-industrial levels. For each time frame, risk levels are estimated for the current state of adaptation and for a hypothetical highly adapted state. As the assessment considers potential impacts on different physical, biological, and human systems, risk levels should not necessarily be used to evaluate relative risk across key risks. Relevant climate variables are indicated by symbols.



Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Increased risk of crop failure and lower crop production could lead to food insecurity in Asia (*medium confidence*) [24.4.4]	Autonomous adaptation of farmers on-going in many parts of Asia.	Warming trend, Drying trend, Extreme precipitation, Extreme temperature, Damaging cyclone, Sea level	Present Near term (2030-2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Water shortage in arid areas of Asia (*medium confidence*) [24.4.1.3, 24.4.1.4]	Limited capacity for water resource adaptation; options include developing water saving technology, changing drought-resilient crops, building more water reservoirs.	Warming trend, Drying trend	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Increased riverine, coastal, and urban flooding leading to widespread damage to infrastructure, livelihoods, and settlements in Asia (*medium confidence*) [24.4]	• Exposure reduction via structural and non-structural measures, effective land-use planning, and selective relocation • Reduction in the vulnerability of lifeline infrastructure and services (e.g., water, energy, waste management, food, biomass, mobility, local ecosystems, telecommunications) • Construction of monitoring and early warning systems; Measures to identify exposed areas, assist vulnerable areas and households, and diversify livelihoods • Economic diversification	Extreme precipitation, Damaging cyclone, Sea level	Present Near term (2030–2040) Long-term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Increased risk of flood-related deaths, injuries, infectious diseases and mental disorders (*medium confidence*) [24.4.6.2, 24.4.6.3, 24.4.6.5]	Disaster preparedness including early-warning systems and local coping strategies.	Extreme precipitation, Damaging cyclone	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Increased risk of heat-related mortality (*high confidence*) [24.4]	• Heat health warning systems • Urban planning to reduce heat islands; Improvement of the built environment; Development of sustainable cities • New work practices to avoid heat stress among outdoor workers	Warming trend, Extreme temperature	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Increased risk of drought-related water and food shortage causing malnutrition (*high confidence*) [24.4]	• Disaster preparedness including early-warning systems and local coping strategies • Adaptive/integrated water resource management • Water infrastructure and reservoir development • Diversification of water sources including water re-use • More efficient use of water (e.g., improved agricultural practices, irrigation management, and resilient agriculture)	Warming trend, Extreme temperature, Drying trend	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high
Increased risk of water and vector-borne diseases (*medium confidence*) [24.4.6.2, 24.4.6.3, 24.4.6.5]	Early-warning systems, vector control programs, water management and sanitation programs.	Warming trend, Drying trend, Extreme temperature, Extreme precipitation	Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low – Medium – Very high

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Table 24-1 (continued)

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Exacerbated poverty, inequalities and new vulnerabilities (*high confidence*) [24.4.5, 24.4.6]	Insufficient emphasis and limited understanding on urban poverty, interaction between livelihoods, poverty and climate change.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Coral reef decline in Asia (*high confidence*) [24.4.3.3, 24.4.3.5, CC-CR, CC-OA]	The limited adaptation options include minimizing additional stresses in marine protected areas sited where sea surface temperatures are expected to change least and reef resilience is expected to be highest.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Mountain-top extinctions in Asia (*high confidence*) [24.4.2.4, 24.4.2.5]	Adaptation options are limited. Reducing non-climate impacts and maximizing habitat connectivity will reduce risks to some extent, while assisted migration may be practical for some species.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high

availability is highly uneven and requires assessment on the sub-regional scale because of Asia's huge range of climates (Pfister et al., 2009).

Adequate water supply is one of the major challenges in many regions (Vörösmarty et al., 2010), particularly Central Asia. Growing demand for water is driven by soaring populations, increasing per capita domestic use due to urbanization and thriving economic growth, and increasing use of irrigation.

24.4.1.2. Observed Impacts

The impact of changes in climate, particularly precipitation, on water resources varies cross Asia (Table SM24-4). There is *medium confidence* that water scarcity in northern China has been exacerbated by decreasing precipitation, doubling population, and expanding water withdrawal (Xu et al., 2010). There is no evidence that suggests significant changes of groundwater in the Kherlen River Basin in Mongolia over the past half century (Brutsaert and Sugita, 2008). Apart from water availability, there is *medium confidence* that climate change also leads to degradation of water quality in most regions of Asia (Delpla et al., 2009; Park et al., 2010), although this is also heavily influenced by human activities (Winkel et al., 2011).

Glaciers are important stores of water and any changes have the potential to influence downstream water supply in the long term (see Section 24.9.2). Glacier mass loss shows a heterogeneous pattern across Asia (Gardner et al., 2013).

Glaciers in the polar section of the Ural Mountains; in the Kodar Mountains of Southeast Siberia; in the Suntar Khayata and Chersky Ranges of Northeast Siberia; in Georgia and Azerbaijan on the southern flank of the Greater Caucasus Range; on the Tibetan Plateau (see Box 3-1) and the surrounding areas; and on Puncak Jaya, Papua, Indonesia lost 9 to 80% of their total area in different periods within the 1895–2010 time interval (Ananicheva et al., 2005, 2006; Anisimov et al., 2008; Prentice and Glidden, 2010; Allison, 2011; Shahgedanova et al., 2012; Yao, T. et al., 2012; Stokes et al., 2013) due to increased temperature (Casassa et al., 2009; Shrestha and Aryal, 2011). Changes in the Kamchatka glaciers are driven by both warming and volcanic activity, with the area of some glaciers decreasing, while others increased because they are covered by ash and clinker (Anisimov et al., 2008).

24.4.1.3. Projected Impacts

Projected impacts of climate change on future water availability in Asia differ substantially among river basins and seasons (A1B scenario with five General Circulation Models (GCMs): Immerzeel et al., 2010; A1B with Meteorological Research Institute of Japan Meteorological Agency (MRI)-Atmospheric General Circulation Models (AGCMs): Nakaegawa et al., 2013). There is *high confidence* that water demand in most Asian countries is increasing because of increases in population, irrigated agriculture (Lal, 2011), and industry.

24.4.1.3.1. Tropical Asia

Future projections (A1B with MRI-AGCMs) suggest a decrease in river runoff in January in the Chao Phraya River basin in Thailand (Champathong et al., 2013). In a study of the Mahanadi River Basin in India, a water availability projection (A2, Coupled General Circulation Model 2 (CGCM2)) indicated increasing possibility of floods in September but increasing water scarcity in April (Asokan and Dutta, 2008).

In the Ganges, an increase in river runoff could offset the large increases in water demand due to population growth in a +4°C world (ensemble

Frequently Asked Questions

FAQ 24.1 | What will the projected impact of future climate change be on freshwater resources in Asia?

Asia is a huge and diverse region, so both climate change and the impact on freshwater resources will vary greatly depending on location. But throughout the region, adequate water resources are particularly important because of the massive population and heavy dependence of the agricultural sector on precipitation, river runoff, and groundwater. Overall, there is *low confidence* in the projections of specifically how climate change will impact future precipitation on a sub-regional scale, and thus in projections of how climate change might impact the availability of water resources. However, water scarcity is expected to be a big challenge in many Asian regions because of increasing water demand from population growth and consumption per capita with higher standards of living. Shrinkage of glaciers in central Asia is expected to increase as a result of climate warming, which will influence downstream river runoff in these regions. Better water management strategies could help ease water scarcity. Examples include developing water saving technologies in irrigation, building reservoirs, increasing water productivity, changing cropping systems, and water reuse.

GCMs), due to a projected large increase in average rainfall, although high uncertainties remain at the seasonal scale (Fung et al., 2011).

24.4.1.3.2. Northern and temperate Asia

Projections (A2 and B2 with the Global Assessment of Security (GLASS) model) suggest an increase in average water availability in Russia in the 2070s (Alcamo et al., 2007). In China, a projection (downscaling Hadley Centre Atmospheric Model version 3H (HadAM3H) A2 and B2 scenarios with the Providing Regional Climates for Impacts Studies (PRECIS) regional model) suggests that there will be insufficient water for agriculture in the 2020s and 2040s due to the increases in water demand for non-agricultural uses, although precipitation may increase in some areas (Xiong et al., 2010). In the late-21st century (MRI-AGCMs, A1B), river discharge in northern Japan is projected to increase in February but decrease in May, due to increased winter precipitation and decreased spring snowmelt (Sato et al., 2013).

24.4.1.3.3. Central and West Asia

Given the already very high level of water stress in many parts of Central Asia, projected temperature increases and precipitation decreases (SRES scenarios from IPCC AR4, 23 models) in the western part of Kazakhstan, Uzbekistan, and Turkmenistan could exacerbate the problems of water shortage and distribution (Lioubimtseva and Henebry, 2009). Considering the dependence of Uzbekistan's economy on its irrigated agriculture, which consumes more than 90% of the available water resources of the Amu Darya basin, climate change impacts on river flows would also strongly affect the economy (Schlüter et al., 2010).

24.4.1.4. Vulnerabilities to Key Drivers

It is suggested that freshwater resources will be influenced by changes in rainfall variability, snowmelt, glacier retreat (Im et al., 2010; Li, Z. et al., 2010; Sato et al., 2012; Yamanaka et al., 2012; Nakaegawa et al., 2013), or evapotranspiration in the river catchment, which are associated with climate change (Jian et al., 2009). Mismanagement of water resources has increased tension because of water scarcity in arid areas (Biswas and Seetharam, 2008; Lioubimtseva and Henebry, 2009; Siegfried et al., 2010; Aarnoudse et al., 2012). Unsustainable consumption of groundwater for irrigation and other uses is considered to be the main cause of groundwater depletion in the Indian states of Rajasthan, Punjab, and Haryana (Rodell et al., 2009).

24.4.1.5. Adaptation Options

Adaptation of freshwater resources to climate change can be identified as developing adaptive/integrated water resource management (Sadoff and Muller, 2009; Schlüter et al., 2010) of the trade-offs balancing water availability against increasing demand, in order to cope with uncertainty and change (Molle and Hoanh, 2009).

Examples of the options include: developing water saving technologies in irrigation (Ngoundo et al., 2007); water infrastructure development in the Ganges river basin (Bharati et al., 2011); increasing water productivity in the Indus and Ganges river basins (Cai et al., 2010), Taiwan, China, and the Philippines (Barker and Levine, 2012), and Uzbekistan (Tischbein et al., 2011); changing cropping systems and patterns in West Asia (Thomas, 2008); and water reuse in China (Yi et al., 2011). During the second half of the 20th century, Asia built many reservoirs and almost tripled its surface water withdrawals for irrigation (Biemans et al., 2011). Reservoirs partly mitigate seasonal differences and increase water availability for irrigation (Biemans et al., 2011). Water management in river basins would benefit from integrated coordination among countries (Kranz et al., 2010). For example, water management in the Syr Darya river basin relates to Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan, and Kazakhstan (Siegfried et al., 2010), while the Indus and Ganges-Brahmaputra-Meghna river basins concern Bangladesh, India, Nepal, and Pakistan (Uprety and Salman, 2011).

24.4.2. Terrestrial and Inland Water Systems

24.4.2.1. Sub-regional Diversity

Boreal forests and grasslands dominate in North Asia, deserts and semi-deserts in Central and West Asia, and alpine ecosystems on the Tibetan Plateau. Human-dominated landscapes predominate in the other sub-regions, but the major natural ecosystems are temperate deciduous and subtropical evergreen forests in East Asia, with boreal forest in the northeast and grasslands and deserts in the west, while Southeast Asia was largely covered in tropical forests. South Asia also has tropical forests, with semi-desert in the northwest and alpine ecosystems in the north. Asia includes several of the world's largest river systems, as well as the world's deepest freshwater lake, Lake Baikal, the semi-saline Caspian Sea, and the saline Aral Sea.

24.4.2.2. Observed Impacts

Biological changes consistent with climate trends have been reported in the north and at high altitudes, where rising temperatures have relaxed constraints on plant growth and the distributions of organisms. Few changes have been reported from tropical lowlands and none linked to climate change with *high confidence*, although data are insufficient to distinguish lack of observations from lack of impacts. Impacts on inland water systems have been difficult to disentangle from natural variability and other human impacts (Bates et al., 2008; Vörösmarty et al., 2010; Zheng, 2011; see Section 4.3.3.3). For example, the shrinking of the Aral Sea over the last 50 years has resulted largely from excessive water extraction from rivers, but was probably exacerbated by decreasing precipitation and increasing temperature (Lioubimtseva and Henebry, 2009; Kostianoy and Kosarev, 2010).

24.4.2.2.1. Phenology and growth rates

In humid temperate East Asia, plant observations and satellite measurements of "greenness" (Normalized Difference Vegetation Index (NDVI); see Section 4.3.2.2) show a trend to earlier leafing in spring since the 1980s, averaging 2 days per decade, although details vary between sites, species, and periods (Table SM24-6; detected with *high confidence* and attributed to warming with *medium confidence*). Earlier spring flowering and delayed autumn senescence have also been recorded (Table SM24-6). Trends in semiarid temperate regions were heterogeneous in space and time (Liu et al., 2013a; Yu, Z. et al., 2013a,b). Earlier greening has been reported from boreal forests (Delbart et al., 2008) and from the Hindu-Kush-Himalayan region (Panday and Ghimire, 2012; Shrestha et al., 2012), but with spatial and temporal heterogeneity. Patterns were also heterogeneous in Central Asia (Kariyeva et al., 2012). On the Tibetan Plateau, spring growth advanced until the mid-1990s, but the trend subsequently differs between areas and NDVI data sets (Yu et al., 2010, 2012; Dong et al., 2013; Jin et al., 2013; Shen et al., 2013; Yu, Z. et al., 2013a; Zhang, G. et al., 2013; Zhang, L. et al., 2013).

