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Taking action against climate change will benefit health and advance health equity in the Americas

ISBN: 979-11-86795-68-2(93400)

This report can be found at
https://ianas.org

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Acknowledgements
Carina De Micheli (Canada and Brazil), Alvaro Osornio Vargas (Canada and Mexico), Chris Purdon (United Kingdom), and Kelsey Robertson (Canada)

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Suggested citation
IANAS (2022). *Taking action against climate change will benefit health and advance health equity in the Americas*. (S.L. Harper & J.N. McNeil, Eds.) Inter-American Network of Academies of Sciences (IANAS) and InterAcademy Partnership (IAP). DOI##

ISBN – 978-0-00-020573-5

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Typeset in Frutiger by The Clyvedon Press Ltd, Cardiff, United Kingdom

Printed by "Soluciones Gráficas", Obispo Trejo 295 - x5000IYE, Córdoba – República Argentina.
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Foreword

Recently, the Americas, like the rest of the world, have seen an upswing in extreme weather events as a result of climate change. The numbers of injuries and deaths resulting from these disasters have been well documented, but those numbers alone do not fully capture the myriad ways in which climate change has affected and will continue to affect human health.

To date, the health sector has been the focus of national, regional, and global policy changes to reduce the possible direct and indirect effects of climate change. The emphasis on protecting human health must continue and increase as we move forward.

In 2019 the European Academies' Science Advisory Council (EASAC) produced their report "The imperative of climate action to protect human health in Europe". Subsequently, the InterAcademy Partnership (IAP) sponsored the other regional networks (Africa, the Americas, and Asia) to prepare similar documents.

In this report, prepared by the Inter-American Network of Academies of Sciences (IANAS), we consider how, through adaptation and mitigation, we can combat the negative effects of climate change on health, and also how we can reduce the ways in which the health system itself contributes to the problem of climate change.

As we have seen with the COVID-19 pandemic, the effects of climate change disproportionately impact the health of Indigenous Peoples, aging populations, children, women and girls, those living in challenging socioeconomic settings, and geographically vulnerable populations. Their voices must be heard, and as we advance with preparedness and robust response planning it is essential that issues of equity and social justice are incorporated.

This publication is one of several prepared for a project by the German National Academy of Sciences Leopoldina and the InterAcademy Partnership. Funding was provided by the German Federal Ministry of Education and Research. We would like to thank all those scholars who contributed to this volume either as authors or reviewers, as well as IAP, IANAS, and RSC secretariats for their unwavering support during the preparation and diffusion of this report.

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The InterAcademy Partnership (IAP) has more than 140 national, regional, and global member academies who work together to support the vital role of science in seeking evidence-based solutions to the world's most challenging problems.

The Inter-American Network of Academies of Sciences (IANAS) is a regional network with 24 national or regional academies that was created to support cooperation towards the strengthening of science and technology as a tool for advancing research and development, prosperity, and equity in the Americas.

Summary

Climate change is impacting health now

Climate change is affecting the Americas. We have already experienced record-breaking increases in mean and extreme temperatures, lengthened wildfire seasons, increased intensity and frequency of extreme precipitation and floods, ocean warming, permafrost thaw, increased drought, increased aridity, sea level rise, and coastal flooding and erosion. The impacts of these events have widespread and sweeping implications for the entire planet, presenting an urgent global public health challenge.

This report focuses on the ways in which climate change is affecting human health throughout the Americas. The report documents how climate change is increasing heat-related morbidity and mortality, increasing air pollution-related disease and death, threatening nutrition and food security, challenging mental health and wellbeing, damaging respiratory health, and increasing the incidence and prevalence of waterborne, foodborne, and vector-borne illnesses throughout the Americas (Figure 1).

The report assesses options for reducing the impacts of climate change on human health. It offers recommendations for climate-resilient pathways forward that are transdisciplinary in structure and underpinned by principles of equity, human rights, and social justice.

Climate change converges with and compounds other health crises

This report comes at a time when the effects of the climate crisis on human health have converged with the effects of the COVID-19 pandemic. Over the past two years, health systems have had to respond to COVID-19 as well as the impacts of record-breaking heatwaves, intense storms and disasters, and wildfires. For example, in July 2020 Hurricane Hanna made landfall in southern Texas at a time when the state was experiencing the highest COVID-19 hospitalization incidence in the United States. Efforts to evacuate and provide shelter for people while simultaneously limiting viral transmission presented difficult logistical challenges, and residents who chose not to evacuate due to fear of COVID-19 increased their risk of injury and drowning.

Both crises are pertinent reminders of how the interconnectedness of social, environmental, and climatic factors have exacerbated existing social and health inequities. Many factors that increase vulnerability to climate change impacts, such as age, sex and gender, socioeconomic status, and environmental degradation, also increase vulnerability to COVID-19. Thus, it is essential that we move forward with preparedness and robust response planning that consider and incorporate issues of equity and social justice.

Climate change action will improve human health in the Americas

Health systems must coordinate with other sectors to adapt to climate change

Climate change has already negatively impacted health in the Americas. In this report, we address how our health systems can adapt to cope with current and expected climate change and simultaneously reduce harmful health impacts through both adaptation and mitigation efforts. Examples of climate change adaptations include the following: (i) raising public awareness of climate–health risks including improved climate–health education in schools; (ii) developing heat action plans; (iii) modifying the built environment to cope with higher temperatures; (iv) explicitly incorporating health provisions into disaster risk management plans; (v) establishing and frequently testing early warning and response systems; (vi) incorporating mental health impacts into disaster risk management; (vii) developing integrated environment and health surveillance and response systems; and (viii) improving access to key services, including

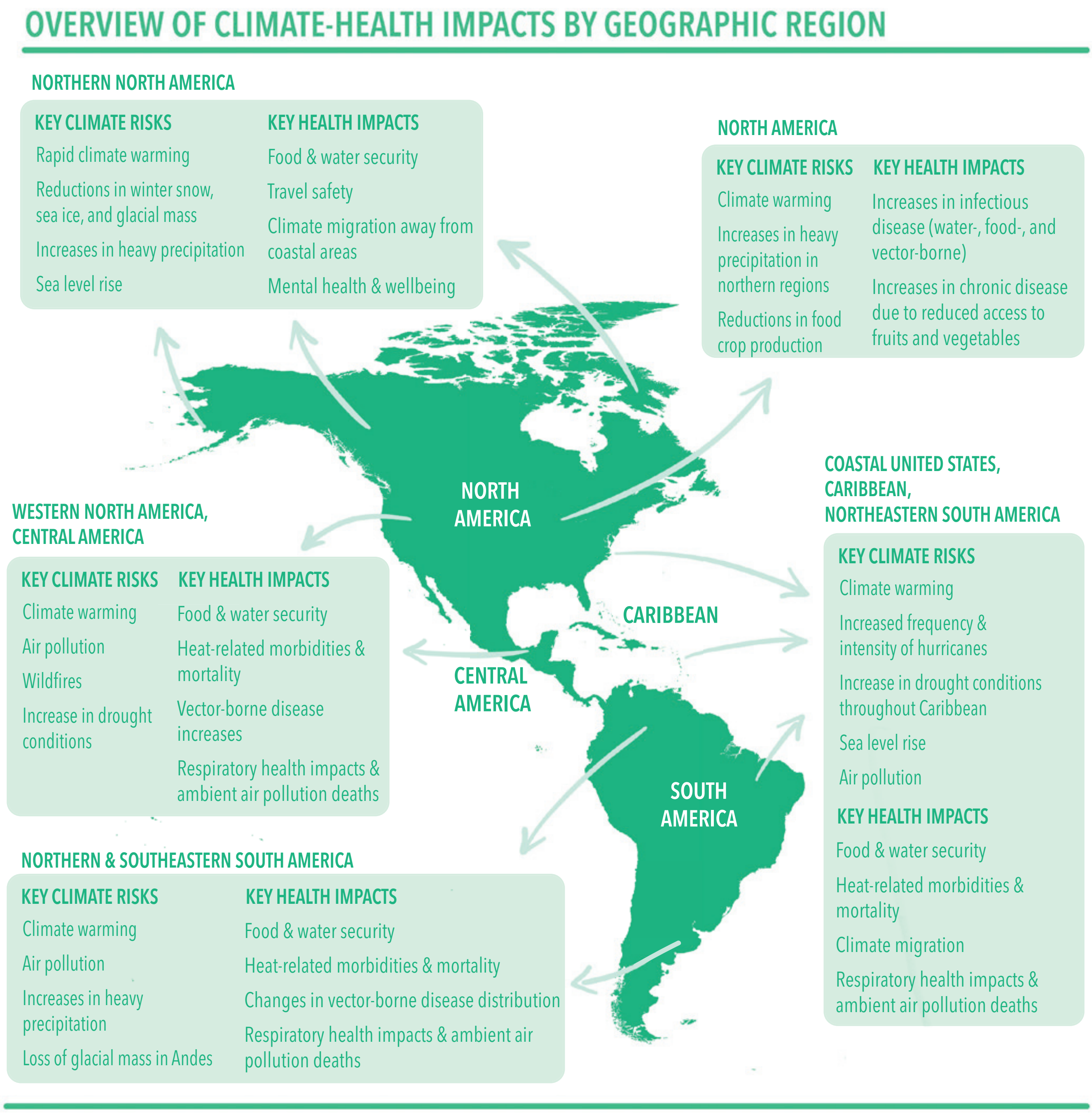

Figure 1 Summary of the climate change hazards and key health impacts by location in the Americas.

improved water, sanitation, and hygiene systems. Importantly, when developing adaptation strategies to reduce the health impacts of climate change, it is essential that the health sector coordinates its efforts with other sectors, including water and sanitation, energy, food production, transportation, housing, education, and land-use planning.