Satellite NDVI for Asia for 1988–2010 shows a general greening trend (i.e., increasing NDVI, a rough proxy for increasing plant growth), except where water is limiting (Dorigo et al., 2012). Changes at high latitudes (>60°N) show considerable spatial and temporal variability, despite a consistent warming trend, reflecting water availability and non-climatic factors (Bi et al., 2013; Jeong et al., 2013). Arctic tundra generally showed increased greening since 1982, while boreal forests were variable (Goetz et al., 2011; de Jong et al., 2012; Epstein et al., 2012; Xu et al., 2013). An overall greening trend for 2000–2011 north of the boreal forest correlated with increasing summer warmth and ice retreat (Dutrieux et al., 2012). In China, trends have varied in space and time, reflecting positive impacts of warming and negative impacts of increasing drought stress (Peng et al., 2011; Sun et al., 2012; Xu et al., 2012). The steppe region of northern Kazakhstan showed an overall browning (decreasing NDVI) trend for 1982–2008, linked to declining precipitation (de Jong et al., 2012). In Central Asia, where NDVI is most sensitive to precipitation (Gessner et al., 2013), there was a heterogeneous pattern for 1982–2009, with an initial greening trend stalled or reversed in some areas (Mohammat et al., 2013).

Tree-ring data for 800–1989 for temperate East Asia suggests recent summer temperatures have exceeded those during past warm periods of similar length, although this difference was not statistically significant (Cook et al., 2012). Where temperature limits tree growth, growth rates have increased with warming in recent decades (Duan et al., 2010; Sano et al., 2010; Shishov and Vaganov, 2010; Borgaonkar et al., 2011; Xu et al., 2011; Chen et al., 2012a,b,c,d, 2013; Li et al., 2012), while where drought limits growth, there have been increases (Li et al., 2006; Davi et al., 2009; Shao et al., 2010; Yang et al., 2010) or decreases (Li et al., 2007; Dulamsuren et al., 2010a, 2011; Kang et al., 2012; Wu et al., 2012; Kharuk et al., 2013; Liu et al., 2013b), reflecting decreasing or increasing water stress (*high confidence* in detection, *medium confidence* in attribution to climate change). In boreal forest, trends varied between species and locations, despite consistent warming (Lloyd and Bunn, 2007; Goetz et al., 2011).

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24.4.2.2.2. Distributions of species and biomes

Changes in species distributions consistent with a response to warming have been widely reported: upwards in elevation (Soja et al., 2007; Bickford et al., 2010; Kharuk et al., 2010a,b,e; Moiseev et al., 2010; Chen et al., 2011; Jump et al., 2012; Grigor'ev et al., 2013; Telwala et al., 2013) or polewards (Tougou et al., 2009; Ogawa-Onishi and Berry, 2013) (*high confidence* in detection, *medium confidence* in attribution to climate change). Changes in the distributions of major vegetation types (biomes) have been reported from the north and high altitudes, where trees are invading treeless vegetation, and forest understories are being invaded from adjacent biomes (Kharuk et al., 2006; Soja et al., 2007; Bai et al., 2011; Singh et al., 2012; Wang and Liu, 2012). In central Siberia, dark needle conifers (DNCs) and birch have invaded larch-dominated forest over the last 3 decades (Kharuk et al., 2010c,d; Osawa et al., 2010; Lloyd et al., 2011). Meanwhile, warming has driven larch stand crown closure and larch invasion into tundra at a rate of 3 to 10 m yr^{-1} in the northern forest-tundra ecotone (Kharuk et al., 2006). Shrub expansion in arctic tundra has also been observed (Blok et al., 2011; Myers-Smith et al., 2011; see Section 28.2.3.1). Soil moisture and light are the main factors governing the forest-steppe ecotone (Soja et al., 2007; Zeng et al., 2008; Eichler et al., 2011; Kukavskaya et al., 2013), and Mongolian taiga forests have responded heterogeneously to recent climate changes, but declines in larch growth and regeneration are more widespread than increases (Dulamsuren et al., 2010a,b).

24.4.2.2.3. Permafrost

Permafrost degradation, including reduced area and increased active layer thickness, has been reported from parts of Siberia, Central Asia, and the Tibetan Plateau (*high confidence*; Romanovsky et al., 2010; Wu and Zhang, 2010; Zhao et al., 2010; Yang et al., 2013). Most permafrost observatories in Asian Russia show substantial warming of permafrost during the last 20 to 30 years (Romanovsky et al., 2008, 2010). Permafrost formed during the Little Ice Age is thawing at many locations and Late Holocene permafrost has begun to thaw at some undisturbed locations in northwest Siberia. Permafrost thawing is most noticeable within the discontinuous permafrost zone, while continuous permafrost is starting to thaw in a few places, so the boundary between continuous and discontinuous permafrost is moving northward (Romanovsky et al., 2008, 2010).

Thawing permafrost may lead to increasing emissions of greenhouse gases from decomposition of accumulated organic matter (see Sections 4.3.3.4, 19.6.3.5). In Mongolia, mean annual permafrost temperature at 10 to 15 m depth increased over the past 10 to 40 years in the Hovsgol, Hangai, and Hentei Mountain regions. Permafrost warming during the past 15 to 20 years was greater than during the previous 15 to 20 years (Sharkhuu et al., 2008; Zhao et al., 2010). In the Kazakh part of the Tien Shan Mountains, permafrost temperature and active layer thickness have increased since the early 1970s. Significant permafrost warming also occurred in the eastern Tien Shan Mountains, in the headwaters of the Urumqi River (Marchenko et al., 2007; Zhao et al., 2010). Monitoring across the Qinghai-Tibet Plateau over recent decades has also revealed permafrost degradation caused by warming and other impacts. Areas of permafrost are shrinking, the active layer depth is increasing, the lower altitudinal limit is rising, and the seasonal frost depth is thinning (Li et al., 2008; Wu and Zhang, 2010; Zhao et al., 2010). In the alpine headwater regions of the Yangtze and Yellow Rivers, rising temperatures and permafrost degradation have resulted in lower lake levels, drying swamps, and shrinking grasslands (Cheng and Wu, 2007; Wang et al., 2011).

24.4.2.3. Projected Impacts

24.4.2.3.1. Phenology and growth rates

Trends toward an earlier spring greening and longer growing season are expected to continue in humid temperate and boreal forest areas, although photoperiod or chilling requirements may reduce responses to warming in some species (Ge et al., 2013; Hadano et al., 2013; Richardson et al., 2013). Changes in precipitation will be important for semiarid and arid ecosystems, as may the direct impacts of atmospheric carbon dioxide (CO_2) concentrations, making responses harder to predict (Liancourt et al., 2012; Poulter et al., 2013). The "general flowering" at multi-year intervals in lowland rainforests in Southeast Asia is triggered by irregular droughts (Sakai et al., 2006), so changes in drought frequency or intensity could have large impacts.

24.4.2.3.2. Distributions of species and biomes

Climate change is expected to modify the vegetation distribution across the region (Tao and Zhang, 2010; Wang, 2013), but responses will be slowed by limitations on seed dispersal, competition from established plants, rates of soil development, and habitat fragmentation (*high confidence*; Corlett and Westcott, 2013). Rising CO_2 concentrations are expected to favor increased woody vegetation in semiarid areas (*medium confidence*; Higgins and Scheiter, 2012; Donohue et al., 2013; Poulter et al., 2013; Wang, 2013). In North Asia, rising temperatures are expected to lead to large changes in the distribution of potential natural ecosystems (*high confidence*; Ni, 2011; Tchebakova et al., 2011; Insarov et al., 2012; Pearson et al., 2013). It is *likely* that the boreal forest will expand northward and eastward, and that tundra will decrease, although differences in models, time periods, and other assumptions have resulted in widely varying projections for the magnitude of this change (Woodward and Lomas, 2004; Kaplan and New, 2006; Lucht et al., 2006; Golubyatnikov and Denisenko, 2007; Sitch et al., 2008; Korzukhin and Tcelniker, 2010; Tchebakova et al., 2010, 2011; Pearson et al., 2013). Boreal forest expansion and the continued invasion of the existing larch-dominated forest by DNCs could lead to larch reaching the Arctic shore, while the traditional area of larch dominance turns into mixed forest (Kharuk et al., 2006, 2010c). Both the replacement of summer-green larch with evergreen conifers and expansion of trees and shrubs into tundra decrease albedo, causing regional warming and potentially accelerating vegetation change (Kharuk et al., 2006, 2010d; McGuire et al., 2007; Pearson et al., 2013). The future direction and rate of change of steppe vegetation are unclear because of uncertain precipitation trends (Golubyatnikov and Denisenko, 2007; Tchebakova et al., 2010). The role of CO_2 fertilization is also potentially important here (Poulter et al., 2013; see WGI AR5 Box 6.3).

In East Asia, subtropical evergreen forests are projected to expand north into the deciduous forest and tropical forests to expand along China's southern coast (Choi et al., 2011; Wang, 2013), but vegetation change may lag climate change by decades or centuries (Corlett and Westcott, 2013). On the Tibetan Plateau, projections suggest that alpine vegetation will be largely replaced by forest and shrubland, with tundra and steppe retreating to the north (Liang et al., 2012; Wang, 2013). Impacts in Central and West Asia will depend on changes in precipitation. In India, a dynamic vegetation model (A2 and B2 scenarios) projected changes in more than a third of the forest area by 2100, mostly from deciduous to evergreen forest in response to increasing rainfall, although fragmentation and other human pressures are expected to slow these changes (Chaturvedi et al., 2011). By 2100, large areas of tropical and subtropical lowland Asia are projected to experience combinations of temperature and rainfall outside the current global range, under a variety of model projections and emission scenarios (Williams et al., 2007; Beaumont et al., 2010; García-López and Allué, 2013), but the potential impacts of these novel conditions on biodiversity are largely unknown (Corlett, 2011).

In Southeast Asia, projected climate (A2 and B1 scenarios) and vegetation changes are expected to produce widespread declines in bat species richness, northward range shifts for many species, and large reductions in the distributions of most species (Hughes et al., 2012). Projections for various bird species in Asia under a range of scenarios also suggest major impacts on distributions (Menon et al., 2009; Li, R. et al., 2010; Ko et al., 2012). Projections for butterflies in Thailand (A2 and B2 scenarios) suggest that species richness within protected areas will decline approximately 30% by 2070–2099 (Klorvuttimontara et al., 2011). Projections for dominant bamboos in the Qinling Mountains (A2 and B2 scenarios) suggest substantial range reductions by 2100, with potentially adverse consequences for the giant pandas that eat them (Tuanmu et al., 2012). Projections for snow leopard habitat in the Himalayas (B1, A1B, and A2 scenarios) suggest contraction by up to 30% as forests replace open habitats (Forrest et al., 2012).

24.4.2.3.3. Permafrost

In the Northern Hemisphere, a 20 to 90% decrease in permafrost area and a 50 to 300 cm increase in active layer thickness driven by surface warming is projected for 2100 by different models and scenarios (Schaefer et al., 2011). It is *likely* that permafrost degradation in North Asia will spread from the southern and low-altitude margins, advancing northward and upward, but rates of change vary greatly between model projections (Cheng and Wu, 2007; Riseborough et al., 2008; Romanovsky et al., 2008; Anisimov, 2009; Eliseev et al., 2009; Nadyozhina et al., 2010; Schaefer et al., 2011; Wei et al., 2011). Substantial retreat is also expected on the Qinghai-Tibet Plateau (Cheng and Wu, 2007). Near-surface permafrost is expected to remain only in Central and Eastern Siberia and parts of the Qinghai-Tibet Plateau in the late-21st century.

24.4.2.3.4. Inland waters

Climate change impacts on inland waters will interact with dam construction, pollution, and land use changes (Vörösmarty et al., 2010; see also Sections 3.3.2, 24.9.1). Increases in water temperature will impact species- and temperature-dependent processes (Hamilton, 2010; Dudgeon, 2011, 2012). Coldwater fish will be threatened as rising water temperatures make much of their current habitat unsuitable (Yu, D. et al., 2013). Climate change is also expected to change flow regimes in running waters and consequently impact habitats and species that are sensitive to droughts and floods (see Box CC-RF). Habitats that depend on seasonal inundation, including floodplain grasslands and freshwater swamp forests, will be particularly vulnerable (Maxwell, 2009; Bezuijen, 2011; Arias et al., 2012). Reduced dry season flows are expected to combine with sea level rise to increase saltwater intrusion in deltas (Hamilton, 2010; Dudgeon, 2012), although non-climatic impacts will continue to dominate in most estuaries (Syvitski et al., 2009). For most Asian lakes, it is difficult to disentangle the impacts of water pollution, hydro-engineering, and climate change (Battarbee et al., 2012).

24.4.2.4. Vulnerabilities to Key Drivers

Permafrost melting in response to warming is expected to impact ecosystems across large areas (*high confidence*; Cheng and Wu, 2007; Tchebakova et al., 2011). The biodiversity of isolated mountains may also be particularly vulnerable to warming, because many species already have small geographical ranges that will shrink further (La Sorte and Jetz, 2010; Liu et al., 2010; Chou et al., 2011; Noroozi et al., 2011; Peh et al., 2011; Jump et al., 2012; Tanaka, N. et al., 2012; Davydov et al., 2013). Many freshwater habitats are similarly isolated and their restricted-range species may be equally vulnerable (Dudgeon, 2012). In flatter topography, higher velocities of climate change (the speeds that species need to move to maintain constant climate conditions) increase the vulnerabilities of species that are unable to keep pace, as a result of limited dispersal ability, habitat fragmentation, or other non-climatic constraints (Corlett and Westcott, 2013). In the tropics, temperature extremes above the present range are a potential threat to organisms and ecosystems (Corlett, 2011; Jevanandam et al., 2013; Mumby et al., 2013). For much of interior Asia, increases in drought stress, as a result of declining rainfall and/or rising temperatures, are the key concern. Because aridity is projected to increase in the northern Mongolian forest belt during the 21st century (Sato et al., 2007), larch cover will likely be reduced (Dulamsuren et al., 2010a). In the boreal forest region, a longer, warmer growing season will increase vulnerability to fires, although other human influences may overshadow climate impacts in accessible areas (Flannigan et al., 2009; Liu et al., 2012; Li et al., 2013; see Section 4.3.3.1.1). If droughts intensify in lowland Southeast Asia, the synergies between warmth, drought, logging, fragmentation, and fire (Daniau et al., 2012) and tree mortality (Kumagai and Porporato, 2012; Tan et al., 2013), possibly acerbated by feedbacks between deforestation, smoke aerosols, and reduced rainfall (Aragão, 2012; Tosca et al., 2012), could greatly increase the vulnerability of fragmented forest landscapes (*high confidence*).

24.4.2.5. Adaptation Options

Suggested strategies for maximizing the adaptive capacity of ecosystems include reducing non-climate impacts, maximizing landscape connectivity, and protecting "refugia" where climate change is expected to be less than the regional mean (Hannah, 2010; Game et al., 2011; Klorvuttimontara et al., 2011; Murthy et al., 2011; Ren et al., 2011; Shoo et al., 2011; Mandych et al., 2012). Additional options for inland waters include operating dams to maintain environmental flows for biodiversity, protecting catchments, and preserving river floodplains (Vörösmarty et al., 2010). Habitat restoration may facilitate species movements across climatic gradients (Klorvuttimontara et al., 2011; Hughes et al., 2012) and long-distance seed dispersal agents may need protection (McConkey et al., 2012). Assisted migration of genotypes and species is possible where movements are constrained by poor dispersal, but risks and benefits need to be considered carefully (Liu et al., 2010; Olden et al., 2010; Tchebakova et al., 2011; Dudgeon, 2012; Ishizuka and Goto, 2012; Corlett and Westcott, 2013). *Ex situ* conservation can provide backup for populations and species most at risk from climate change (Chen et al., 2009).

24.4.3. Coastal Systems and Low-Lying Areas

24.4.3.1. Sub-regional Diversity

Asia's coastline includes the global range of shore types. Tropical and subtropical coasts support approximately 45% of the world's mangrove forest (Giri et al., 2011) and low-lying areas in equatorial Southeast Asia support most of the world's peat swamp forests, as well as other forested swamp types. Intertidal salt marshes are widespread along temperate and arctic coasts, while a variety of non-forested wetlands occur inland. Asia supports approximately 40% of the world's coral reef area, mostly in Southeast Asia, with the world's most diverse reef communities in the "coral triangle" (Spalding et al., 2001; Burke et al., 2011). Seagrass beds are widespread and support most of the world's seagrass species (Green and Short, 2003). Six of the seven species of sea turtle are found in the region and five nest on Asian beaches (Spotila, 2004). Kelp forests and other seaweed beds are important on temperate coasts (Bolton, 2010; Nagai et al., 2011). Arctic sea ice supports a specialized community of mammals and other organisms (see Sections 28.2.3.3-4.).

24.4.3.2. Observed Impacts

Most of Asia's non-Arctic coastal ecosystems are under such severe pressure from non-climate impacts that climate impacts are hard to detect (see Section 5.4.2). Most large deltas in Asia are sinking (as a result of groundwater withdrawal, floodplain engineering, and trapping of sediments by dams) much faster than global sea level is rising (Syvitski et al., 2009). Widespread impacts can be attributed to climate change only for coral reefs, where the temporal and spatial patterns of bleaching correlate with higher than normal sea surface temperatures (*very high confidence*; Section 5.4.2.4; Box CC-CR). Increased water temperatures may also explain declines in large seaweed beds in temperate Japan (Nagai et al., 2011; Section 5.4.2.3). Warming coastal waters have also been implicated in the northward expansion of tropical and subtropical macroalgae and toxic phytoplankton (Nagai et al., 2011), fish (Tian et al., 2012), and tropical corals, including key reef-forming species (Yamano et al., 2011), over recent decades. The decline of large temperate seaweeds and expansion of tropical species in southwest Japan has been linked to rising sea surface temperatures (Tanaka, K. et al., 2012), and these changes have impacted fish communities (Terazono et al., 2012).

In Arctic Asia, changes in permafrost and the effects of sea level rise and sea ice retreat on storm-wave energy have increased erosion (Are et al., 2008; Razumov, 2010; Handmer et al., 2012). Average erosion rates range from 0.27 m yr^{-1} (Chukchi Sea) to 0.87 m yr^{-1} (East Siberian Sea), with a number of segments in the Laptev and East Siberian Sea experiencing rates greater than 3 m yr^{-1} (Lantuit et al., 2012).

24.4.3.3. Projected Impacts

Marine biodiversity at temperate latitudes is expected to increase as temperature constraints on warmwater taxa are relaxed (*high confidence*; see Section 6.4.1.1), but biodiversity in tropical regions may fall if, as evidence suggests, tropical species are already near their thermal maxima (*medium confidence;* Cheung et al., 2009, 2010; Nguyen et al., 2011). Individual fish species are projected to shift their ranges northward in response to rising sea surface temperatures (Tseng et al., 2011; Okunishi et al., 2012; Tian et al., 2012). The combined effects of changes in distribution, abundance, and physiology may reduce the body size of marine fishes, particularly in the tropics and intermediate latitudes (Cheung et al., 2013).

Continuation of current trends in sea surface temperatures and ocean acidification would result in large declines in coral-dominated reefs by mid-century (*high confidence*; Burke et al., 2011; Hoegh-Guldberg, 2011; see Section 5.4.2.4; Box CC-CR). Warming would permit the expansion of coral habitats to the north but acidification is expected to limit this (Yara et al., 2012). Acidification is also expected to have negative impacts on other calcified marine organisms (algae, molluscs, larval echinoderms), while impacts on non-calcified species are unclear (Branch et al., 2013; Kroeker et al., 2013; see Box CC-OA). On rocky shores, warming and acidification are expected to lead to range shifts and changes in biodiversity (see Section 5.4.2.2).

Future rates of sea level rise are expected to exceed those of recent decades (see WGI AR5 Section 13.5.1), increasing coastal flooding, erosion, and saltwater intrusion into surface and groundwaters. In the absence of other impacts, coral reefs may grow fast enough to keep up with rising sea levels (Brown et al., 2011; Villanoy et al., 2012; see Section 5.4.2.4), but beaches may erode and mangroves, salt marshes, and seagrass beds will decline, unless they receive sufficient fresh sediment to keep pace or they can move inland (Gilman et al., 2008; Bezuijen, 2011; Kintisch, 2013; see Section 5.3.2.3). Loucks et al. (2010) predict a 96% decline in tiger habitat in Bangladesh's Sunderbans mangroves with a 28 cm sea level rise if sedimentation does not increase surface elevations. Rising winter temperatures are expected to result in poleward expansion of mangrove ecosystems (see Section 5.4.2.3). Coastal freshwater wetlands may be vulnerable to saltwater intrusion with rising sea levels, but in most river deltas local subsidence for non-climatic reasons will be more important (Syvitski et al., 2009). Current trends in cyclone frequency and intensity are unclear (Section 24.3.2; Box CC-TC), but a combination of cyclone intensification and sea level rise could increase coastal flooding (Knutson et al., 2010) and losses of coral reefs and mangrove forests would exacerbate wave damage (Gedan et al., 2011; Villanoy et al., 2012).

In the Asian Arctic, rates of coastal erosion are expected to increase as a result of interactions between rising sea levels and changes in permafrost and the length of the ice-free season (*medium evidence*; *high agreement*; Pavlidis et al., 2007; Lantuit et al., 2012). The largest changes are expected for coasts composed of loose permafrost rocks and therefore subject to intensive thermal abrasion. If sea level rises by 0.5 m over this century, modeling studies predict that the rate of recession will increase 1.5- to 2.6-fold for the coasts of the Laptev Sea, East Siberian Sea, and West Yamal in the Kara Sea, compared to the rate observed in the first years of the 21st century.

24.4.3.4. Vulnerabilities to Key Drivers

Offshore marine systems are most vulnerable to rising water temperatures and ocean acidification, particularly for calcifying organisms such as corals. Sea level rise will be the key issue for many coastal areas, particularly if combined with changes in cyclone frequency or intensity, or, in Arctic Asia, with a lengthening open-water season. The expected continuing decline in the extent of sea ice in the Arctic may threaten the survival of some ice-associated organisms (see Section 28.2.2.1), with expanded human activities in previously inaccessible areas an additional concern (Post et al., 2013).

24.4.3.5. Adaptation Options

The connectivity of marine habitats and dispersal abilities of marine organisms increase the capacity for autonomous (spontaneous) adaptation in coastal systems (Cheung et al., 2009). Creating marine protected areas where sea surface temperatures are projected to change least may increase their future resilience (Levy and Ban, 2013). For coral reefs, potential indicators of future resilience include later projected onset of annual bleaching conditions (van Hooidonk et al., 2013), past temperature variability, the abundance of heat-tolerant coral species, coral recruitment rates, connectivity, and macroalgae abundance (McClanahan et al., 2012). Similar strategies may help identify reefs that are more resilient to acidification (McLeod et al., 2013). Hard coastal defenses, such as sea walls, protect settlements at the cost of preventing adjustments by mangroves, salt marshes, and seagrass beds to rising sea levels. Landward buffer zones that provide an opportunity for future inland migration could mitigate this problem (Tobey et al., 2010). More generally, maintaining or restoring natural shorelines where possible is expected to provide coastal protection and other benefits (Tobey et al., 2010; Crooks et al., 2011). Projected increases in the navigability of the Arctic Ocean because of declining sea ice suggest the need for a revision of environmental regulations to minimize the risk of marine pollution (Smith and Stephenson, 2013).

24.4.4. Food Production Systems and Food Security

It is projected that climate change will affect food security by the middle of the 21st century, with the largest numbers of food-insecure people located in South Asia (see Chapter 7).

24.4.4.1. Sub-regional Diversity

WGII AR4 Section 10.4.1.1 pointed out that there will be regional differences within Asia in the impacts of climate change on food production. Research since then has validated this divergence and new data are available especially for West and Central Asia (see Tables SM24-4, SM24-5). In WGII AR4 Section 10.4.1, climate change was projected to lead mainly to reductions in crop yield. New research shows there will also be gains for specific regions and crops in given areas. Thus, the current assessment encompasses an enormous variability, depending on the regions and the crops grown.

24.4.4.2. Observed Impacts

There are very limited data globally for observed impacts of climate change on food production systems (see Chapter 7) and this is true also for Asia. In Jordan, it was reported that the total production and average yield for wheat and barley were lowest in 1999 for the period 1996–2006 (Al-Bakri et al., 2010), which could be explained by the low rainfall during that year, which was 30% of the average (*high confidence* in detection, *low confidence* in attribution). In China, rice yield responses to recent climate change at experimental stations were assessed for the period 1981–2005 (Zhang et al., 2010). In some places, yields were positively correlated with temperature when they were also positively related with solar radiation. However, in other places, lower yield with higher temperature was accompanied by a positive correlation between yield and rainfall (*high confidence* in detection, *high confidence* in attribution). In Japan, where mean air temperature rose by about 1°C over the 20th century, effects of recent warming include phenological changes in many crops, increases in fruit coloring disorders and incidences of chalky rice kernels, reductions in yields of wheat, barley, vegetables, flowers, milk, and eggs, and alterations in the type of disease and pest (*high confidence* in detection, *high confidence* in attribution; Sugiura et al., 2012).

24.4.4.3. Projected Impacts

24.4.4.3.1. Production

WGII AR4 Section 10.4.1.1 mainly dealt with cereal crops (rice, wheat, corn). Since then, impacts of climate change have been modeled for additional cereal crops and sub-regions. It is *very likely* that climate change effects on crop production in Asia will be variable, negative for specific regions and crops in given areas and positive for other regions and crops (*medium evidence*, *high agreement*). It is also *likely* that an elevated CO_2 concentration in the atmosphere will be beneficial to most crops (*medium evidence*, *high agreement*).

In semiarid areas, rainfed agriculture is sensitive to climate change both positively and negatively (Ratnakumar et al., 2011). In the mountainous Swat and Chitral districts of Pakistan (average altitudes 960 and 1500 m above sea level, respectively), there were mixed results as well (Hussain and Mudasser, 2007). Projected temperature increases of 1.5°C and 3°C would lead to wheat yield declines (by 7% and 24%, respectively) in Swat district but to increases (by 14% and 23%) in Chitral district. In India, climate change impacts on sorghum were analyzed using the InfoCrop-SORGHUM simulation model (Srivastava et al., 2010). A changing climate was projected to reduce monsoon sorghum grain yield by 2 to 14% by 2020, with worsening yields by 2050 and 2080. In the Indo-Gangetic Plains, a large reduction in wheat yields is projected (see Section 24.4.4.3.2), unless appropriate cultivars and crop management practices are adopted (Ortiz et al., 2008). A systematic review and meta-analysis of data in 52 original publications projected mean changes in yield by the 2050s across South Asia of 16% for maize and 11% for sorghum (Knox et al., 2012). No mean change in yield was projected for rice.

In China, modeling studies of the impacts of climate change on crop productivity have had mixed results. Rice is the most important staple food in Asia. Studies show that climate change will alter productivity in China but not always negatively. For example, an ensemble-based probabilistic projection shows rice yield in eastern China would change on average by 7.5 to 17.5% (–10.4 to 3.0%), 0.0 to 25.0% (–26.7 to 2.1%), and –10.0 to 25.0% (–39.2 to –6.4%) during the 2020s, 2050s, and 2080s, respectively, in response to climate change, with (without) consideration of CO_2 fertilization effects, using all 10 combinations of two emission scenarios (A1FI and B1) and five GCMs (Hadley Centre climate prediction model 3 (HadCM3), Parallel Climate Model (PCM), CGCM2, Commonwealth Scientific and Industrial Research Organisation 2 (CSIRO2), and European Centre for Medium Range Weather Forecasts

Frequently Asked Questions

FAQ 24.2 | How will climate change affect food production and food security in Asia?