The Americas need adaptation strategies, policies, programs, and the finances to build climate-resilient and environmentally sustainable health and healthcare systems. This report outlines how assessments of the vulnerability of regions, populations, and individuals, as well as evaluations of the capacity of governments, organizations, and individuals to prepare for and manage changes in the magnitude and pattern of risks, have been used to establish a knowledge base of current and projected climate–health risks in the Americas. These assessments are important for informing the health components of national adaptation plans (HNAPs), Nationally Determined Contributions, and other key climate change planning, programming, and response policies.

But there are limits to our ability to adapt to future climate change, as currently effective adaptations may become inadequate over the medium to longer term. Furthermore, it is critical to understand that adaptations designed without sufficient attention to equity, and the needs of the most vulnerable, may increase risks or shift risks across groups. Therefore, this report identifies situations where health systems might face intolerable risks due to the extent of climate change alone or in combination with physiological, institutional, technological, social, behavioral, or economic factors. For example, climatic conditions could significantly change the geographic range of vectors carrying climate-sensitive infectious diseases, thereby placing stress on health systems already facing capacity constraints or on those not yet equipped to manage those diseases. Similarly, if average global temperature increases exceed 2°C, outdoor workers in several Latin American countries could experience extreme heat conditions that exceed the threshold for safe moderate physical labor during the hottest months of the year. These impacts are likely to increase poverty and inequities, with the potential to undermine or reverse previous gains made towards the United Nations Sustainable Development Goals.

Ambitious climate change mitigation can produce both immediate and long-term health benefits

There are clear benefits to drastically reducing greenhouse gas (GHG) emissions to meet the Paris Agreement targets, including reduced health risks in the coming decades; however, there are also immediate and nearer-term benefits of mitigation against climate change. This report provides examples of how climate change mitigation can improve human health and reduce healthcare costs here and now, providing decision-makers with an important rationale to take more aggressive action now.

- Phasing out the use of coal will produce major benefits for the environment and human health in the Americas. In addition to reducing global GHG emissions, coal phase-out will immediately reduce the burden of disease, disability, and premature death from air pollution-related cardiovascular disease, respiratory disease, lung cancer, premature birth, and neurodevelopmental disorders in infants and children.

- Road traffic currently accounts for nearly three-quarters of transport-related emissions, which, based on current trends, will only increase. Modifying transportation systems to reduce emissions can provide both environmental and health benefits. For example, the construction of safe, affordable, and reliable public transport systems and the use of active transport methods (e.g. cycling, walking, and running) would reduce emissions while providing important health benefits, including significant reductions in ischemic heart disease, cerebrovascular disease, depression, and diabetes.

- The food production system contributes an estimated 20–30% of global GHG emissions. Because livestock production contributes substantially more to GHG emissions than plant-based products, this represents a critical area of focus for mitigation. Reducing the consumption of animal-based food products would also have health co-benefits. Diets low in red and processed meats and high in fruit, vegetables, and legumes are associated with reduced mortality and lower risk of cardiovascular disease, coronary heart disease, and colorectal cancer. However, equity and justice must be carefully considered in these mitigation efforts. Indeed, dietary transitions may not have the same impact, or be appropriate, in all settings.

Addressing equity and justice underpins effective climate change actions that improve health

Climate change affects the health of all people, but the burden is not distributed evenly or fairly. Instead, it falls most heavily on minorities, those in low socio-economic conditions, and the marginalized, and is influenced by intersecting factors such as health status, social, economic, and environmental conditions, and governance structures. Climate change impacts exacerbate insecurities and injustices currently experienced by vulnerable populations, many of which are founded in injustices such as colonialism, racism, discrimination, oppression, and development challenges. This report examines climate change health risks for various vulnerable groups, and emphasizes that health-related adaptation and mitigation efforts must prioritize Indigenous Peoples, aging populations, children, women and girls, those living in challenging socioeconomic settings, and geographically vulnerable populations.

This report also highlights how the integrity and legitimacy of decisions made by governing bodies in response to climate change rely on the extent to which equity and justice are incorporated in decision-making processes and their respective outcomes. It presents equity and justice considerations for decision-makers, including distributional, procedural, capability, and recognition considerations in all climate–health actions.

Evidence-based recommendations support an emergency response to climate change

Based on the assessment and knowledge synthesis provided in this report, we have arrived at the following key conclusions:

- Climate change is already impacting everyone, everywhere—but the magnitude and distribution of those impacts vary.
- Every degree (Celsius) of climate warming matters in the Americas, emphasizing the importance of taking all possible actions to limit warming to well below 2°C.
- Climate change intersects with, and exacerbates, other global challenges such as COVID-19. The current pandemic has highlighted the intersections between climate, environment, and society, and has demonstrated how these factors can exacerbate existing health and social inequities in the Americas. COVID-19 also provides us with important lessons about responding to grand global challenges through cooperation and rapid mobilization at a large scale.
- Equity is at the core of effective responses. Globally, groups that are socially, politically, and geographically excluded are at the highest risk of health impacts from climate change, yet they are not adequately represented in the evidence base. Therefore, equity at the local, regional, and international scale must be at the forefront of research and policy responses moving forward.
- Actions taken now to build climate–health resilience will reduce future risks. Investing in climate-resilient infrastructure, programming, and healthcare systems will support adaptation and decrease future health risks from climate change.
- A "health in all policies" response will support climate change adaptation and mitigation actions to help meet the goals of the Paris Agreement, will have co-benefits for health, and will support the achievement of key international initiatives such as the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction targets and priorities.
- A focus on building climate–health research momentum in the Americas is needed. The body of literature is growing, and yet climate–health interactions are still understudied compared with other areas of climate research. Continuing efforts to build the evidence base are needed,

particularly for regions of the Americas that are currently underrepresented in the literature, such as the Caribbean, Central America, and South America.

- Cross-sectoral and global collaboration is crucial. Addressing research gaps and acting on the current evidence base will require intersectional, intersectoral, and interdisciplinary approaches that bring decision-makers together with microbiologists, epidemiologists, social scientists, environmental scientists, engineers, economists, demographers, and climatologists.

1 Introduction

Climate change threatens ecosystems, societies, and human health on a global scale and at an increasingly alarming rate (IPCC 2018, 2019a, 2019b). Climate change has already had profound impacts in the Americas, including increased mean and extreme temperatures; increased frequencies of floods and droughts; increased frequency of intense storms; shrinking of the cryosphere; and increased sea level rise and coastal erosion (IPCC 2021) (Table 1.1). These climate hazards have had substantial direct impacts on human health, including increased heat-related morbidity and mortality, as well as increased risk of injury and death from climate-related disasters. These effects may become more severe in coming years as climate change continues. Climate change-related environmental changes will also result in negative indirect health effects, including increasing undernutrition; changing ranges of and vulnerabilities to vector-borne, foodborne, and waterborne diseases; increasing wildfires, aeroallergens, and air pollution that increase the burden of chronic diseases; and increasingly widespread mental health challenges (Smith *et al.* 2014; Watts *et al.* 2021).

Importantly, the pathways through which climate change affects health are underpinned by the social determinants of health, which can amplify, mediate, or modify how the impacts of climate change are experienced and addressed (Smith *et al.* 2014). Climate change can act as a stress multiplier that exacerbates existing pressures, inequities, and injustices across and within systems, populations, and regions such that the burden of climate-related disease and death falls disproportionately on the poor, minorities, and the marginalized (Ebi 2020; Watts *et al.* 2018). As such, climate change is a grand and urgent challenge for health policy-makers, practitioners, and researchers in the Americas.

1.1 Global climate change policies and their relevance to human health in the Americas

Recognizing the need for an ambitious, globally coordinated effort to respond to the overwhelmingly negative impacts of climate change resulted in the historic Paris Agreement in December 2015. With signatories from 195 countries, including 33 countries in the Americas, the core goal of the Agreement is to limit average warming "well below 2°C", and preferably to 1.5°C above pre-industrial levels, while strengthening climate change resilience and adaptation (UNFCCC 2015).

Scientific evidence makes it clear that every degree (°C) of global warming matters (IPCC 2018), and this underpins the Paris Agreement's goal to keep global warming "well below 2°C" (UNFCCC 2015). The differentiated impacts of 1.5°C versus 2°C of global warming vary substantially for the Americas (Figure 1.1), reflecting the diverse climates, ecosystems, and human health and population systems across this vast region. Furthermore, the evidence makes it clear that every degree (°C) of warming matters, every year of action or inaction matters, and every choice matters (IPCC 2018). For example, 420 million fewer people would be exposed to extreme heatwaves if global warming was limited to 1.5°C instead of 2°C, assuming vulnerability factors were held constant (IPCC 2018). In the Caribbean, about 50% of the year is projected to be under warm spell conditions (i.e. the maximum temperature exceeds the 90th percentile for 6 consecutive days) at 1.5°C of global warming compared with up to 69% of the year at 2°C of warming, relative to the 1971–2000 baseline (IPCC 2018). Eastern North America, as well as high-latitude regions such as Alaska and western Canada, are projected to have some of the largest increases in heavy precipitation events in the world when projections

Table 1.1 A summary of observed and/or projected climate change hazards in the Americas reported by the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (IPCC 2021)