Climate change impacts on temperature and precipitation will affect food production and food security in various ways in specific areas throughout this diverse region. Climate change will have a generally negative impact on crop production Asia, but with diverse possible outcomes (*medium confidence*). For example most simulation models show that higher temperatures will lead to lower rice yields as a result of a shorter growing period. But some studies indicate that increased atmospheric CO_2 that leads to those higher temperatures could enhance photosynthesis and increase rice yields. This uncertainty on the overall effects of climate change and CO_2 fertilization is generally true for other important food crops such as wheat, sorghum, barley, and maize, among others.

Yields of some crops will increase in some areas (e.g., cereal production in north and east Kazakhstan) and decrease in others (e.g., wheat in the Indo-Gangetic Plain of South Asia). In Russia, climate change may lead to a food production shortfall, defined as an event in which the annual potential production of the most important crops falls 50% or more below its normal average. Sea level rise is projected to decrease total arable areas and thus food supply in many parts of Asia. A diverse mix of potential adaptation strategies, such as crop breeding, changing crop varieties, adjusting planting time, water management, diversification of crops, and a host of indigenous practices will all be applicable within local contexts.

and Hamburg 4 (ECHAM4)) relative to 1961–1990 levels (Tao and Zhang, 2013a). With rising temperatures, the process of rice development accelerates and reduces the duration for growth. Wassmann et al. (2009a,b) concluded that, in terms of risks of increasing heat stress, there are parts of Asia where current temperatures are already approaching critical levels during the susceptible stages of the rice plant. These include Pakistan/North India (October), South India (April/August), East India/Bangladesh (March-June), Myanmar/Thailand/Laos/Cambodia (March-June), Vietnam (April/August), Philippines (April/June), Indonesia (August), and China (July/August).

There have also been simulation studies for other crops in China. In the Huang-Hai Plain, China's most productive wheat growing region, modeling indicated that winter wheat yields would increase on average by 0.2 Mg ha^{-1} in 2015–2045 and by 0.8 Mg ha^{-1} in 2070–2099, due to warmer nighttime temperatures and higher precipitation, under A2 and B2 scenarios using the HadCM3 model (Thomson et al., 2006). In the North China Plain, an ensemble-based probabilistic projection projected that maize yield will change by –9.7 to –9.1%, –19.0 to –15.7%, and –25.5 to –24.7%, during 2020s, 2050s, and 2080s as a percentage of 1961–1990 yields (Tao et al., 2009). In contrast, winter wheat yields could increase with high probability in future due to climate change (Tao and Zhang, 2013b).

It should be noted that crop physiology simulation models may overstate the impact of CO_2 fertilization. Free Atmosphere Carbon Exchange (FACE) experiments show that measurable CO_2 fertilization effects are typically less than modeled results (see Section 7.3).

Extreme weather events are also expected to negatively affect agricultural crop production (IPCC, 2012). For example, extreme temperatures could lower yields of rice (Mohammed and Tarpley, 2009; Tian et al., 2010). With higher precipitation, flooding could also lead to lower crop production (see SREX Chapter 4).

24.4.4.3.2. Farming systems and crop areas

Since the release of the AR4 (see WGII AR4 Section 10.4.1.2), more information is available on the impacts of climate change on farming systems and cropping areas in more countries in Asia and especially in Central Asia. Recent studies validate the likely northward shifts of crop production with current croplands under threat from the impacts of climate change (*medium evidence*, *medium agreement*). Cooler regions are likely to benefit as warmer temperatures increase arable areas (*medium evidence*, *high agreement*).

Central Asia is expected to become warmer in the coming decades and increasingly arid, especially in the western parts of Turkmenistan, Uzbekistan, and Kazakhstan (Lioubimtseva and Henebry, 2009). Some parts of the region could be winners (cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters, and a slight increase in winter precipitation), while others could be losers (particularly western Turkmenistan and Uzbekistan, where frequent droughts could negatively affect cotton production, increase already extremely high water demands for irrigation, and exacerbate the already existing water crisis and human-induced desertification). In India, the Indo-Gangetic Plains are under threat of a significant reduction in wheat yields (Ortiz et al., 2008). This area produces 90 million tons of wheat grain annually (about 14 to 15% of global wheat production). Climate projections based on a doubling of CO_2 using a CCM3 model downscaled to a 30 arc-second resolution as part of the WorldClim data set showed that there will be a 51% decrease in the most favorable and high yielding area due to heat stress. About 200 million people (using the current population) in this area whose food intake relies on crop harvests would experience adverse impacts.

Rice growing areas are also expected to shift with climate change throughout Asia. In Japan, increasing irrigation water temperature (1.6°C to 2.0°C) could lead to a northward shift of the isochrones of safe transplanting dates for rice seedlings (Ohta and Kimura, 2007). As a result, rice cultivation period will be prolonged by approximately 25 to 30 days. This will allow greater flexibility in the cropping season than at present, resulting in a reduction in the frequency of cool-summer damage in the northern districts. Sea level rise threatens coastal and deltaic rice production areas in Asia, such as those in Bangladesh and the Mekong River Delta (Wassmann et al., 2009b). For example, about 7% of Vietnam's agriculture land may be submerged due to 1-m sea level rise (Dasgupta et al., 2009). In Myanmar, saltwater intrusion due to sea level rise could also decrease rice yield (Wassmann et al., 2009b).

24.4.4.3.3. Fisheries and aquaculture

Asia dominates both capture fisheries and aquaculture (FAO, 2010). More than half of the global marine fish catch in 2008 was in the West Pacific and Indian Ocean, and the lower Mekong River basin supports the largest freshwater capture fishery in the world (Dudgeon, 2011). Fish production is also a vital component of regional livelihoods, with 85.5% of the world's fishers (28 m) and fish farmers (10 m) in Asia in 2008. Many more people fish part time. Fish catches in the Asian Arctic are relatively small, but important for local cultures and regional food security (Zeller et al., 2011).

Inland fisheries will continue to be vulnerable to a wide range of ongoing threats, including overfishing, habitat loss, water abstraction, drainage of wetlands, pollution, and dam construction, making the impacts of climate change hard to detect (see also Section 24.9.1). Most concerns have centered on rising water temperatures and the potential impacts of climate change on flow regimes, which in turn are expected to affect the reproduction of many fish species (Allison et al., 2009; Barange and Perry, 2009; Bezuijen, 2011; Dudgeon, 2011; see also Section 24.4.2.3). Sea level rise is expected to impact both capture fisheries and aquaculture production in river deltas (De Silva and Soto, 2009). For marine capture fisheries, Cheung et al. (2009, 2010) used a dynamic bioclimate envelope model to project the distributions of 1066 species of exploited marine fish and invertebrates for 2005–2055, based on the SRES A1B scenario and a stable-2000 CO_2 scenario. This analysis suggests that climate change may lead to a massive redistribution of fisheries catch potential, with large increases in high-latitude regions, including Asian Russia, and large declines in the tropics, particularly Indonesia. Other studies have made generally similar predictions, with climate change impacts on marine productivity expected to be large and negative in the tropics, in part because of the vulnerability of coral reefs to both warming and ocean acidification (see also Section 24.4.3.3), and large and positive in Arctic and sub-Arctic regions, because of sea ice retreat and poleward species shifts (*high confidence*; Sumaila et al., 2011; Blanchard et al., 2012; Doney et al., 2012). Predictions of a reduction in the average maximum body weight of marine fishes by 14 to 24% by 2050 under a high-emission scenario are an additional threat to fisheries (Cheung et al., 2013).

24.4.4.3.4. Future food supply and demand

WGII AR4 Section 10.4.1.4 was largely based on global models that included Asia. There are now a few quantitative studies in Asia and its individual countries. In general, these show that the risk of hunger, food insecurity, and loss of livelihood due to climate change will *likely* increase in some regions (*low evidence*, *medium agreement*).

Rice is a key staple crop in Asia and 90% or more of the world's rice production is from Asia. An Asia-wide study revealed that climate change scenarios (using 18 GCMs for A1B, 14 GCMs for A2, and 17 GCMs for B1) would reduce rice yield over a large portion of the continent (Masutomi et al., 2009). The most vulnerable regions were western Japan, eastern China, the southern part of the Indochina peninsula, and the northern part of South Asia. In Russia, climate change may also lead to "food production shortfall," which was defined as an event in which the annual potential (i.e., climate-related) production of the most important crops in an administrative region in a specific year falls below 50% of its climate-normal (1961–1990) average (Alcamo et al., 2007). The study shows that the frequency of shortfalls in five or more of the main crop growing regions in the same year is around 2 years per decade under normal climate but could climb to 5 to 6 years per decade in the 2070s, depending on the scenario and climate model (using the GLASS, Global Agro-Ecological Zones (GAEZ), and Water-Global Assessment and Prognosis (WaterGAP-2) models and ECHAM and HadCM3 under the A2 and B2 scenarios). The increasing shortfalls were attributed to severe droughts. The study estimated that the number of people living in regions that may experience one or more shortfalls each decade may grow to 82 to 139 million in the 2070s. Increasing frequency of extreme climate events will pose an increasing threat to the security of Russia's food system.

In contrast, climate change may provide a windfall for wheat farmers in parts of Pakistan. Warming temperatures would make it possible to grow at least two crops (wheat and maize) a year in mountainous areas (Hussain and Mudasser, 2007). In the northern mountainous areas, wheat yield was projected to increase by 50% under SRES A2 and by 40% under the B2 scenario, whereas in the sub-mountainous, semiarid, and arid areas, it is *likely* to decrease by the 2080s (Iqbal et al., 2009).

24.4.4.4. Vulnerabilities to Key Drivers

Food production and food security are most vulnerable to rising air temperatures (Wassmann et al., 2009a,b). Warmer temperatures could depress yields of major crops such as rice. However, warmer temperatures could also make some areas more favorable for food production (Lioubimtseva and Henebry, 2009). Increasing CO_2 concentration in the atmosphere could lead to higher crop yields (Tao and Zhang, 2013a). Sea level rise will be a key issue for many coastal areas as rich agricultural lands may be submerged and taken out of production (Wassmann et al., 2009b).

24.4.4.5. Adaptation Options

Since AR4, there have been additional studies of recommended and potential adaptation strategies and practices in Asia (Table SM24-7) and there is new information for West and Central Asia. There are also many more crop-specific and country-specific adaptation options available. Farmers have been adapting to climate risks for generations. Indigenous and local adaptation strategies have been documented for

Southeast Asia (Peras et al., 2008; Lasco et al., 2010, 2011) and could be used as a basis for future climate change adaptation. Crop breeding for high temperature conditions is a promising option for climate change adaptation in Asia. For example, in the North China Plain, simulation studies show that using high-temperature sensitive varieties, maize yield in the 2050s could increase on average by 1.0 to 6.0%, 9.9 to 15.2%, and 4.1 to 5.6%, by adopting adaptation options of early planting, fixing variety growing duration, and late planting, respectively (Tao and Zhang, 2010). In contrast, no adaptation will result in yield declines of 13.2 to 19.1%.

24.4.5. Human Settlements, Industry, and Infrastructure

24.4.5.1. Sub-regional Diversity

Around one in every five urban dwellers in Asia lives in large urban agglomerations and almost 50% of these live in small cities (UN DESA Population Division, 2012). North and Central Asia are the most urbanized areas, with more than 63% of the population living in urban areas, with the exception of Kyrgyzstan and Tajikistan (UN-HABITAT, 2010; UN ESCAP, 2011). South and Southwest Asia are the least urbanized sub-regions, with only a third of their populations living in urban areas. However, these regions have the highest urban population growth rates within Asia, at an average of 2.4% per year during 2005–2010 (UN ESCAP, 2011). By the middle of this century, Asia's urban population will increase by 1.4 billion and will account for more than 50% of the global population (UN DESA Population Division, 2012).

24.4.5.2. Observed Impacts

Asia experienced the highest number of weather- and climate-related disasters in the world during the period 2000–2008 and suffered huge economic losses, accounting for the second highest proportion (27.5%) of the total global economic loss (IPCC, 2012). Flood mortality risk is heavily concentrated in Asia. Severe floods in Mumbai in 2005 have been attributed to both climatic factors and non-climatic factors. Strengthened capacities to address the mortality risk associated with major weather-related hazards, such as floods, have resulted in a downward trend in mortality risk relative to population size, as in East Asia, where it is now a third of its 1980 level (UNISDR, 2011).

24.4.5.3. Projected Impacts

A large proportion of Asia's population lives in low elevation coastal zones that are particularly at risk from climate change hazards, including sea level rise, storm surges, and typhoons (see Sections 5.3.2.1, 8.2.2.5; Box CC-TC). Depending on region, half to two-thirds of Asia's cities with 1 million or more inhabitants are exposed to one or multiple hazards, with floods and cyclones most important (UN DESA Population Division, 2012).

24.4.5.3.1. Floodplains and coastal areas

Three of the world's five most populated cities (Tokyo, Delhi, and Shanghai) are located in areas with high risk of floods (UN DESA Population Division, 2012). Flood risk and associated human and material losses are heavily concentrated in India, Bangladesh, and China. At the same time, the East Asia region in particular is experiencing increasing water shortages, negatively affecting its socioeconomic, agricultural, and environmental conditions, which is attributed to lack of rains and high evapotranspiration, as well as over-exploitation of water resources (IPCC, 2012). Large parts of South, East, and Southeast Asia are exposed to a high degree of cumulative climate-related risk (UN-HABITAT, 2011). Asia has more than 90% of the global population exposed to tropical cyclones (IPCC, 2012; see Box CC-TC). Damage due to storm surge is sensitive to change in the magnitude of tropical cyclones. By the 2070s, the top Asian cities in terms of population exposure (including all environmental and socioeconomic factors) to coastal flooding are expected to be Kolkata, Mumbai, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai, Bangkok, Rangoon, and Hai Phòng (Hanson et al., 2011). The top Asian cities in terms of assets exposed are expected to be Guangzhou, Kolkata, Shanghai, Mumbai, Tianjin, Tokyo, Hong Kong, and Bangkok. Asia includes 15 of the global top 20 cities for projected population exposure and 13 of the top 20 for asset exposure.

24.4.5.3.2. Other issues in human settlements

Asia has a large—and rapidly expanding—proportion of the global urban exposure and vulnerability related to climate change hazards (see SREX Section 4.4.3). In line with the rapid urban growth and sprawl in many parts of Asia, the periurban interface between urban and rural areas deserves particular attention when considering climate change vulnerability (see also Section 18.4.1). Garschagen et al. (2011) find, for example, that periurban agriculturalists in the Vietnamese Mekong Delta are facing a multiple burden because they are often exposed to overlapping risks resulting from (1) socioeconomic transformations, such as land title insecurity and price pressures; (2) local biophysical degradation, as periurban areas serve as sinks for urban wastes; and (3) climate change impacts, as they do not benefit from the inner-urban disaster risk management measures. Nevertheless, the periurban interface is still underemphasized in studies on impacts, vulnerability, and adaptation in Asia.

Groundwater sources, which are affordable means of high-quality water supply in cities of developing countries, are threatened due to over-withdrawals. Aquifer levels have fallen by 20 to 50 m in cities such as Bangkok, Manila, and Tianjin and between 10 and 20 m in many other cities (UNESCO, 2012). The drop in groundwater levels often results in land subsidence, which can enhance hazard exposure due to coastal inundation and sea level rise, especially in settlements near the coast, and deterioration of groundwater quality. Cities susceptible to human-induced subsidence (developing country cities in deltaic regions with rapidly growing populations) could see significant increases in exposure (Nicholls et al., 2008). Settlements on unstable slopes or landslide-prone areas face increased prospects of rainfall-induced landslides (IPCC, 2012).

24.4.5.3.3. Industry and infrastructure

The impacts of climate change on industry include both direct impacts on industrial production and indirect impacts on industrial enterprises due to the implementation of mitigation activities (Li, 2008). The impact of climate change on infrastructure deterioration cannot be ignored, but can be addressed by changes to design procedures, including increases in cover thickness, improved quality of concrete, and coatings and barriers (Stewart et al., 2012). Climate change and extreme events may have a greater impact on large and medium-sized construction projects (Kim et al., 2007).

Estimates suggest that, by upgrading the drainage system in Mumbai, losses associated with a 1-in-100 year flood event today could be reduced by as much as 70% and, through extending insurance to 100% penetration, the indirect effects of flooding could be almost halved, speeding recovery significantly (Ranger et al., 2011). On the east coast of India, clusters of districts with poor infrastructure and demographic development are also the regions of maximum vulnerability. Hence, extreme events are expected to be more catastrophic in nature for the people living in these districts. Moreover, the lower the district is in terms of the infrastructure index and its growth, the more vulnerable it is to the potential damage from extreme events and hence people living in these regions are prone to be highly vulnerable (Patnaik and Narayanan, 2009). In 2008, the embankments on the Kosi River (a tributary of the Ganges) failed, displacing more than 60,000 people in Nepal and 3.5 million in India. Transport and power systems were disrupted across large areas. However, the embankment failure was not caused by an extreme event but represented a failure of interlinked physical and institutional infrastructure systems in an area characterized by complex social, political, and environmental relationships (Moench, 2010).

24.4.5.4. Vulnerabilities to Key Drivers

Disruption of basic services such as water supply, sanitation, energy provision, and transportation systems have implications for local economies and "strip populations of their assets and livelihoods," in some cases leading to mass migration (UN-HABITAT, 2010). Such impacts are not expected to be evenly spread among regions and cities, across sectors of the economy, or among socioeconomic groups. They tend to reinforce existing inequalities and disrupt the social fabric of cities and exacerbate poverty.

24.4.5.5. Adaptation Options

An ADB and UN report estimates that "about two-thirds of the $8 trillion needed for infrastructure investment in Asia and the Pacific between 2010 and 2020 will be in the form of new infrastructure, which creates tremendous opportunities to design, finance and manage more sustainable infrastructure" (UN ESCAP et al., 2012, p. 18). Adaptation measures that offer a "no regrets" solution are proposed for developing countries, "where basic urban infrastructure is often absent (e.g., appropriate drainage infrastructure), leaving room for actions that both increase immediate well-being and reduce vulnerability to future climate change" (Hallegatte and Corfee-Morlot, 2011). The role of urban planning and urban planners in adaptation to climate change impacts has been emphasized (Fuchs et al., 2011; IPCC, 2012; Tyler and Moench, 2012). The focus on solely adapting through physical infrastructure in urban areas requires complementary adaptation planning, management,

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Frequently Asked Questions

FAQ 24.3 | Who is most at risk from climate change in Asia?

People living in low-lying coastal zones and flood plains are probably most at risk from climate change impacts in Asia. Half of Asia's urban population lives in these areas. Compounding the risk for coastal communities, Asia has more than 90% of the global population exposed to tropical cyclones. The impact of such storms, even if their frequency or severity remains the same, is magnified for low-lying and coastal zone communities because of rising sea level (*medium confidence*). Vulnerability of many island populations is also increasing due to climate change impacts. Settlements on unstable slopes or landslide-prone areas, common in some parts of Asia, face increased likelihood of rainfall-induced landslides.

Asia is predominantly agrarian, with 58% of its population living in rural areas, of which 81% are dependent on agriculture for their livelihoods. Rural poverty in parts of Asia could be exacerbated due to negative impacts from climate change on rice production, and a general increase in food prices and the cost of living (*high confidence*).

Climate change will have widespread and diverse health impacts. More frequent and intense heat waves will increase mortality and morbidity in vulnerable groups in urban areas (*high confidence*). The transmission of infectious disease, such as cholera epidemics in coastal Bangladesh, and schistosomiasis in inland lakes in China, and diarrheal outbreaks in rural children will be affected as a result of warmer air and water temperatures and altered rain patterns and water flows (*medium confidence*). Outbreaks of vaccine-preventable Japanese encephalitis in the Himalayan region and malaria in India and Nepal have been linked to rainfall. Changes in the geographical distribution of vector-borne diseases, as vector species that carry and transmit diseases migrate to more hospitable environments, will occur (*medium confidence*). These effects will be most noted close to the edges of the current habitats of these species.

governance, and institutional arrangements to be able to deal with the uncertainty and unprecedented challenges implied by climate change (Revi, 2008; Birkmann et al., 2010; Garschagen and Kraas, 2011).

24.4.6. Human Health, Security, Livelihoods, and Poverty

24.4.6.1. Sub-regional Diversity

Although rapidly urbanizing, Asia is still predominantly an agrarian society, with 57.28% of its total population living in rural areas, of which 81.02% are dependent on agriculture for their livelihoods (FAOSTAT, 2011). Rural poverty is higher than urban poverty, reflecting the heavy dependence on natural resources that are directly influenced by changes in weather and climate (Haggblade et al., 2010; IFAD, 2010). Rural poverty is expected to remain more prevalent than urban poverty for decades to come (Ravallion et al., 2007). However, climate change will also affect urbanizing Asia, where the urban poor will be impacted indirectly, as evident from the food price rises in the Middle East and other areas in 2007–2008. Certain categories of urban dwellers, such as urban wage labor households, are particularly vulnerable (Hertel et al., 2010).

Agriculture has been identified as a key driver of economic growth in Asia (World Bank, 2007). Although economic growth was impressive in recent decades, there are still gaps in development compared to the rest of the world (World Bank, 2011). Southeast Asia is the third poorest performing region after sub-Saharan Africa and southern Asia in terms of the Human Development Indicators (UN DESA Statistics Division, 2009). Impacts on human security in Asia will manifest primarily through impacts on water resources, agriculture, coastal areas, resource-dependent livelihoods, and urban settlements and infrastructure, with implications for human health and well-being. Regional disparities on account of socioeconomic context and geographical characteristics largely define the differential vulnerabilities and impacts within countries in Asia (Thomas, 2008; Sivakumar and Stefanski, 2011).

24.4.6.2. Observed Impacts

24.4.6.2.1. Floods and health

Epidemics have been reported after floods and storms (Bagchi, 2007) as a result of decreased drinking water quality (Harris et al., 2008; Hashizume et al., 2008; Solberg, 2010; Kazama et al., 2012), mosquito proliferation (Pawar et al., 2008), and exposure to rodent-borne pathogens (Kawaguchi et al., 2008; Zhou et al., 2011) and the intermediate snail hosts of *Schistosoma* (Wu et al., 2008).

Contaminated urban flood waters have caused exposure to pathogens and toxic compounds, for example, in India and Pakistan (Sohan et al., 2008; Warraich et al., 2011).

Mental disorders and posttraumatic stress syndrome have also been observed in disaster-prone areas (Udomratn, 2008) and, in India, have been linked to age and gender (Telles et al., 2009). See also Section 11.4.2 for flood-attributable deaths.

24.4.6.2.2. Heat and health

The effects of heat on mortality and morbidity have been studied in many countries, with a focus on the elderly and people with cardiovascular and respiratory disorders (Kan et al., 2007; Guo et al., 2009; Huang et al., 2010). Associations between high temperatures and mortality have been shown for populations in India and Thailand (McMichael et al., 2008) and in several cities in East Asia (Kim et al., 2006; Chung et al., 2009). Several studies have analyzed the health effects of air pollution in combination with increased temperatures (Lee et al., 2007; Qian et al., 2010; Wong et al., 2010; Yi et al., 2010). Intense heat waves have been shown to affect outdoor workers in South Asia (Nag et al., 2007; Hyatt et al., 2010).

24.4.6.2.3. Drought and health

Dust storms in Southwest, Central, and East Asia result in increased hospital admissions and worsen asthmatic conditions, as well as causing skin and eye irritations (Griffin, 2007; Hashizume et al., 2010; Kan et al., 2012). Droughts may also lead to wildfires and smoke exposure, with increased morbidity and mortality, as observed in Southeast Asia (Johnston et al., 2012). Drought can also disrupt food security, increasing malnutrition (Kumar et al., 2005) and thus susceptibility to infectious diseases.

24.4.6.2.4. Water-borne diseases

Many pathogens and parasites multiply faster at higher temperatures. Temperature increases have been correlated with increased incidence of diarrheal diseases in East Asia (Huang et al., 2008; Zhang et al., 2008; Onozuka et al., 2010). Other studies from South and East Asia have shown an association between increased incidence of diarrhea and higher temperatures and heavy rainfall (Hashizume et al., 2007; Chou et al., 2010). Increasing coastal water temperatures correlated with outbreaks of systemic *Vibrio vulnificus* infection in Israel (Paz et al., 2007) and South Korea (Kim and Jang, 2010). Cholera outbreaks in coastal populations in South Asia have been associated with increased water temperatures and algal blooms (Huq et al., 2005). The El Niño-Southern Oscillation (ENSO) cycle and Indian Ocean Dipole have been associated with cholera epidemics in Bangladesh (Pascual et al., 2000; Rodó et al., 2002; Hashizume et al., 2011).

24.4.6.2.5. Vector-borne diseases

Increasing temperatures affect vector-borne pathogens during the extrinsic incubation period and shorten vector life-cycles, facilitating larger vector populations and enhanced disease transmission, while the vector's ability to acquire and maintain a pathogen tails off (Paaijmans et al., 2012). Dengue outbreaks in South and Southeast Asia are correlated with temperature and rainfall with varying time lags (Su, 2008; Hii et al., 2009; Hsieh and Chen, 2009; Shang et al., 2010; Sriprom et al., 2010; Hashizume et al., 2012). Outbreaks of vaccine-preventable Japanese encephalitis have been linked to rainfall in studies from the Himalayan region (Partridge et al., 2007; Bhattachan et al., 2009), and to rainfall and temperature in South and East Asia (Bi et al., 2007; Murty et al., 2010). Malaria prevalence is often influenced by non-climate variability factors, but studies from India and Nepal have found correlations with rainfall (Devi and Jauhari, 2006; Dev and Dash, 2007; Dahal, 2008; Laneri et al., 2010). Temperature was linked to distribution and seasonality of malaria mosquitoes in Saudi Arabia (Kheir et al., 2010). The reemergence of malaria in central China has been attributed to rainfall and increases in temperature close to water bodies (Zhou et al., 2010). In China, temperature, precipitation, and the virus-carrying index among rodents have been found to correlate with the prevalence of hemorrhagic fever with renal syndrome (Guan et al., 2009).