	Central and South America	North America
Heat	• Increases in mean and extreme temperatures	• Increases in mean and extreme temperatures • Warming at a higher rate than the global mean in the Arctic
Wet and dry	• Increases in extreme and mean precipitation in southeastern South America • Decreases in precipitation and increases in drought in northeastern South America • Increases in intensity and frequency of extreme precipitation and pluvial floods in southeastern South America, southern South America, northern South America, South American Monsoon, and northeastern South America • Increases in agricultural and ecological drought in South American Monsoon, and southern South America • Increases in conditions favorable to wildfires in several regions	• Increases in precipitation in eastern and central North America • Decreases in precipitation in areas of the southwestern United States and northwestern Mexico • Lengthened wildfire season and expansion into tundra regions in the Arctic • Decreases in aridity and dry days in the Arctic • Intensification of water cycle and subsequent increase in total precipitation and heavy precipitation events in the Arctic • Increases in river flooding across all of North America except northern Central America • Increases in agricultural and ecological drought in western North America • Increases in aridity in southwestern United States and northern Central America
Wind	• Increases in mean wind speed and in wind power potential over the Amazon, including northern South America, South American Monsoon, northeastern South America	• Increases in frequency of the most intense tropical cyclones and higher rainfall on Mexico's Pacific coast, the Gulf Coast, and the United States' eastern coast • Decreases in mean wind speed in western North America • Decreases in wind speed over the northeast Arctic
Snow and ice	• Decreases in glacial volume and increases in permafrost thaw in the Andes Cordillera, resulting in reduced river flow as ice reserves decrease and potential high magnitude glacial lake outburst floods	• Increases in winter snow water equivalent in high-latitude regions • Loss of almost all glacial mass in western Canada and western North America • Increases in glacial loss and permafrost thaw in the Arctic • Decreases in snow cover in the Arctic • Decreases in coastal sea ice coverage, leading to increases in coastal hazards (e.g. storm surges, erosion, flooding) in the Arctic
Coasts	• Increases in shoreline retreat in southern Central America, southeastern South America, and southern South America • Sea level rise at a higher rate than the global mean in the South Atlantic and tropical North Atlantic, and at a slower rate than the global mean in the East Pacific • Increases in shoreline propagation in northwest South America and northern South America	• Sea level rise at a higher rate than the global mean in subtropical North Atlantic, and at a slower rate than the global mean in subpolar North Atlantic and the East Pacific • Increases in episodic coastal flooding • Increases in shoreline retreat in northwestern North America, northern Central America, and the Gulf Coast • Increases in shoreline propagation in northeastern North America • Increases in Arctic coastal flooding and erosion

shift from 1.5 to 2°C of global warming (IPCC 2018). These warming temperatures and changing precipitation patterns have important implications for the environment in the Americas. In the Arctic, a sea ice-free summer is expected once every 100 years with 1.5°C of global warming compared with once every 10 years if there is a 2°C increase (IPCC 2018), the consequences of which range from local impacts on culture and subsistence to international impacts that affect travel, trade, and global security (IPCC 2019a). In Central and South America, warmer and drier conditions will increase wildfires and drought conditions, whereas drought conditions in the Caribbean are projected to last on average 9% longer with 2°C compared with 1.5°C of warming, which has important implications

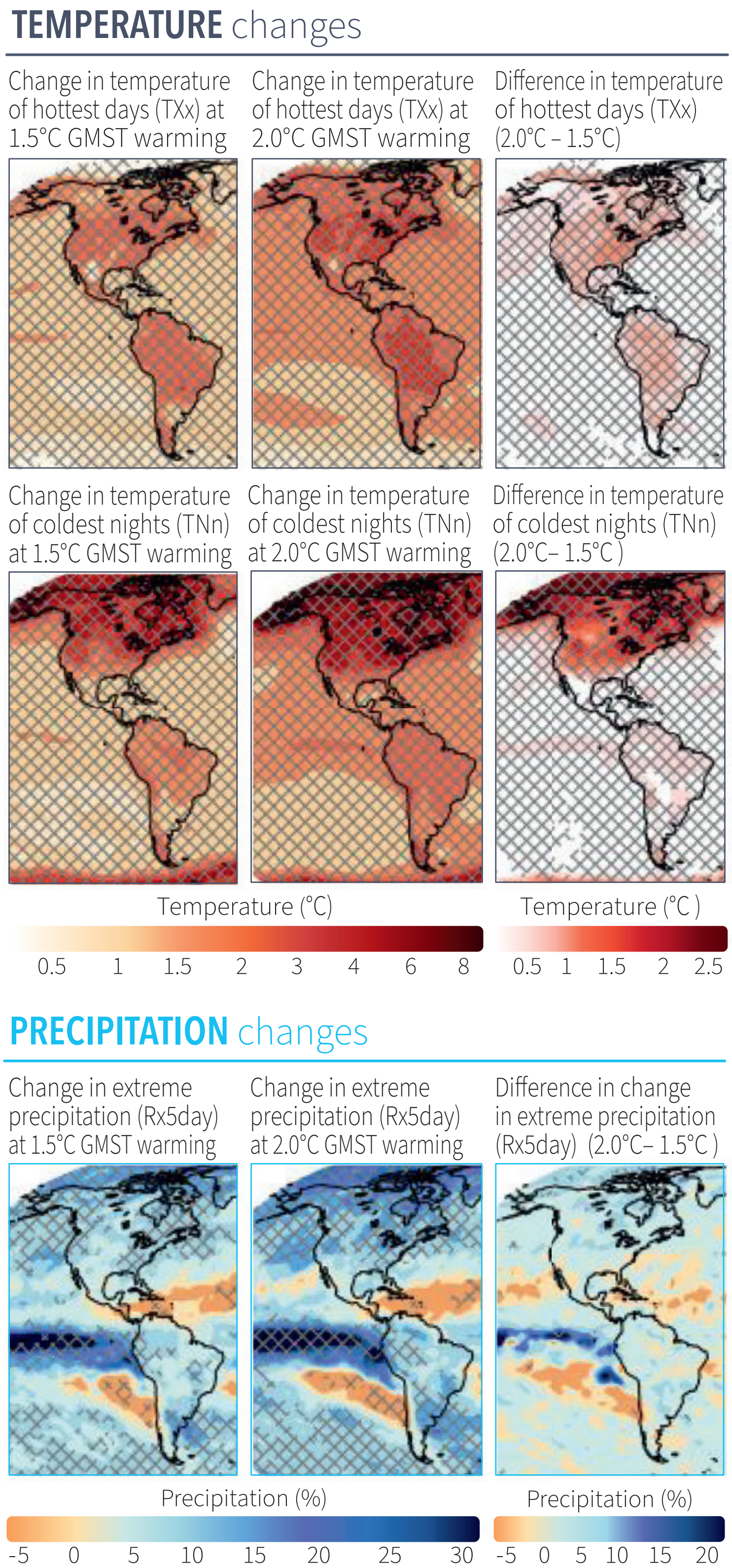

Figure 1.1 A summary of the change in the temperature of the hottest days and coldest nights, and extreme precipitation for 1.5°C versus 2°C of global warming (adapted from IPCC 2018).
GMST, global mean surface temperature.

for water security. Food security challenges are also projected to be prevalent throughout the Americas, especially in the Amazon, where food insecurity risks would transition from medium risk under 1.5°C to high risk under 2°C of global warming (IPCC 2018). Similarly, health impacts will vary under different levels of climate warming: for example, a 2°C increase will result in more heat-related mortality and morbidity (Ebi *et al.* 2018a), and an additional 10–40 million people will be undernourished (Hasegawa *et al.* 2016) compared with 1.5°C of warming.

Therefore, concerted and urgent mitigation efforts are required to minimize climate–health risks and achieve the Paris Agreement's goal. Key climate change mitigation activities include reducing greenhouse gas (GHG) emissions and conserving and enhancing GHG sinks such as forests (UNFCCC 2015). These actions are critical if the Americas are to achieve the Paris Agreement goals, as approximately 25% of global GHG emissions are produced in the Americas, led by the United States (11.9% of global emissions) and Brazil (5.6% of global emissions) (World Bank 2016a).

Although lower levels of risk are anticipated at 1.5°C (IPCC 2018), even if this target is achieved through immediate and aggressive reductions in emissions, climate change will continue to impact health in the Americas for decades. As such, Article 7 in the Paris Agreement builds upon the 2010 Cancun Adaptation Framework, which calls for climate change adaptation to be addressed with the same urgency as mitigation, and recognizes adaptation as an issue affecting all nations (UNFCCC 2011). For the health sector, climate change adaptation efforts include actions that reduce exposure to risks, reduce morbidity, and prevent mortality.

Under the Paris Agreement, each member party is responsible for developing and submitting Nationally Determined Contributions (NDCs), which provide a nation-specific roadmap for GHG reduction and adaptation responses. Many countries have outlined several self-determined goals, but as global progress to date is considered insufficient to limit warming even to 2°C, substantial increases in government commitment will be required to meet the emission reduction goals outlined in the Agreement (UNEP 2019). Leadership from the Americas will be critical, given the high total and per capita emission levels of several countries in the region; for example, the United States is the second largest contributor to carbon dioxide (CO_2) emissions globally, and countries such as Canada, the United States, Trinidad and Tobago, and Curaçao have some of the highest global emissions per capita (World Bank 2016b). Some progress in the transition to cleaner sources of energy is being made in the region, with increases in the proportion of clean energy consumption in the residential sector, although overall reliance on cleaner energy sources remains low (Watts *et al.* 2021). Furthermore, while emissions were driven down substantially in 2020 due to travel restrictions and the economic consequences of the COVID-19 pandemic, it is uncertain whether these reductions will be sustained over time (Watts *et al.* 2021).