24.4.6.2.6. Livelihoods and poverty

An estimated 51% of total income in rural Asia comes from non-farm sources (Haggblade et al., 2009, 2010), mostly local non-farm business and employment. The contribution of remittances to rural income has grown steadily (Estudillo and Otsuka, 2010). Significant improvements have been made in poverty eradication over the past decade (World Bank, 2007), with rapid reductions in poverty in East Asia, followed by South Asia (IFAD, 2010). A significant part of the reduction has come from population shifts, rapid growth in agriculture, and urban contributions (Janvry and Sadoulet, 2010). Climate change negatively impacts livelihoods (see Table SM24-4) and these impacts are directly related to natural resources affected by changes in weather and climate. Factors that have made agriculture less sustainable in the past include input non-responsive yields, soil erosion, natural calamities, and water and land quality related problems (Dev, 2011). These have predisposed rural livelihoods to climate change vulnerability. Livelihoods are impacted by droughts (Selvaraju et al., 2006; Harshita, 2013), floods (Nguyen, 2007; Keskinen et al., 2010; Nuorteva et al., 2010; Dun, 2011), and typhoons (Huigen and Jens, 2006; Gaillard et al., 2007; Uy et al., 2011). Drought disproportionately impacts small farmers, agricultural laborers, and small businessmen (Selvaraju et al., 2006), who also have least access to rural safety net mechanisms, including financial services (IFAD, 2010), despite recent developments in microfinance services in parts of Asia. Past floods have exposed conditions such as lack of access to alternative livelihoods, difficulty in maintaining existing livelihoods, and household debts leading to migration in the Mekong region (Dun, 2011). Similar impacts of repeated floods leading to perpetual vulnerability were found in the Tonle Sap Lake area of Cambodia (Nuorteva et al., 2010; Keskinen et al., 2010). Typhoon impacts are mainly through damage to the livelihood assets of coastal populations in the Philippines and the level of ownership of livelihood assets has been a major determinant of vulnerability (Uy et al., 2011).

24.4.6.3. Projected Impacts

24.4.6.3.1. Health effects

An emerging public health concern in Asia is increasing mortality and morbidity due to heat waves. An aging population will increase the number of people at risk, especially those with cardiovascular and respiratory disorders. Urban heat island effects have increased (Tan et al., 2010), although local adaptation of the built environment and urban planning will determine the impacts on public health. Heat stress disorders among workers and consequent productivity losses have also been reported (Lin et al., 2009; Langkulsen et al., 2010). The relationship between temperature and mortality is often U-shaped (Guo et al., 2009), with increased mortality also during cold events, particularly in rural environments, even if temperatures do not fall below 0°C (Hashizume et al., 2009). However, some studies in developing areas suggest that factors other than climate can be important, so warming may not decrease cold-related deaths much in these regions (Honda and Ono, 2009).

Climate change will affect the local transmission of many climate-sensitive diseases. Increases in heavy rain and temperature are projected to increase the risk of diarrheal diseases in, for example, China (Zhang et al., 2008). However, the impact of climate change on malaria risk will differ between areas, as projected for West and South Asia (Husain and Chaudhary, 2008; Garg et al., 2009; Majra and Gur, 2009), while a study suggested that the impact of socioeconomic development will be larger than that of climate change (Béguin et al., 2011).

Climate change is also expected to affect the spatiotemporal distribution of dengue fever in the region, although the level of evidence differs across geographical locations (Banu et al., 2011). Some studies have developed climate change-disease prevalence models; for example, one for schistosomiasis in China shows an increased northern distribution of the disease with climate change (Zhou et al., 2008; Kan et al., 2012). Impacts of climate change on fish production (Qiu et al., 2010) are being studied, along with impacts on chemical pathways in the marine environment and consequent impacts on food safety (Tirado et al., 2010), including seafood safety (Marques et al., 2010).

24.4.6.3.2. Livelihood and poverty

Floods, droughts, and changes in seasonal rainfall patterns are expected to negatively impact crop yields, food security, and livelihoods in vulnerable areas (Dawe et al., 2008; Kelkar et al., 2008; Douglas, 2009). Rural poverty in parts of Asia could be exacerbated (Skoufias et al., 2011) as a result of impacts on the rice crop and increases in food prices and the cost of living (Hertel et al., 2010; Rosegrant, 2011). The poverty impacts of climate change will be heterogeneous among countries and social groups (see Table SM24-5). In a low crop productivity scenario, producers in food exporting countries, such as Indonesia, the Philippines, and Thailand, would benefit from global food price rises and reduce poverty, while countries such as Bangladesh would experience a net increase in poverty of approximately 15% by 2030 (Hertel et al., 2010). These impacts will also differ within food exporting countries, with disproportionate negative impacts on farm laborers and the urban poor. Skoufias et al. (2011) project significant negative impacts of a rainfall shortfall on the welfare of rice farmers in Indonesia, compared to a delay in rainfall onset. These impacts may lead to global mass migration and related conflicts (Laczko and Aghazarm, 2009; Barnett and Webber, 2010; Warner, 2010; World Bank, 2010).

In North Asia, climate-driven changes in tundra and forest-tundra biomes may influence indigenous peoples who depend on nomadic tundra pastoralism, fishing, and hunting (Kumpula et al., 2011).

24.4.6.4. Vulnerabilities to Key Drivers

Key vulnerabilities vary widely within the region. Climate change can exacerbate current socioeconomic and political disparities and add to the vulnerability of Southeast Asia and Central Asia to security threats that may be transnational in nature (Jasparro and Taylor, 2008; Lioubimtseva and Henebry, 2009). Apart from detrimental impacts of extreme events, vulnerability of livelihoods in agrarian communities also arises from geographic settings, demographic trends, socioeconomic factors, access to resources and markets, unsustainable water consumption, farming practices, and lack of adaptive capacity (Acosta-Michlik and Espaldon, 2008; Allison et al., 2009; Byg and Salick, 2009; Lioubimtseva and Henebry, 2009; Salick and Ross, 2009; Salick et al., 2009; UN DESA Statistics Division, 2009; Xu et al., 2009; Knox et al., 2011; Mulligan et al., 2011). Urban wage laborers were found to be more vulnerable to cost of living related poverty impacts of climate change than those who directly depend on agriculture for their livelihoods (Hertel et al., 2010). In Indonesia, drought-associated fires increase vulnerability of agriculture, forestry, and human settlements, particularly in peatland areas (Murdiyarso and Lebel, 2007). Human health is also a major area of focus for Asia (Munslow and O'Dempsey, 2010), where the magnitude and type of health effects from climate change depend on differences in socioeconomic and demographic factors, health systems, the natural and built environment, land use changes, and migration, in relation to local resilience and adaptive capacity. The role of institutions is also critical, particularly in influencing vulnerabilities arising from gender (Ahmed and Fajber, 2009), caste and ethnic differences (Jones and Boyd, 2011), and securing climate-sensitive livelihoods in rural areas (Agrawal and Perrin, 2008).

24.4.6.5. Adaptation Options

Disaster preparedness on a local community level could include a combination of indigenous coping strategies, early-warning systems, and adaptive measures (Paul and Routray, 2010). Heat warning systems have been successful in preventing deaths among risk groups in Shanghai (Tan et al., 2007). New work practices to avoid heat stress among outdoor workers in Japan and the United Arab Emirates have also been successful (Morioka et al., 2006; Joubert et al., 2011). Early warning models have been developed for haze exposure from wildfires, in, for example, Thailand (Kim Oanh and Leelasakultum, 2011), and are being tested in infectious disease prevention and vector control programs, as for malaria in Bhutan (Wangdi et al., 2010) and Iran (Haghdoost et al., 2008), or are being developed, as for dengue fever region-wide (Wilder-Smith et al., 2012).

Some adaptation practices provide unexpected livelihood benefits, as with the introduction of traditional flood mitigation measures in China, which could positively impact local livelihoods, leading to reductions in both the physical and economic vulnerabilities of communities (Yu et al., 2009). A greater role of local communities in decision making is also proposed (Alauddin and Quiggin, 2008) and in prioritization and adoption of adaptation options (Prabhakar et al., 2010; Prabhakar and Srinivasan, 2011). Defining adequate community property rights, reducing income disparity, exploring market-based and off-farm livelihood options, moving from production-based approaches to productivity and efficiency decision-making based approaches, and promoting integrated decision-making approaches have also been suggested (Merrey et al., 2005; Brouwer et al., 2007; Paul et al., 2009; Niino, 2011; Stucki and Smith, 2011).

Climate-resilient livelihoods can be fostered through the creation of bundles of capitals (natural, physical, human, financial, and social capital) and poverty eradication (Table SM24-8). Greater emphasis on agricultural growth has been suggested as an effective means of reducing rural poverty (Janvry and Sadoulet, 2010; Rosegrant, 2011). Bundled approaches are known to facilitate better adaptation than individual adaptation options (Acosta-Michlik and Espaldon, 2008; Fleischer et al., 2011). Community-based approaches have been suggested to identify adaptation options that address poverty and livelihoods, as these techniques help capture information at the grassroots (Huq and Reid, 2007; van Aalst et al., 2008), and help integration of disaster risk reduction, development, and climate change adaptation (Heltberg et al., 2010), connect local communities and outsiders (van Aalst et al., 2008), address the location-specific nature of adaptation (Iwasaki et al., 2009; Rosegrant, 2011), help facilitate community learning processes (Baas and Ramasamy, 2008), and help design location-specific solutions (Ensor and Berger, 2009). Some groups can become more vulnerable to change after being "locked into" specialized livelihood patterns, as with fish farmers in India (Coulthard, 2008).

Livelihood diversification, including livelihood assets and skills, has been suggested as an important adaptation option for buffering climate change impacts on certain kinds of livelihoods (Selvaraju et al., 2006; Nguyen, 2007; Agrawal and Perrin, 2008; IFAD, 2010; Keskinen et al., 2010; Uy et al., 2011). The diversification should occur across assets, including productive assets, consumption strategies, and employment opportunities (Agrawal and Perrin, 2008). Ecosystem-based adaptation has been suggested to secure livelihoods in the face of climate change (Jones et al., 2012), integrating the use of biodiversity and ecosystem services into an overall strategy to help people adapt (IUCN, 2009). Among financial means, low-risk liquidity options such as microfinance programs and risk transfer products can help lift the rural poor from poverty and accumulate assets (Barrett et al., 2007; Jarvis et al., 2011).

24.4.7. Valuation of Impacts and Adaptation

Economic valuation in Asia generally covers impacts and vulnerabilities of disperse sectors such as food production, water resources, and human health (Aydinalp and Cresser, 2008; Kelkar et al., 2008; Lioubimtseva and Henebry, 2009; Su et al., 2009; Srivastava et al., 2010). Multi-sector evaluation that unpacks the relationships between and across sectors, particularly in a context of resource scarcity and competition, is very limited. Information is scarce especially for North, Central, and West Asia.

Generally, annual losses from drought are expected to increase based on various projections under diverse scenarios, but such losses are expected to be reduced if adaptation measures are implemented (ADB, 2009; Sutton et al., 2013). It is also stressed that there are great uncertainties associated with the economic aspects of climate change. In China, the total loss due to drought projected in 2030 is expected to range from US$1.1 to 1.7 billion for regions in northeast China and about US$0.9 billion for regions in north China (ECA, 2009), with adaptation measures having the potential to avert half of the losses. In India, the estimated countrywide agricultural loss in 2030—more than US$7 billion, which will severely affect the income of 10% of the population—could be reduced by 80% if cost-effective climate resilience measures are implemented (ECA, 2009).

In Indonesia, the Philippines, Thailand, and Vietnam, under the A2 scenario, the Policy Analysis for the Greenhouse Effect 2002 (PAGE2002) integrated assessment model projects a mean loss of 2.2% of GDP by 2100 on an annual basis, if only the market impact (mainly related to agriculture and coastal zones) is considered (ADB, 2009). This is well above the world's projected mean GDP loss of 0.6% each year by 2100 due to market impact alone. In addition, the mean cost for the four countries could reach 5.7% of GDP if non-market impacts related to health and ecosystems are included and 6.7% of GDP if catastrophic risks are also taken into account. The cost of adaptation for agriculture and coastal zones is expected to be about US$5 billion per year by 2020 on average. Adaptation that is complemented with global mitigation measures is expected to be more effective in reducing the impacts of climate change (IPCC, 2007; ADB, 2009; UNFCCC, 2009; MNRE, 2010; Begum et al., 2011).

24.5. Adaptation and Managing Risks

24.5.1. Conservation of Natural Resources

Natural resources are already under severe pressure from land use change and other impacts in much of Asia. Deforestation in Southeast Asia has received most attention (Sodhi et al., 2010; Miettinen et al., 2011a), but ecosystem degradation, with the resulting loss of natural goods and services, is also a major problem in other ecosystems. Land use change is also a major source of regional greenhouse gas emissions, particularly in Southeast Asia (see WGI AR5 Section 6.3.2.2, Table 6.3). Projected climate change is expected to intensify these pressures in many areas (see Sections 24.4.2.3, 24.4.3.3), most clearly for coral reefs, where increases in sea surface temperature and ocean acidification are a threat to all reefs in the region and the millions of people who depend on them (see Section 5.4.2.4; Boxes CC-CR, CC-OA). Adaptation has so far focused on minimizing non-climate pressures on natural resources and restoring connectivity to allow movements of genes and species between fragmented populations (see Section 24.4.2.5). Authors have also suggested a need to identify and protect areas that will be subject to the least damaging climate change ("climate refugia") and to identify additions to the protected area network that will allow for expected range shifts, for example, by extending protection to higher altitudes or latitudes. Beyond the intrinsic value of wild species and ecosystems, ecosystem-based approaches to adaptation aim to use the resilience of natural systems to buffer human systems against climate change, with potential social, economic, and cultural co-benefits for local communities (see Box CC-EA).

24.5.2. Flood Risks and Coastal Inundation

Many coasts in Asia are exposed to threats from floods and coastal inundation (see also Section 24.4.5.3). Responding to a large number of climate change impact studies for each Asian country over the past decade (e.g., Karim and Mimura, 2008; Pal and Al-Tabbaa, 2009), various downscaled tools to support, formulate, and implement climate change adaptation policy for local governments are under development. One of the major tools is vulnerability assessment and policy option identification with Geographical Information Systems (GIS). These tools are expected to be of assistance in assessing city-specific adaptation options by examining estimated impacts and identified vulnerability for some coastal cities and areas in Asian countries (e.g., Brouwer et al., 2007; Taylor, 2011; Storch and Downes, 2011). These tools and systems sometimes take the form of integration of top-down approaches and bottom-up (community-based) approaches (see Section 14.5). Whereas top-down approaches give scientific knowledge to local actors, community-based approaches are built on existing knowledge and expertise to strengthen coping and adaptive capacity by involving local actors (van Aalst et al., 2008). Community-based approaches may have a limitation in that they place greater responsibility on the shoulders of local people without necessarily increasing their capacity proportionately (Allen, 2006). As the nature of adaptive capacity varies depending on the formulation of social capital and institutional context in the local community, it is essential for the approaches to be based on an understanding of local community structures (Adger, 2003).