The interconnectedness of climate change and human health is being increasingly recognized and incorporated into global climate action plans and policies, as is evidenced by the Paris Agreement and many subsequent NDCs. Indeed, relative to some other regions, the Americas have a high level of consideration of health in NDCs, with over 90% of NDCs referencing health (Watts *et al.* 2021). Furthermore, spending on health and health-related adaptation efforts in the Americas far exceeds that of other regions and has increased over time, reaching over USD$30 per capita in 2018–2019 (Watts *et al.* 2021). The integration of health aspects into climate planning and policies reflects a "health in all policies" approach to climate change action, and such consideration of health across all sectors can lead to improvements in health, health equity, and sustainable development (Rudolph *et al.* 2013; Sellers *et al.* 2019; Watts *et al.* 2021; WHO 2014a). This type of approach is crucial as the impacts of climate

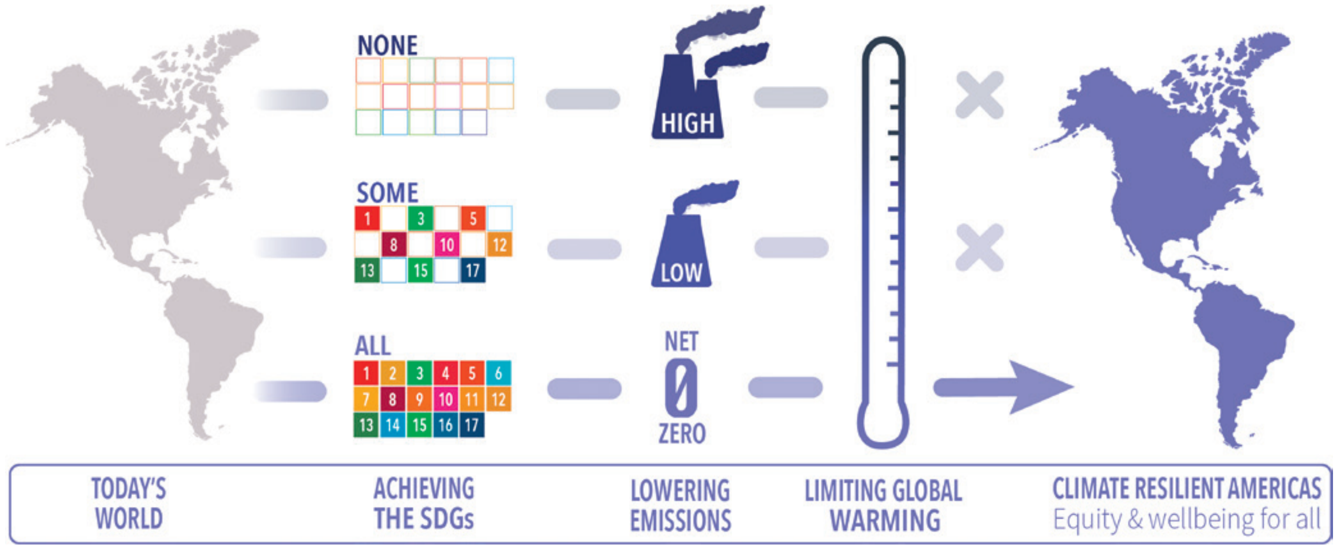

Figure 1.2 Climate change adaptation and mitigation are inextricably linked to all SDGs. Achieving the SDGs and maintaining their benefits into the future requires decision-making that considers climate change and health in all policies (adapted from IPCC 2018).

change are already challenging current progress and threaten to undermine, or even reverse, progress made through initiatives such as the Sustainable Development Goals (SDGs), which were established to promote health, prosperity, and a sustainable planet for all people. Climate change intersects with all SDGs (Figure 1.2), notably by threatening to push more people into poverty (SDG-1) and poor health (SDG-3), reducing food security (SDG-2), reducing access to safe water (SDG-6), and challenging sustained, inclusive, and sustainable economic growth (SDG-8) (United Nations Economic and Social Council 2020).

1.2 Climate change and inequity

The health impacts of climate change will not be experienced equally or equitably. Certain populations are at a disproportionately high risk for negative health outcomes due to complex interactions between geographical, political, and economic factors, as well as social determinants of health including gender. In particular, those living in lower income nations that contribute less to global GHG emissions typically bear a greater burden of climate-related health impacts (IPCC 2018). In 2016, the 31 countries classified as low income by the World Bank accounted for less than 0.5% of global CO_2 emissions combined, whereas the top three emitting nations (China, United States, and India) combined accounted for 48.1% (World Bank 2016a). At the same time, in low income countries, people exposed to climate-related disasters are six times more likely to be affected (e.g. injured, displaced, required medical attention) and seven times more likely to die compared with those in high income countries (CRED and UNISDR 2017). These disparities reflect the greater economic impact of climate disasters in low income countries, the limited health sector resources available, and the relatively limited capacity to invest in climate-resilient infrastructure and adaptation, as well as existing challenges related to the underlying social determinants of health for low income and disadvantaged populations (CRED and UNISDR 2017; WHO and Commission on Social Determinants of Health 2008). It is precisely to address these stark disparities in the health impacts of climate change that the concept of equity is specifically referenced in the Paris Agreement, embedded in the context of the SDGs, and is a long-standing foundation of international climate change law (Bodansky *et al.* 2017).

1.3 The intersection of health crises in a global context

This report comes at a time when the unprecedented global health challenges of climate change, pollution, and biodiversity loss are compounded by the COVID-19 pandemic (Case Study 1). The COVID-19 pandemic has had a transformative impact on all aspects of society. It is a pertinent reminder of the interconnectedness of social, environmental, and climatic factors, and how the intersections of these factors can exacerbate not only the effects of the COVID-19 pandemic but also existing social and health inequities (Ebi and Hess 2020; Krieger 2020).

A clear example of a climate hazard intersecting with those of the COVID-19 pandemic occurred in July 2020, when Hurricane Hanna made landfall in southern Texas—which at the time was experiencing the highest COVID-19 hospitalization rates in the United States (Shultz *et al.* 2020a). Efforts to evacuate and provide shelter for people while simultaneously limiting viral transmission presented difficult logistical challenges, and residents who chose not to evacuate for fear of COVID-19 increased their risk of injury and drowning (Shultz *et al.* 2020a). Importantly, factors that increase vulnerability to climate change impacts, such as age, gender, ethnicity, and socioeconomic status, overlap with those that increase vulnerability to COVID-19, with risks being inequitably distributed in society (Schipper *et al.* 2020). Similar layered health crises linked to climate-related disasters have occurred in the past (Ivers and Ryan 2006; Watson *et al.* 2007) and will continue to occur in the future, highlighting the need for preparedness and robust response planning that incorporate issues of equity and social justice.

Immense resources have been, and will continue to be, invested in the response to COVID-19 to reduce disease transmission. This includes access to personal protective equipment and vaccines, as well as increasing funding to improve the capacity of health services and to support economic recovery (Hale *et al.* 2021; IMF 2021). The pandemic has forced governments and society at large to adapt to massive shifts in daily life over the course of a few months. These changes have not only emphasized the inherent vulnerabilities in societal structures, but have also provided an opportunity to invest in pandemic management and recovery responses that have co-benefits for climate change. For example, any COVID-19 recovery actions that continue divestment from fossil fuels and encourage investment in sustainable energy will not only help to avoid an emissions rebound but will also help to meet the targets outlined in the Paris Agreement (Le Quéré *et al.* 2021).

Immediate global participation is essential to ensure that policies and programming put in place to respond to and recover from COVID-19 also align with the emission reduction targets in the Paris Agreement (UNFCCC 2015), international commitments to establish universal health coverage by 2030 (UHC2030) (WHO and World Bank Group 2019), and the SDGs (United Nations 2020). Importantly, lessons learned from the rapid scale-up of the pandemic response can be applied to climate change responses, including the need for cross-sector collaboration and global solidarity, as well as consistent consideration of trade-offs, equity, and social and environmental justice (Klenert *et al.* 2020; The *Lancet* COVID-19 Commissioners *et al.* 2020; WHO 2020a). Additionally, economic responses during and post-COVID-19 can benefit health while also reducing GHG emissions. Such responses include removing subsidies that are harmful to health and/or the environment, supporting renewable energy development, and considering environmental and health criteria when recapitalizing companies (Guerriero *et al.* 2020).

The unprecedented impacts of the COVID-19 pandemic present an opportunity for nations worldwide to set themselves on a trajectory for a low carbon future with concurrent economic recovery. However, few countries have effectively utilized the trillions of dollars of stimulus funds made available throughout the pandemic to do so. According to the Greenness of Stimulus Index, Canada is the only country in the Americas to change its recovery towards more sustainable growth and climate resilience, whereas the United

Case Study 1 COVID-19 and climate change in the Americas

As communities around the world grapple with the impacts of climate change, their capacity to respond to compounding public health issues is compromised. The ongoing COVID-19 pandemic provides several examples of how this situation can play out. First reported in Wuhan, China, in 2019, COVID-19 rapidly spread around the globe through highly connected global travel networks to become the century's first major pandemic. The disease reached even the remotest corners of the planet, such as the Indigenous Amazonian communities, in fewer than 6 months (Zavaleta-Cortijo *et al.* 2020). COVID-19 presents an unprecedented challenge to humanity, with widespread implications for health, livelihoods, and wellbeing that may undermine progress towards achieving the SDGs (The *Lancet* COVID-19 Commissioners *et al.* 2020). The COVID-19 pandemic is exacerbating existing social, economic, and political inequalities, with marginalized and vulnerable groups experiencing higher burdens of cases and deaths, further widening poverty and educational gaps (Douglas *et al.* 2020; Krieger 2020; Nicola *et al.* 2020; The *Lancet* COVID-19 Commissioners *et al.* 2020).

Climate change and COVID-19 are interacting in complex ways, creating compound risks through multiple pathways and further threatening lives and wellbeing. Climate-related factors affect the transmission of COVID-19, although in ways not yet fully understood. The survival and transmission of coronaviruses in the air depend on many factors, including temperature and humidity (Kubota *et al.* 2020; Sasikumar *et al.* 2020), although non-weather factors are typically more important in explaining disease transmission (Auler *et al.* 2020; Bashir *et al.* 2020; Briz-Redón and Serrano-Aroca 2020; Carlson *et al.* 2020; Kubota *et al.* 2020; Méndez-Arriaga 2020; Pequeno *et al.* 2020; Prata *et al.* 2020; Ribeiro Ribeiro and Alves Sousa 2020; To *et al.* 2021; Zaitchik *et al.* 2020). With respect to exposure and transmission, the relative importance of weather directly affecting the virus versus how it changes peoples' behaviors remains unclear. There is negligible evidence that climate change will directly or substantively affect COVID-19 viral transmission over time. However, there are strong correlations between exposure to particulate matter (PM) from fossil fuel combustion (e.g. $PM_{2.5}$ (particulate matter of sub-2.5 μm size), NO_2) and high COVID-19 case burdens and mortality (Ali and Islam 2020; Petroni *et al.* 2020; Salas *et al.* 2020b; Srivastava 2021; Wu *et al.* 2020b). One study suggested that particulate air pollution might have contributed approximately 15% (95% confidence interval 7–33%) to COVID-19 mortality worldwide, and 17% (6–39%) in North America (Pozzer *et al.* 2020). In Europe, West Asia, and North America, as much as 70–80% of the attributable anthropogenic fraction of particulate matter is related to fossil fuel use, indicating a potential link between fossil fuel consumption and negative COVID-19 outcomes in those regions (Pozzer *et al.* 2020).