24.5.3. Economic Growth and Equitable Development

Climate change challenges fundamental elements in social and economic policy goals such as prosperity, growth, equity, and sustainable development (Mearns and Norton, 2010). Economic, social, and environmental equity is an enduring challenge in many parts of Asia. Generally, the level of wealth (typically GDP) has been used as a measure of human vulnerability of a country but this approach has serious limitations (Dellink et al., 2009; Mattoo and Subramanian, 2012). In many cases, social capital—an indicator of equity in income distribution within countries—is a more important factor in vulnerability and resilience than GDP per capita (Islam et al., 2006; Lioubimtseva and Henebry, 2009). Furthermore, political and institutional instabilities can undermine the influence of economic development (Lioubimtseva and Henebry, 2009). Poor and vulnerable countries are at greater risk of inequity and loss of livelihoods from the impacts of climate extremes as their options for coping with such events are limited. Many factors contribute to this limitation, including poverty, illiteracy, weak institutions and infrastructures, poor access to resources, information and technology, poor health care, and low investment and management capabilities. The overexploitation of land resources including forests, increases in population, desertification, and land degradation pose additional threats (UNDP, 2006). This is particularly true for developing countries in Asia with a high level of natural resource dependency. Provision of adequate resources based on the burden sharing and the equity principle will serve to strengthen appropriate adaptation policies and measures in such countries (Su et al., 2009).

24.5.4. Mainstreaming and Institutional Barriers

Mainstreaming climate change adaptation into sustainable development policies offers a potential opportunity for good practice to build resilience and reduce vulnerability, depending on effective, equitable, and legitimate actions to overcome barriers and limits to adaptation (ADB, 2005; Lim et al., 2005; Lioubimtseva and Henebry, 2009). The level of adaptation mainstreaming is most advanced in the context of official development assistance, where donor agencies and international financial institutions have made significant steps toward taking climate change adaptation into account in their loan and grant making processes (Gigli and Agrawala, 2007; Klein et al., 2007). Although some practical experiences of adaptation in Asia at the regional, national, and local level are emerging, there can be barriers that impede or limit adaptation. These include challenges related to competing national priorities, awareness and capacity, financial resources for adaptation implementation, institutional barriers, biophysical limits to ecosystem adaptation, and social and cultural factors (Lasco et al., 2009, 2012; Moser and Ekstrom, 2010). Issues with resource availability might not only result from climate change, but also from weak governance mechanisms and the breakdown of policy and regulatory structures, especially with common-pool resources (Moser and Ekstrom, 2010). Furthermore, the impact of climate change depends on the inherent vulnerability of the socio-ecological systems in a region as much as on the magnitude of the change (Evans, 2010). Recent studies linking climate-related resource scarcities and conflict call for enhanced regional cooperation (Gautam, 2012).

24.5.5. Role of Higher Education in Adaptation and Risk Management

To enhance the development of young professionals in the field of climate change adaptation, the topic could be included in higher education, especially in formal education programs. Shaw et al. (2011) mentioned that higher education in adaptation and disaster risk reduction in the Asia-Pacific region can be done through environment disaster linkage, focus on hydro-meteorological disasters, and emphasizing synergy issues between adaptation and risk reduction. Similar issues are also highlighted by other authors (Chhokar, 2010; Niu et al., 2010; Nomura and Abe, 2010; Ryan et al., 2010). Higher education should be done through lectures and course work, field studies, internships, and establishing the education-research link by exposing students to field realities. In this regard, guiding principles could include an inclusive curriculum, focus on basic theory, field orientation, multidisciplinary courses, and practical skill enhancement. Bilateral or multilateral practical research programs on adaptation and risk management by graduate students and young faculty members would expose them to real field problems.

24.6. Adaptation and Mitigation Interactions

Integrated mitigation and adaptation responses focus on either land use changes or technology development and use. Changes in land use, such as agroforestry, may provide both mitigation and adaptation benefits (Verchot et al., 2007), or otherwise, depending on how they are implemented. Agroforestry practices provide carbon storage and may decrease soil erosion, increase resilience against floods, landslides, and drought, increase soil organic matter, reduce the financial impact of crop failure, as well as have biodiversity benefits over other forms of agriculture, as shown, for example, in Indonesia (Clough et al., 2011). Integrated approaches are often needed when developing mitigation-adaptation synergies, as seen in waste-to-compost projects in Bangladesh (Ayers and Huq, 2009). Other adaptation measures that increase biomass and/or soil carbon content, such as ecosystem protection and reforestation, will also contribute to climate mitigation by carbon sequestration. However, exotic monocultures may fix more carbon than native mixtures while supporting less biodiversity and contributing less to ecological services, calling for compromises that favor biodiversity-rich carbon storage (Diaz et al., 2009). The potential for both adaptation and mitigation through forest restoration is greatest in the tropics (Sasaki et al., 2011). At higher latitudes (>45°N), reforestation can have a net warming influence by reducing surface albedo (Anderson-Teixeira et al., 2012). Expansion of biofuel crops on abandoned and marginal agricultural lands could potentially make a large contribution to mitigation of carbon emissions from fossil fuels, but could also have large negative consequences for both carbon and biodiversity if it results directly or indirectly in the conversion of carbon-rich ecosystems to cropland (Fargione et al., 2010; Qin et al., 2011). Mechanisms, such as Reduction of Emissions from Deforestation and Forest Degradation (REDD+), that put an economic price on land use emissions, could reduce the risks of such negative consequences (Thomson et al., 2010), but the incentive structures need to be worked out very carefully (Busch et al., 2012).

Forests and their management are also often emphasized for providing resilient livelihoods and reducing poverty (Chhatre and Agrawal, 2009; Noordwijk, 2010; Persha et al., 2010; Larson, 2011). Securing rights to resources is essential for greater livelihood benefits for poor indigenous and traditional people (Macchi et al., 2008) and the need for REDD+ schemes to respect and promote community forest tenure rights has been emphasized (Angelsen, 2009). It has been suggested that indigenous people can provide a bridge between biodiversity protection and climate change adaptation (Salick and Ross, 2009): a point that appears to be missing in the current discourse on ecosystem-based adaptation. There are arguments against REDD+ supporting poverty reduction due to its inability to promote productive use of forests, which may keep communities in perpetual poverty (Campbell, 2009), but there is a contrasting view that REDD+ can work in forests managed for timber production (Guariguata et al., 2008; Putz et al., 2012), especially through reduced impact logging (Guariguata et al., 2008) and other approaches such as assuring the legality of forest products, certifying responsible management, and devolving control over forests to empowered local communities (Putz et al., 2012).

On rivers and coasts, the use of hard defenses (e.g., channelization, sea walls, bunds, dams) to protect agriculture and human settlements from flooding may have negative consequences for both natural ecosystems and carbon sequestration by preventing natural adjustments to changing conditions (see Section 24.4.3.5). Conversely, setting aside landward buffer zones along coasts and rivers would be positive for both. The very high carbon sequestration potential of the organic-rich soils in mangroves (Donato et al., 2011) and peat swamp forests (Page et al., 2011) provides opportunities for combining adaptation with mitigation through restoration of degraded areas.

Mitigation measures can also result in public health benefits (Bogner et al., 2008; Haines et al., 2009). For example, sustainable cities with fewer fossil fuel-driven vehicles (mitigation) and more trees and greenery (carbon storage and adaptation to the urban heat island effect) would have a number of co-benefits, including public health—a promising strategy for "triple win" interventions (Romero-Lankao et al., 2011). Other examples include efforts to decarbonize electricity production in India and China that are projected to decrease mortality due to reduced particulate matter with aerodynamic diameter <5 μm (PM_5) and <2.5 μm ($PM_{2.5}$) (Markandya et al., 2009); policies to increase public transportation, promote walking and cycling, and reduce private cars that will increase air quality and decrease the health burden, particularly in urban environments as projected in India (Woodcock et al., 2009); and abandoning the use of biomass fuel or coal for indoor cooking and heating to improve indoor air quality and respiratory and cardiac health among, in particular, women and children in India and China (Wilkinson et al., 2009). Conversely, actions to reduce current environmental-public health issues may often have beneficial mitigation effects, like traffic emissions reduction programs in China (Wu et al., 2011) and India (Reynolds and Kandikar, 2008).

24.7. Intra-regional and Inter-regional Issues

24.7.1. Transboundary Pollution

Many Asian countries and regions face long-distance and transboundary air pollution problems. In eastern China, Japan, and the Korean Peninsula, these include dust storms that originate in the arid and semiarid regions upwind, with impacts on climate, human health, and ecosystems (Huang et al., 2013). The susceptibility of the land surface to wind erosion is strongly influenced by vegetation cover, which is in turn sensitive to climate change and other human impacts. In the humid tropics of Southeast Asia, in contrast, the major transboundary pollution issue involves smoke aerosols from burning of biomass and peatlands, mostly during clearance for agriculture (Miettinen et al., 2011b; Gautam et al., 2013). Apart from the large impact on human health, these aerosols may be having a significant effect on rainfall in equatorial regions, leading to the possibility of climate feedbacks, with fires reducing rainfall and promoting further fires (Tosca et al., 2012).

Pollutants of industrial origin are also a huge problem in many parts of the region, with well-documented impacts on human health (Section 24.4.6) and the climate (see WGI AR5 Chapters 7, 8).

24.7.2. Trade and Economy

The ASEAN Free Trade Agreement (AFTA) and the Indonesia-Japan Economic Partnership Agreement (IJEPA) have positively impacted the Indonesian economy and reduced water pollution, but increased CO_2 emissions by 0.46% compared to the business-as-usual situation, mainly due to large emission increases in the transportation sector (Gumilang et al., 2011). Full liberalization of tariffs and GDP growth concentrated in China and India have led to transport emissions growing much faster than the value of trade, as result of a shift toward distant trading partners (Cristea et al., 2013). China's high economic growth and flourishing domestic and international trade has resulted in increased consumption and pollution of water resources (Guan and Hubacek, 2007). Japanese imports from the ASEAN region are negatively correlated with per capita carbon emissions (Atici, 2012) owing to strict regulations in Japan that prevent import from polluting sectors. Export-led growth is central to the economic progress and well-being of Southeast Asian countries. Generally, as exports rise, carbon emissions tend to rise. International trading systems that help address the challenge of climate change need further investigation.

24.7.3. Migration and Population Displacement

Floods and droughts are predominant causes for internal displacement (IDMC, 2011). In 2010 alone, 38.3 million people were internally displaced: 85% because of hydrological hazards and 77% in Asia. Floods are increasingly playing a role in migration in the Mekong Delta (Warner, 2010). Often some migrants return to the vulnerable areas (Piguet, 2008) giving rise to ownership, rights of use, and other issues (Kolmannskog, 2008). Increasing migration has led to increasing migration-induced remittances contributing to Asian economies, but has had negligible effect on the poverty rate (Vargas-Silva et al., 2009). In Bangladesh, migrant workers live and work under poor conditions, such as crowded shelters, inadequate sanitation, conflict and competition with the local population, and exploitation (Penning-Rowsell et al., 2011). Forced migration can result from adaptation options such as construction of dams, but the negative outcomes could be allayed by putting proper safeguards in place (Penning-Rowsell et al., 2011). Managed retreat of coastal communities is a suggested option to address projected sea level rise (Alexander et al., 2012). A favorable approach to deal with migration is within a development framework and through adaptation strategies (Penning-Rowsell et al., 2011; ADB, 2012).

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24.8. Research and Data Gaps

Studies of observed climate changes and their impacts are still inadequate for many areas, particularly in North, Central, and West Asia (Table 24-2). Improved projections for precipitation, and thus water supply, are most urgently needed. Another priority is developing water management strategies for adaptation to changes in demand and supply. More research is also needed on the health effects of changes in water quality and quantity. Understanding of climate change impacts on ecosystems and biodiversity in Asia is currently limited by the poor quality and low accessibility of biodiversity information (UNEP, 2012). National biodiversity inventories are incomplete and few sites have the baseline information needed to identify changes. For the tropics, major research gaps include the temperature dependence of carbon fixation by tropical trees, the thermal tolerances and acclimation capacities of both plants and animals, and the direct impacts of rising CO_2 (Corlett, 2011; Zuidema et al., 2013). Rising CO_2 is also expected to be important in cool-arid ecosystems, where lack of experimental studies currently limits ability to make predictions (Poulter et al., 2013). Boreal forest dynamics will be influenced by complex interactions between rising temperatures and CO_2, permafrost thawing, forest fires, and insect outbreaks (Osawa et al., 2010; Zhang et al., 2011), and understanding this complexity will require enhanced monitoring of biodiversity and species ranges, improved modeling, and greater knowledge of species biology (Meleshko and Semenov, 2008).

Rice is the most studied crop but there are still significant uncertainties in model accuracy, CO_2-fertilization effects, and regional differences (Masutomi et al., 2009; Zhang et al., 2010; Shuang-He et al., 2011). For other crops, there is even greater uncertainty. Studies are also needed of the health effects of interactions between heat and air pollution in urban and rural environments.