Climate-related extreme events across the Americas, including wildfires, hurricanes, floods, and droughts, can exacerbate vulnerability and undermine efforts to control the pandemic (Pei *et al.* 2020; Salas *et al.* 2020b; Walton and van Aalst 2020). Evidence on the interaction between climatic extremes and COVID-19 is only just emerging, with several potential discernible pathways including the following:

- **Modified disease exposure pathways.** Extreme weather events result in mass displacement (e.g. evacuation, migration, mass sheltering), thereby introducing diseases into new regions, clustering survivors in temporary accommodation where social distancing is more challenging, increasing levels of social contact, and, in the case of temperature extremes, making face coverings more difficult to use (Li *et al.* 2005; Phillips *et al.* 2020; Salas *et al.* 2020b). Regular handwashing can be challenging in circumstances where clean water may not be widely available (Armitage and Nellums 2020). In the United States, the 2020 Atlantic hurricane season was extremely active, and model simulations of southeast Florida indicated possible increases in the total number of COVID-19 cases in both the origin and destination locations of hurricane evacuees (Pei *et al.* 2020).
- **Increased susceptibility to COVID-19.** The indirect effects of climate-related disasters can have implications for individuals' susceptibility to and the severity of COVID-19 infections. For example, exposure to smoke from wildfires in preceding months has been linked to increased morbidity from influenza (Landguth *et al.* 2020), raising concerns about increased risks of COVID-19 infections associated with wildfires (Kizer 2020; Xu *et al.* 2020a). Additionally, individuals with COVID-19-related pulmonary or cardiac impairment are more at risk for negative effects of wildfire-related smoke and heatwaves (Salas *et al.* 2020b). There is evidence of increasing wildfire activity, including in western North America, driven partly by climate change in combination with other anthropogenic factors (e.g. land management practices) (Schoennagel *et al.* 2017; Williams *et al.* 2019; Xu *et al.* 2020a). Several large wildfires also coincided with COVID-19 in California, western and central Canada, and the Brazilian Amazon. Smoke from the 2020 California wildfire season limited outdoor activities and exacerbated social isolation, which may have had mental health implications (Kizer 2020).
- **Reduced access to healthcare services.** Extreme events complicate the ability of patients with COVID-19 to seek diagnosis and access care, and these disasters can also lead to the failure of critical public services (e.g. disruption of power supplies and emergency services) (Frausto-Martínez *et al.* 2020; Salas *et al.* 2020b).
- **Compromised emergency response.** Natural disasters can challenge government and public health COVID-19 responses by disrupting supply chains, limiting access to humanitarian aid, and reducing the number of mobilizable front-line staff and resources (Frausto-Martínez *et al.* 2020; Walton and van Aalst 2020). These disruptions can place further stress on health systems that are already struggling to cope with COVID-19 cases (Salas *et al.* 2020b). COVID-19 in turn has created challenges for managing and responding to extreme climatic events. Stay-at-home orders and concerns over COVID-19 may result in people failing to heed evacuation orders (e.g. in hurricane zones, wildfire regions), leading to preventable injuries and deaths (Phillips *et al.* 2020; Shultz *et al.* 2020b). Efforts to control wildfires in California, for example, were limited both by high heat, low humidity, and high winds along with a lack of prison inmates (an integral part of the fire control in the state) to fight fires due to quarantines and early releases related to the pandemic (Kizer 2020). In 2020, the presence of COVID-19 challenged emergency responses during major flooding events in Canada, Colombia, Bolivia, Ecuador, Guatemala, Haiti, Honduras, Mexico, Panama, Peru, Salvador, Trinidad and Tobago, the United States, and Uruguay (Simonovic *et al.* 2021).

Longer-term climate change has undermined resilience to emerging threats such as COVID-19 for some populations. Indigenous populations in South America have been among those most impacted by COVID-19, and this disparity is reflective of multiple interconnecting factors such as structural inequalities, marginalization, land dispossession, and government policy (Menton *et al.* 2021; Polidoro *et al.* 2020; The *Lancet* 2020), as well as climate change, which has exacerbated these other underlying factors. For example, in the Peruvian Amazon, changes in precipitation regimes, seasonality, hydrology, and temperatures have undermined Indigenous food systems by disrupting community fisheries, reducing access to and availability of highly valued forest animals, and undermining traditional knowledge systems (Zavaleta *et al.* 2018). This has compromised the resilience of remote Indigenous populations to withstand the negative food security implications of COVID-19, since they can no longer rely on forest resources when travel restrictions make local food markets inaccessible (Zavaleta-Cortijo *et al.* 2020). As another example, in Kashechewan, Canada, First Nations Indigenous Peoples have faced compounding impacts from COVID-19 and flooding, which have exacerbated existing housing shortages and complicated evacuation efforts.

States, Mexico, Argentina, Brazil, and Colombia remain on a net negative trajectory (Vivid Economics and Finance for Biodiversity Initiative 2020).

1.4 The role of this IANAS report in responding to climate change-related health risks

This report is a response to the need for a focused synthesis of climate–health evidence in the Americas. It reflects the urgent need for clear, actionable recommendations to support responses to and preparations for the health impacts of the climate crisis. Given the inherent complexity, urgency, and magnitude of climate change impacts on the health sector, it is critical that robust and timely evidence is available to inform effective, feasible, and equitable responses and strategies. The challenge, however, is the exponentially increasing volume and varying quality of research through which decision-makers must sift and sort. For example, since 2007, the quantity of research publications relating to climate change and health has increased eightfold globally (Watts *et al.* 2021), with similar trends in research documented specifically in the Americas (Berrang-Ford *et al.* 2021b; Harper *et al.* 2021a, 2021b). However, an international literature review found approximately three times as many publications from North America as from South America (Berrang-Ford *et al.* 2021b).

The Inter-American Network of Academies of Sciences (IANAS) is well positioned to assess the climate–health evidence base because: (i) it is independent of commercial and political vested interests; and (ii) it brings together an expansive network of leading experts who can assess the state of the climate–health evidence base and make recommendations based on verifiable science and transdisciplinary engagement. This report therefore has the following objectives:

1. Use a collaborative and transdisciplinary approach to assess and synthesize available peer-reviewed evidence on current and projected climate change health risks in the Americas.

2. Outline feasible, effective, and timely mitigation and adaptation options to protect and promote the health of people in the Americas in the short, medium, and long term, and to provide clear, useable, and relevant policy recommendations that support the implementation of those options.

3. Highlight case studies to illustrate climate change health risks and the potential benefits of adaptation and mitigation strategies.

4. Identify important climate–health research gaps and suggest future research that is urgently needed to inform decision-making.

5. Provide an evidentiary resource and a public health framework for policy-makers, practitioners, and researchers that will help to increase public engagement in climate change discussions and motivate climate change action.

2 IANAS' assessment approach

2.1 Building from and advancing previous climate change and health publications from national academies

Several national academies or networks have published climate change and health synthesis reports (Table 2.1). This IANAS report draws on, builds from, and advances previous syntheses, providing an in-depth examination of climate change and health in the Americas and presenting case studies to highlight the climate–health nexus (Box 2.1). The sources of evidence assessed in this report are outlined in Section 2.2.

2.2 The scope of this report

2.2.1 Evidence assessed in this report

Similar to the EASAC's (2019) report, we focus on synthesizing evidence to inform

Table 2.1 An overview of published and forthcoming climate change and health synthesis reports by international academies. Adapted from Table 2.1 in the European Academies' Science Advisory Council's report "The imperative of climate action to protect human health in Europe" (EASAC 2019).

Academy	Report	Year of publication
European Academies' Science Advisory Council (EASAC)	*"Climate change and infectious diseases in Europe"*	2010
Interacademy Medical Panel (IAMP)	*"Statement on the health co-benefits of policies to tackle climate change"*	2010
German National Academy of Sciences Leopoldina	*"The co-benefits of actions on climate change and public health"*	2015
Swiss Academies of Arts and Sciences	*"Health and global change in an interconnected world"*	2015
Australian Academy of Science	*"Climate change challenge to health: risks and opportunities"*	2016
Inter-American Network of Academies of Sciences (IANAS)	*"Challenges opportunities for food and nutrition security in the Americas: The view of the Academies of Sciences"*	2017
European Academies' Science Advisory Council	*"Opportunities and challenges for research on food and nutrition security and agriculture in Europe"*	2017
Pontifical Academy of Sciences	*"Declaration of the health of people, health of planet, and our responsibility"*	2017
Royal Society of New Zealand	*"Human health impacts of climate change for New Zealand"*	2017
US National Academies of Sciences	*"Protecting the health and well-being of communities in a changing climate"*	2017
European Academies' Science Advisory Council; Norwegian Meteorological Institute	*"Extreme weather events in Europe. Preparing for climate change adaptation: an update on EASAC's 2013 study"*	2018
European Academies' Science Advisory Council	*"The imperative of climate action to protect human health in Europe"*	2019
Association of Academies and Societies in Asia (AASSA)	*"The imperative of climate action to promote and protect health in Asia"*	2021
Network of African Science Academies (NASAC)	Report on climate change and health in Africa. Title pending	Forthcoming 2022
National Academy of Medicine; National Academies of Sciences, Engineering, and Medicine	Report on climate change and health in the United States. Title pending	Forthcoming

Box 2.1 Key questions addressed in this report, building on questions addressed in EASAC's (2019) report about climate change and health

Climate change and health risks in the Americas

1. What are the major climate change health risks in the Americas?
2. Who are those at greatest risk? Where do they live?
3. How do the social determinants of health mediate, modify, amplify, or reduce climate change risks and responses?