More generally, research is needed on impacts, vulnerability, and adaptation in urban settlements, especially cities with populations of less than 500,000, which share half the region's urban population. Greater understanding is required of the linkages between local livelihoods, ecosystem functions, and land resources for creating a positive impact on livelihoods in areas with greater dependence on natural resources (Paul et al., 2009). Increasing regional collaboration in scientific research and policy making has been suggested for reducing climate change impacts on water, biodiversity, and livelihoods in the Himalayan region (Xu et al., 2009) and could be considered elsewhere. The literature suggests that work must begin now on building understanding of the impacts of climate change and moving forward with the most cost-effective adaptation measures (ADB, 2007; Cai et al., 2008; Stage, 2010).

For devising mitigation policies, the key information needed is again the most cost-effective measures (Nguyen, 2007; Cai et al., 2008; Mathy and Guivarch, 2010).

Table 24-2 | The amount of information supporting conclusions regarding observed and projected impacts in Asia.

Sector	Topics/issues	North Asia		East Asia		Southeast Asia		South Asia		Central Asia		West Asia	
	O = Observed impacts, P = Projected Impacts	O	P	O	P	O	P	O	P	O	P	O	P
Freshwater resources	Major river runoff	/	x	/	/	/	/	/	x	x	x	x	x
	Water supply	x	x	x	x	x	x	x	x	x	x	x	x
Terrestrial and inland water systems	Phenology and growth rates	/	/	/	/	x	x	x	x	x	x	x	x
	Distributions of species and biomes	/	/	/	/	x	x	x	/	x	x	x	x
	Permafrost	/	/	/	/	/	x	/	/	/	/	/	x
	Inland waters	x	x	/	x	x	x	x	x	x	x	x	x
Coastal systems and low-lying areas	Coral reefs	NR	NR	/	/	/	/	/	/	NR	NR	/	/
	Other coastal ecosystems	x	x	/	/	x	x	x	x	NR	NR	x	x
	Arctic coast erosion	/	/	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Food production systems and food security	Rice yield	x	x	/	/	x	/	x	/	x	x	X	/
	Wheat yield	x	x	x	x	x	x	x	/	x	x	/	/
	Corn yield	x	x	x	/	x	x	x	x	x	x	x	x
	Other crops (e.g., barley, potato)	x	x	/	/	x	x	x	x	x	X	/	/
	Vegetables	x	x	/	x	x	x	x	x	x	x	x	x
	Fruits	x	x	/	x	x	x	x	x	x	x	x	x
	Livestock	x	x	/	x	x	x	x	x	x	x	x	x
	Fisheries and aquaculture production	x	/	x	/	x	/	x	x	x	x	x	x
	Farming area	x	/	x	/	x	x	x	/	x	/	x	x
	Water demand for irrigation	x	/	x	/	x	x	x	/	x	x	x	x
	Pest and disease occurrence	x	x	x	x	x	x	x	/	x	x	x	x
Human settlements, industry, and infrastructure	Floodplains	x	x	/	/	/	/	/	/	x	x	x	x
	Coastal areas	x	x	/	/	/	/	/	/	NR	NR	x	x
	Population and assets	x	x	/	/	/	/	/	/	x	x	x	x
	Industry and infrastructure	x	x	/	/	/	/	/	/	x	x	x	x
Human health, security, livelihoods, and poverty	Health effects of floods	x	x	x	x	x	x	/	x	x	x	x	x
	Health effects of heat	x	x	/	x	x	x	x	x	x	x	x	x
	Health effects of drought	x	x	x	x	x	x	x	x	x	x	x	x
	Water-borne diseases	x	x	x	x	/	x	/	x	x	x	x	x
	Vector-borne diseases	x	x	x	x	/	x	/	x	x	x	x	x
	Livelihoods and poverty	x	x	/	x	x	x	/	x	x	x	x	x
	Economic valuation	x	x	x	x	/	/	/	/	x	x	x	x

Key:
/ = Relatively abundant/sufficient information; knowledge gaps need to be addressed but conclusions can be drawn based on existing information.
x = Limited information/no data; critical knowledge gaps, difficult to draw conclusions.
NR = Not relevant.

24.9. Case Studies

24.9.1. Transboundary Adaptation Planning and Management—Lower Mekong River Basin

The Lower Mekong River Basin (LMB) covers an area of approximately 606,000 km^2 across the countries of Thailand, Laos, Cambodia, and Vietnam. More than 60 million people are heavily reliant on natural resources, in particular agriculture and fisheries, for their well-being (MRC, 2009; UNEP, 2010; Figure SM24-2). Thailand and Vietnam produced 51% of the world's rice exports in 2008, mostly in the LMB (Mainuddin et al., 2011).

Observations of climate change over the past 30 to 50 years in the LMB include an increase in temperature, an increase in rainfall in the wet season and decreases in the dry season, intensified flood and drought events, and sea level rise (ICEM, 2010; IRG, 2010). Agricultural output has been noticeably impacted by intensified floods and droughts which caused almost 90% of rice production losses in Cambodia during 1996–2001 (Brooks and Adger, 2003; MRC, 2009). Vietnam and Cambodia are two of the countries most vulnerable to climate impacts on fisheries (Allison et al., 2009; Halls, 2009).

Existing studies about future climate impacts in the Mekong Basin broadly share a set of common themes (MRC, 2009; Murphy and Sampson, 2013): increased temperature and annual precipitation; increased depth and duration of flood in the Mekong Delta and Cambodia floodplain; prolonged agricultural drought in the south and the east of the basin; and sea level rise and salinity intrusion in the Mekong delta. Hydropower dams along the Mekong River and its tributaries will also have severe impacts on fish productivity and biodiversity, by blocking critical fish migration routes, altering the habitat of non-migratory fish species, and reducing nutrient flows downstream (Costanza et al., 2011; Baran and Guerin, 2012; Ziv et al., 2012). Climate impacts, though less severe than the impact of dams, will exacerbate these changes (Wyatt and Baird, 2007; Grumbine et al., 2012; Orr et al., 2012; Räsänen et al., 2012; Ziv et al., 2012).

National climate change adaptation plans have been formulated in all four LMB countries, but transboundary adaptation planning across the LMB does not exist to date. Effective future transboundary adaptation planning and management will benefit from: a shared climate projection across the LMB for transboundary adaptation planning; improved coordination among adaptation stakeholders and sharing of best practices across countries; mainstreaming climate change adaptation into national and sub-national development plans with proper translation from national adaptation strategies into local action plans; integration of transboundary policy recommendations into national climate change plans and policies; and integration of adaptation strategies on landscape scales between ministries and different levels of government within a country (MRC, 2009; Kranz et al., 2010; Lian and Bhullar, 2011; Lebel et al., 2012).

A study of the state-of-adaptation practice in the LMB showed that only 11% (45 of 417) of climate-change related projects in the LMB were on-the-ground adaptation efforts driven by climate risks (Ding, 2012; Neo, 2012; Schaffer and Ding, 2012). Common features of "successful" projects include: robust initial gap assessment, engagement of local stakeholders, and a participatory process throughout (Brown, 2012; Khim and Phearanich, 2012; Mondal, 2012; Panyakul, 2012; Roth and Grunbuhel, 2012). A multi-stakeholder Regional Adaptation Action Network has been proposed with the intent of scaling up and improving mainstreaming of adaptation through tangible actions following the theory and successful examples of the Global Action Networks (GANs) (WCD, 2000; Waddell, 2005; Waddell and Khagram, 2007; GAVI, 2012; Schaffer and Ding, 2012).

24.9.2. Glaciers of Central Asia

In the late 20th century, central Asian glaciers occupied 31,628 km^2 (Dolgushin and Osipova, 1989). All recent basin-scale studies document multi-decadal area loss (see Figure 24-3); where multiple surveys are available, most show accelerating loss. The rate of glacier area change varies (Table SM24-9). Rates between –0.05% yr^{-1} and –0.76% yr^{-1} have been reported in the Altai (Surazakov et al., 2007; Shahgedanova et al., 2010; Yao, X.-J. et al., 2012) and Tien Shan (Lettenmaier et al., 2009; Sorg et al., 2012), and between –0.13% yr^{-1} and–0.30% yr^{-1} in the Pamir (Konovalov and Desinov, 2007; Aizen, 2011a,b,c; Yao, X.-J. et al., 2012). These ranges reflect varying sub-regional distributions of glacier size (smaller glaciers shrink faster) and debris cover (which retards shrinkage), but also varying proportions of ice at high altitudes, where as yet warming has produced little increase in melt (Narama et al., 2010).

Most studies also document mean-annual (e.g., Glazyrin and Tadzhibaeva, 2011, for 1961–1990) and summertime (e.g., Shahgedanova et al., 2010) warming, with slight cooling in the central and eastern Pamir (Aizen, 2011b). Precipitation increases have been observed more often than decreases (e.g., Braun et al., 2009; Glazyrin and Tadzhibaeva, 2011).

Aizen et al. (2007) calculated 21st-century losses of 43% of the volume of Tien Shan glaciers for an 8°C temperature increase accompanied by a 24% precipitation increase, but probable complete disappearance of glaciers if precipitation decreased by 16%; a more moderate 2°C increase led to little loss, but only if accompanied by a 24% precipitation increase. Drawing on CMIP5 simulations, Radić et al. (2013) simulated losses by 2100 of between 25 and 90% of 2006 ice volume (including Tibet Autonomous Region, China, but excluding the Altai and Sayan; range of all single-model simulations); the 14-GCM model mean losses are 55% for RCP4.5 and 75% for RCP8.5. Similarly, Marzeion et al. (2012) found 21st-century volume losses of 50% for RCP2.6, about 57% for both RCP4.5 and RCP6.0, and 67% for RCP8.5.

The glaciers have therefore been a diminishing store of water, and the diminution is projected to continue. Paradoxically, this implies more meltwater, possibly explaining limited observations of increased runoff (Sorg et al., 2012), but also an eventual decrease of meltwater yield (see Section 3.4.4). More immediately, it entails a hazard due to the formation of moraine-dammed glacial lakes (Bolch et al., 2011).

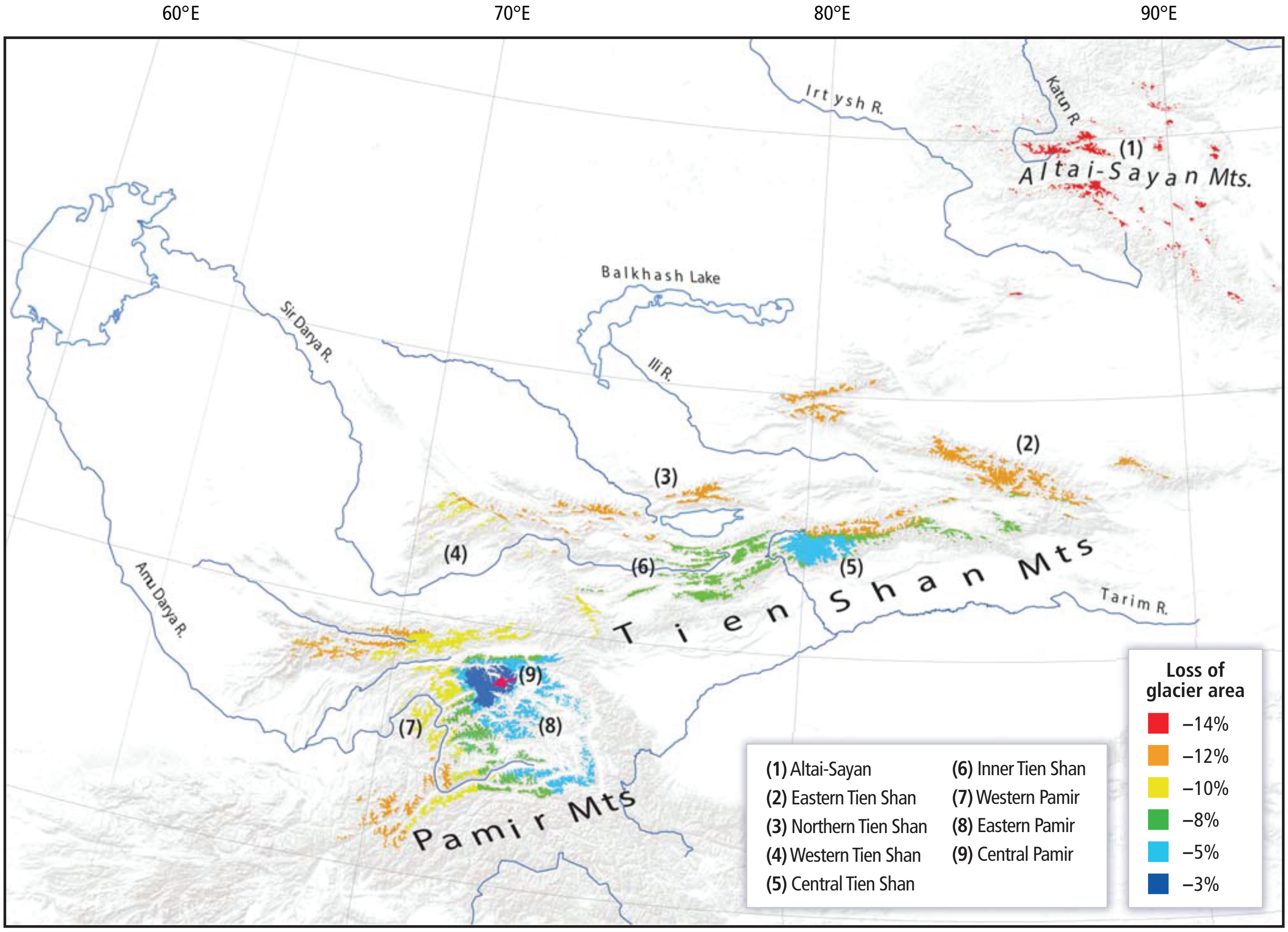

Figure 24-3 | Losses of glacier area in the Altai-Sayan, Pamir, and Tien Shan. Remote-sensing data analysis from 1960s (Corona) through 2008 (Landsat, ASTER, and Alos Prism).

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