Climate change and health responses in the Americas

1. Which policies, plans, and development pathways increase resilience to the impacts of climate change?
2. Which are the best (combinations of) adaptation strategies in different contexts? What are the limits of adaptation?
3. What are the benefits of climate change mitigation for health?
4. What are the trade-offs and synergies associated with different adaptation and mitigation strategies? Are there unintended adverse consequences linked to certain strategies?
5. What are the enablers and barriers to the implementation of responses?

How can the consideration of health in climate policy, programming, and actions be improved?

decision-making, as well as identifying research gaps that have important policy relevance and implications. As such, our intended primary audience are the decision-makers in the Americas, as well as those whose work depends upon, or is influenced by, the Americas. The terminology and conceptual understanding of climate change health risks described in this report align with those established by the Intergovernmental Panel on Climate Change (IPCC 2019c).

We prioritize citing systematic reviews, which use replicable and transparent methods to summarize climate change and health literature, as the most methodologically rigorous sources of collated evidence on climate–health topics. This reflects the penultimate step in knowledge production aimed at the science-policy interface for climate change, which involves assessing research syntheses to produce our scientific assessment (Minx *et al.* 2017) (Figure 2.1). However, we also cite other literature to illustrate particular topics and case studies, guided by our Working Group expert discussions and peer reviewers. All articles cited in this report were published before September 1, 2021, reflecting the IPCC Working Group II publication cut-off date. Our approach does not provide an exhaustive bibliographic listing, but rather enables an assessment of bigger-picture science-policy

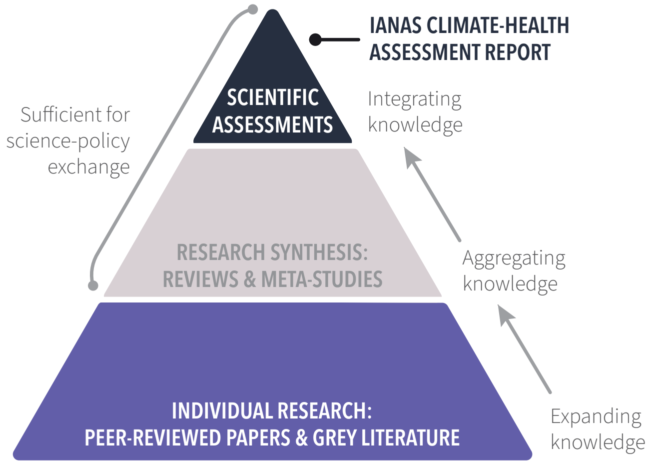

Figure 2.1 Knowledge production for science-policy interactions related to climate change (adapted from Minx et al. 2017).

questions while adding depth and nuance through case study examples.

2.2.2 Geographical scope of this report

The Americas represents a region of vast geographical, political, and socioeconomic diversity. North, Central, and South America encompass 45 countries and/or territories with a combined population of approximately one billion people (World Bank 2019). Most countries (88.8%) are classified as upper middle income (44.4%) or high income (44.4%), with 11.1% considered lower middle income (8.9%) or low income (2.2%) (World Bank 2020). The Americas covers all climate zone types, ranging from Arctic climates to tropical climates, and includes a broad diversity of cultures, languages, and Indigenous Peoples. Covering such diverse climates, ecosystems, cultures, and peoples is a challenge; however, it is also a strength and a key contribution of this report. As such, an important aim of this report is to examine overarching pathways through which climate change impacts health across the range of different natural and human systems in the Americas, while providing depth and nuance through case study examples throughout the region.

2.3 Framework for IANAS' inquiry

2.3.1 Defining risk related to climate change impacts on health

This report makes use of a risk framework that considers climate–health impacts as a function of: (i) climate change-induced hazards; (ii) exposure to these hazards; and (iii) vulnerability of humans and systems (Abram *et al.* 2019; Ebi *et al.* 2006). *Hazards* include the direct and indirect weather or environmental events resulting from climate change (e.g. extreme heat, wildfires, etc.), whereas *exposure* refers to the proximity, type, and scale of climate hazards (e.g. duration of heatwaves, area burned in wildfires, etc.), which may range from long-term climate variability to extreme weather events and climate disasters. *Vulnerability* refers to the extent to which humans and human systems are susceptible to the impacts of climate hazards (Ebi *et al.* 2006), and is affected by numerous biological (e.g. sex, age) and societal (e.g. geopolitics, socioeconomic status, gender roles) conditions.

Adaptation to reduce exposure and vulnerability, and thus overall risk, is critical given that climate change impacts will continue into the future even with the implementation of mitigation strategies. *Resilience* is a property of interconnected natural and human systems that enables those systems to return to a state that is equal to or better than the previous state in response to a climate hazard, event, trend, or disturbance (IPCC 2019c). In this report, *coping capacity* refers to the availability of currently feasible adaptation options, whereas *adaptive capacity* refers to the ability of systems to increase coping capacity in the future (Ebi *et al.* 2006). Adaptations to reduce the risk of negative health burdens may be implemented through individual- and/or population-level interventions, such as policies, programming, and the development of climate-resilient infrastructure (Ebi *et al.* 2006).

Past, current, and future climate–health projections must take into account the drivers of risk, including the ways in which hazards, exposure, and vulnerability may change over time. Hazards will increase as climate change contributes to changing seasonal patterns, as well as changes in the frequency and intensity of extreme weather globally. In particular, climate change is expected to exacerbate climate-sensitive health impacts in populations that are already experiencing these health outcomes as a result of increased exposure to hazards. For example, those living in regions where maximum daytime temperatures already pose substantial health risks are projected to experience additional heat-related morbidity and mortality as climate change progresses (Vicedo-Cabrera *et al.* 2018). Vulnerability may also increase in some contexts, for example because of aging populations, and decrease in other contexts due to improvements in the social determinants of health achieved through policies and programs such as the SDGs (Smith *et al.* 2014). Generally, it is expected that climate-related health risks will be lower at 1.5°C of warming than 2°C (IPCC 2018); therefore, in this report we describe the direct and indirect health impacts of climate change under multiple climate scenarios—including the potential impacts of non-climatic drivers of risk and the potential impacts of mitigation and adaptation strategies. Climate change "impacts", as defined by the IPCC, "generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social and cultural assets; services (including ecosystem services); and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial" (IPCC 2019c). Some consequences of climate change might provide apparently beneficial outcomes in specific circumstances, such as increased rainfall in previously arid regions, out-migration of specific vectors of infection, or in-migration of edible marine species; these changes, however, are likely to be transient, may only affect certain population sectors, and are unlikely, on balance, to outweigh the negative aspects of climate change.

The magnitude, distribution, and frequency of health outcomes regularly change because of multiple intersecting social and environmental factors, so quantifying the actual impacts attributed specifically to climate change can be challenging. The extent to which changes in health outcomes have occurred due to climate change is often grounded in the science of "detection and attribution", defined by the IPCC as "demonstrating that *climate* or a system affected by climate has changed in some defined statistical sense … Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of *confidence*" (emphasis added) (IPCC 2018). In other words, *detection* tells us whether health has changed since a baseline reference period, and *attribution* tells us to what extent this is due to climate change. Detection and attribution science has become increasingly important because international negotiations on climate change under the UNFCCC focus on preventing "dangerous" anthropogenic climate change. Therefore, to align with these international discussions, decisions, and negotiations, this report uses a detection and attribution framework to understand climate change impacts on health outcomes in the Americas. For each health outcome, we considered whether, how, and to what extent climate change affected health in the Americas.

In the past decades, climate change science has advanced significantly due to a much clearer understanding of the character, timing, and spatial distribution of climate change (IPCC 2021). At the same time, advances in health sciences have improved our understanding of how the magnitude, distribution, and frequency of health outcomes have changed over time. At the climate–health interface, it has become increasingly possible to attribute a portion of the changes in health to climate change (Ebi *et al.* 2020, 2017). However, this is not always the case, particularly in research examining the societal impacts of climate change (Ebi *et al.* 2020). For the health sciences, conducting formal detection and attribution research requires long-term datasets, a detailed understanding of the causal pathway between climate change and a health outcome, and data on other determinants of health. The challenges of conducting this type of research are similar to health research examining the causes of cancer: these include identifying counterfactual conditions, availability of observational data, and difficulties in accounting for other factors that can change risk (Ebi *et al.* 2020). Generally, climate change attribution and detection research is often used to investigate the likelihood that an event would occur or the intensity of the event with and without climate change. Often, understanding the intensity of the event is more useful for decision-makers (Ebi *et al.* 2020, 2017; IPCC 2018); therefore, this is often prioritized in health impact assessments (Ebi *et al.* 2020, 2017). In this report, we assessed, when possible, detection and attribution of health impacts of climate change, noting that detection evidence is often more available, and attribution evidence is not always possible.

2.3.2 Cross-cutting themes for this report

Given the complex pathways through which climate affects health and the many factors that modify this relationship, this report aims to highlight several key cross-cutting themes that are crucial to understanding and responding to climate change impacts on health in various geographical and social contexts. Thus, throughout this report we focus on the following themes:

- Urgency of action to limit climate–health impacts.
- Equity in climate–health evidence synthesis and responses.
- The intersection of various social conditions, factors, and characteristics.
- Sustainability, transdisciplinarity, and systems thinking.
- Indigenous knowledge.
- Coupled socio-ecological systems.
- Knowledge communication, including knowledge gaps and uncertainty.
- Cascading and cumulative climate–health risks.
- Issues of scale (geopolitical, temporal, and spatial).

3 How does climate change impact health?

3.1 The scope and scale of climate change health risks

The pathways through which climate change affects health are complex, interconnected, and modified by many environmental, biological, and social factors. Despite these complexities, climate–health risks are generally categorized as direct or indirect impacts. Direct effects include risks such as heat-related morbidity and mortality, as well as injury and death during extreme weather events. Indirect impacts are typically mediated through climate change effects on ecosystems or social systems. These include declining air quality or increasing risks of food- and waterborne diseases as a result of environmental changes, as well as mental health impacts linked to environmental change and social disruptions. It is important to note that these categorizations are broad, and health impacts may be cumulative, cascading, or compounding. For example, heat-related morbidity may include direct impacts on health as well as indirect impacts on mental health, maternal/fetal health, and other outcomes. A conceptual diagram outlining the various pathways and modifiers of climate–health impacts is presented in Figure 3.1. The importance of transdisciplinary and systems thinking approaches is increasingly being recognized as necessary for understanding these complex issues, especially in the context of multiple converging challenges in the 21st century (Bowen and Ebi 2015; Zinsstag *et al.* 2018). Transdisciplinarity and systems thinking represent an important cross-cutting theme of this report.

In this chapter, we present climate–health pathways organized into major health impact categories (Figure 3.2). For each health outcome category there is: (i) a summary of current risks; (ii) a description of future projections; (iii) an outline of possible mitigation and adaptation options; and (iv) an identification of policy-relevant research gaps and recommendations. A synthesis of overarching mitigation and adaptation options and research gaps is presented in Chapters 4 and 5. Case studies are incorporated throughout the report to provide local and regional context and to highlight in-depth

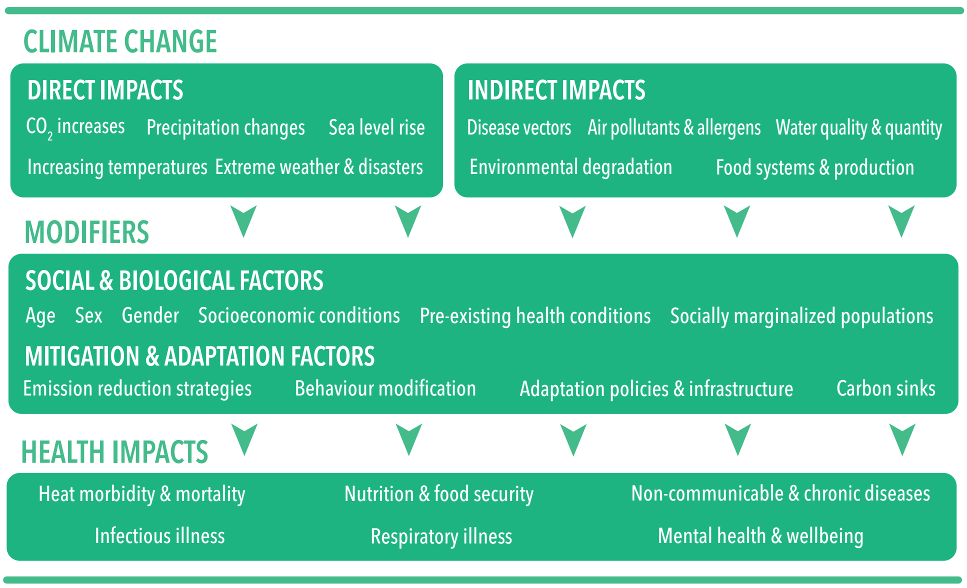

Figure 3.1 An illustration of the conceptual framework that guides this IANAS assessment report.

Figure 3.2 Summary of the climate-sensitive health outcome categories in the Americas that are assessed in this report.

examples of climate–health impacts and response strategies across the Americas.

3.2 Heat-related morbidity and mortality

3.2.1 How does climate change increase the risk of heat-related morbidity and mortality?

Even under low emissions scenarios, the Americas are projected to experience increases in heat-related mortality and morbidities such as heat exhaustion and heatstroke, as well as cardiovascular, renal, and respiratory illnesses linked to heat exposure (Anderson *et al.* 2018b; Ebi *et al.* 2018b; Green *et al.* 2019; Limaye *et al.* 2018; Marsha *et al.* 2018; Morefield *et al.* 2018). Even with strong adaptation efforts, excess mortality due to increased heatwaves is projected across all climate change scenarios in many countries throughout the century, including in Canada, the United States, Chile, Brazil, and Colombia (Guo *et al.* 2018). In the case of the United States, annual heat-related deaths could exceed 36,000 under the moderate Representative Concentration Pathway (RCP)4.5 emission pathway, but would increase to approximately 97,000 annually under the high GHG emission RCP8.5 pathway. These values far exceed the 12,000 heat-related deaths that are estimated to have occurred annually in the United States during the current decade (Shindell *et al.* 2020).

In Nicaragua, approximately 66% of workplaces have no cooling systems. Indoor air temperatures often exceed the local standards for safe work with moderate exertion, a trend that is expected to increase considerably by mid-century (Sheffield *et al.* 2013). In Central America, kidney disease is becoming more prevalent, which may be linked to high temperatures and dehydration, although the specific causes are still under investigation (Glaser *et al.* 2016; González-Quiroz *et al.* 2018). As the risks of heat stress and dehydration increase under climate change, high-risk areas for kidney stone development are projected to expand northward through the United States (Brikowski *et al.* 2008).

Other consequences of increased heat exposure are also gaining increasing attention, including maternal and fetal health impacts (Chersich *et al.* 2020; Zhang *et al.* 2017). For example, in California, increased risk of preterm delivery was associated with higher ambient temperatures (Basu *et al.* 2010), and research conducted in Colombia, Bolivia, and Peru found that exposure to increased temperatures decreased birth weight and increased the probability of low birth weight (Molina and Saldarriaga 2017).

An increasing volume of evidence also supports a link between heat exposure and negative mental health outcomes (Burke *et al.* 2018; Kim *et al.* 2019). Studies have documented an association between extreme heat exposure and suicide in Canada, the United States, Mexico, and Brazil (Burke *et al.* 2018; Kim *et al.* 2019). By 2050, the projected increase in heat-related suicide in the United States and Mexico is estimated to be comparable to other known suicide risk factors, such as economic recessions (Burke *et al.* 2018). This association may be explained by the impact of heat on serotonin function and resultant changes in behavior (Kim *et al.* 2019), although the mechanisms behind this relationship remain unclear.

The impacts of extreme heat exposure are not equitably distributed within and between countries in the Americas, varying greatly on the basis of geography, political landscape, economics, and several biological and social factors (Anderson *et al.* 2018b; Feron *et al.* 2019; Limaye *et al.* 2018; Marsha *et al.* 2018; Morefield *et al.* 2018). The impacts of some social and biological factors on extreme heat-related health outcomes have been well-researched, establishing clear evidence that age, sex, and socioeconomic conditions affect heat-related mortality and morbidity (Green *et al.* 2019; Son *et al.* 2019). For example, in British Columbia, Canada, a heatwave from June 25 through July 1, 2021 resulted in over 500 deaths, which represented a 300% increase in heat-related mortality compared with previous years; of these heat-related deaths, 79% were aged 65 years or older. In Mexico City, projections indicate that the urban heat island effect, together with climate change effects, can increase extreme heat exposure in more urbanized and populated locations within a city (Martilli *et al.* 2020), with the most severe impacts in neighborhoods with lower socioeconomic conditions (Case Study 2). In this context, green spaces can play an important role; for example, the amount of green space in cities has been linked to decreased heat-related health effects (Sera *et al.* 2019). There is less available evidence related to the role of other factors that may affect the relationship between heat exposure and health outcomes, including access to healthcare, housing, education, racism, occupation, and indicators of environmental quality (Green *et al.* 2019; Son *et al.* 2019). These social factors, in addition to human physiological factors (Vanos *et al.* 2020), need to be better integrated into heat–health climate projections to provide more accurate, nuanced, and useful information to policy-makers.

It is clear that climate change will increase heat-related mortality and morbidity, but considerably more research is needed in Central and South America (Berrang-Ford *et al.* 2021b; Harper *et al.* 2021a), which is vital to ensure that past, present, and projected heat–health information within different countries/cities can adequately support country/city-level decision-making to prevent heat-related deaths (Vanos *et al.* 2020). In particular, an ensemble approach has been called for, which not only considers future climate conditions but also future population demographics, human physiology and acclimatization, underlying health conditions, changing socio-cultural norms and behaviors, and adaptation efforts to improve the robustness and utility of future projections (Vanos *et al.* 2020).

3.2.2 What adaptation and mitigation options are available to reduce heat-related morbidity and mortality?

Most of the health impacts of extreme heat exposure are preventable (but see section 4.1.4, outlining the limits of adaptations for heat exposure) through interventions at the individual and population level, emphasizing the importance of adaptation efforts (Vanos *et al.* 2020). Possible interventions, which are not mutually exclusive, may be infrastructural, technological, behavioral, and physiological (Ebi *et al.* 2021b; Jay *et al.* 2021), and include options such as insulation, green infrastructure, external shutters, cool roofs, urban greening, acclimatization, public health programming, subsidies for green initiatives, seeking cooler environments, and changes in clothing. For example, heat warning systems can trigger responses across sectors to protect public health, including providing equitable access to cooling stations, protecting occupational health through regulations, and encouraging behavioral changes (e.g. hydration, checking on neighbors) (Case Study 3). Implementing integrated and intersectoral interventions will require decision-makers to consider different time horizons, as successful adaptation will require both shorter-term (e.g. education and awareness) and longer-term (e.g. long-term city planning for improved green spaces, green infrastructure) interventions. Systematic reviews have indicated that these intersectoral considerations are often overlooked, resulting in insufficient preparedness and/or policies to protect health from extreme heat exposure (Brimicombe *et al.* 2021).

There is evidence that some regions are adapting to increased heat exposure (Arbuthnott *et al.* 2016; Ebi *et al.* 2018a; Sheridan and Dixon 2017) (Case Study 3); however, most of this evidence in the Americas

Case Study 2 Climate change and urban heat island effects in Mexico City

Heat island effects can increase the annual average temperature by 2–6°C in some cities, severely amplifying climate change risks (Estrada *et al.* 2017). This was observed in 2017, when the urban heat island effect in Mexico City resulted in the mean annual temperature being 3.5°C higher than in the surrounding non-urban areas. Projections suggest that the average annual temperature in Mexico City may increase by over 4°C by 2100; however, due to the heat island effect, the more urbanized and populated areas of the city are projected to experience increases of up to 8°C. By 2100, there is a nearly 100% probability that all of Mexico City will experience 5°C of warming. This situation is common to many cities globally; indeed, under a high emissions scenario (i.e. RCP8.5) and with no local urban heat island reduction policies, there is a 60% probability that the mean annual temperatures of all cities will increase by more than 3°C by 2050, and that probability increases to nearly 100% for the most populated areas within cities.

These warming climate conditions present important economic and social risks for Mexicans (Estrada *et al.* 2020; Estrada Porrúa and Martinez López 2011; Sánchez Vargas *et al.* 2011), as heat island effects will amplify health risks disproportionately across different areas and populations within the city (Dell *et al.* 2014; Kjellstrom *et al.* 2018; Sanz-Barbero *et al.* 2018; Watts *et al.* 2019b; Weber *et al.* 2015; WHO 2014b). High-density, low-income populations living in areas with higher concentrations of concrete and less access to green space, who may also have limited access to health services, a high prevalence of pre-existing health conditions, high levels of social isolation, and reduced access to air conditioning, are at increased risk of heat-related morbidity and mortality (Johnson *et al.* 2009; Wilhelmi *et al.* 2013). These considerations have become increasingly important as the COVID-19 pandemic has negatively impacted the economy and air quality in Mexico City, further exacerbating socioeconomic challenges and inequities (Peralta *et al.* 2020). The elderly are also at higher risk of heat-related morbidity and mortality due to physiology and other socioeconomic factors. Therefore, it is important to consider population changes when projecting climate change risks. The population of Mexico City is projected to substantially change by 2050, with critical shifts in age demographics, including a substantially smaller youth population and a substantially larger elderly population (Angel *et al.* 2017).

Proposed modifications to the built environment of Mexico City to reduce heat island effects include expanding areas covered by trees and plants, creating green- and white-colored roofs, and creating pavements with materials that reflect solar energy and release heat quickly. These types of action have clear short- and long-term advantages and relatively low implementation costs, as well as substantial potential health benefits, particularly for the most vulnerable populations. Important additional benefits of these changes to the built environment include reduced energy consumption, increased aesthetic value, and reduced risk of flooding. However, the most effective solutions to reducing heat-related risks are underpinned by equity considerations; for example, initiatives to reduce poverty play a critical role in climate change adaptation for Mexico City and other cities globally.

Case Study 3 Impacts of and solutions to heatwave mortality in Argentina

Research indicates that the frequency and intensity of extreme heat is increasing in Argentina. Rusticucci *et al.* (2016) found that the number of extreme heat days (i.e. those days above the 90th percentile for maximum temperature, using 1960 as the reference year) increased fourfold between 1960 and 2000 in the northwestern region of the country. The frequency of heatwaves has also increased as a result of climate change, with multiple extended heatwaves that were previously classified as one-in-100-year events occurring between 2013 and 2018. Barros *et al.* (2015) reported that the summers of 2013–2014 represented the longest extended heatwaves ever recorded in Argentina, which had substantial impacts on the energy supply in the Buenos Aires region.

In Argentina, the association between high temperatures and mortality was first studied in the cities of Buenos Aires and Rosario (Almeira *et al.* 2016). Although heat-related deaths did not differ substantially by sex, age was identified as a key risk factor, with individuals older than 65 years representing 70–80% of heat-related deaths. On the basis of these data, the Argentina National Weather Service implemented an alert system in both cities with the aim of anticipating extreme meteorological situations to protect public health. The warning system has been expanded to cover the entire country from October to March, which are the hottest months of the year, and could serve as an excellent adaptation tool to improve the resiliency of health systems. An investigation into the impacts of the expanded warning system could provide an opportunity to evaluate the efficacy of these types of warning system for protecting health (Toloo *et al.* 2013; Weinberger *et al.* 2021). The National Weather Service of Argentina is attempting such an evaluation using 3-month probabilistic forecast data for extreme minimum and maximum temperatures, in an effort to better prepare for extreme temperature events and the resultant impacts on health (Collazo *et al.* 2019).

Other solutions to reduce heat-related deaths include those aimed at understanding climate–health impacts through an interdisciplinary lens. These include the research and program development efforts of the Latin American Climate-Health Observatory, sponsored by the Latin American Center for Interdisciplinary Training (CELFI-Datos); the Government Secretariat for Science, Technology and Productive Innovation; and the Ministry of Education, Culture, Science and Technology of Argentina. For example, the Observatory was developed through consultation with a team of students and experts in Buenos Aires in September 2019 to examine several interdisciplinary solutions to local environment–health issues. The proposals being developed represent promising approaches to addressing the complex and multifaceted challenges posed by climate change in Latin America, including reducing heat-related mortality.

comes from Canada and the United States (Hondula *et al.* 2015) and this adaptation is far more challenging in countries, communities, and households facing higher mean and extreme temperatures, lower adaptive capacity, changing demographics, and reduced access to resources, highlighting the importance of equity considerations in response options. For example, future programming and infrastructure planning must consider the specific needs of older populations in many urban centers, as the age distribution

Case Study 4 Heatwaves in Brazil

In Brazil, a series of nationwide epidemiologic studies investigated the role of temperature and temperature variability on morbidity using hospital admissions data from the public health system (Wu *et al.* 2021; Xu *et al.* 2019a, 2019b, 2020b, 2020c; Zhao *et al.* 2018, 2019a, 2019b, 2019c, 2019d). The data in these studies covered 15 years (2000–2015) of daily admissions obtained from 1,869 hospitals with a coverage area representing approximately 70% of the Brazilian population. Generally, temperature deviations from the thermal comfort zone were significantly associated with increased hospital admissions for different diseases, such as cardiovascular conditions, respiratory illnesses, and diabetes (Wu *et al.* 2021; Xu *et al.* 2019a, 2019b, 2020b, 2020c; Zhao *et al.* 2018, 2019a, 2019b, 2019c, 2019d). Children, the elderly, undernourished individuals, and economically deprived people were the most affected by extreme temperatures (Xu *et al.* 2020b; Zhao *et al.* 2018). These results reinforce the concept that climate changes can lead to sustainability and health consequences, but these changes also affect human rights and dignity.

continues to shift in many cities globally (Case Studies 2 and 4). Furthermore, the role that air conditioning has played in adaptation strategies (Sera *et al.* 2020; Vanos *et al.* 2020) demonstrates the need to combine adaptation and mitigation strategies to reduce health risks. For instance, the use of air conditioners to reduce heat exposure is projected to increase mortality from air pollution in the United States, if electricity generation does not transition to renewable sources (Abel *et al.* 2018). Under a high emissions climate change scenario, adaptation efforts are projected to substantially reduce the mean percentage change in heatwave-related excess deaths in Brazil, Canada, Chile, Colombia, and the United States; nonetheless, even with substantial adaptation efforts, the mean percentage increase in heatwave-related excess deaths will still be substantially greater under a high emissions scenario compared with a lower emissions scenario that might be achieved with sustained mitigation efforts (Figure 3.3) (Guo *et al.* 2018).

3.3 Air pollution-related illnesses

3.3.1 How does climate change increase the risk of air pollution-related illnesses?

Ambient air pollution is the world's largest environmental cause of disease and premature death (Academy of South Africa *et al.* 2019; Landrigan *et al.* 2018). The Global Burden of Disease (GBD) study estimated that, in 2019, ambient air pollution was responsible for approximately 6.67 million (95% confidence interval 5.9–7.5 million) premature deaths worldwide and for approximately 206,000 deaths in the Americas (GBD 2019 Risk Factors Collaborators 2020) (Figure 3.4 and Table 3.1). Other estimates based on alternative exposure scenarios and newer exposure–response functions suggest that the annual global numbers of premature deaths attributable to air pollution may be as high as 9–12 million (Burnett *et al.* 2018; Lelieveld *et al.* 2019b; Vohra *et al.* 2021) (Case Study 5).

Ambient air pollution is worsening as climate change progresses. The number of annual global deaths attributable to ambient air pollution has increased by 51% since 1990, and the number continues to rise (Landrigan *et al.* 2018). In the absence of aggressive interventions, the number of global deaths attributable to ambient air pollution is projected to double by 2050 (Lelieveld *et al.* 2015).

Climate change and air pollution are intimately linked (Academy of South Africa *et al.* 2019). Fuel combustion – fossil fuel combustion in high and middle income countries and biomass burning in low income countries – is responsible for 80% of the GHGs and short-lived climate pollutants that drive climate change (Scovronick *et al.* 2015). Additionally, fuel combustion creates 85% of airborne particulate pollution and almost all air pollution associated with sulfur and nitrogen oxides (SO_x and NO_x) (IEA 2016). Importantly, "changes in air quality (near-surface ozone and particulate matter, or PM) at global and local scales are predominantly driven by changes in ozone and aerosol precursor emissions rather than climate" (IPCC 2021).

Coal is the world's most polluting fossil fuel, and coal combustion is a key driver of climate

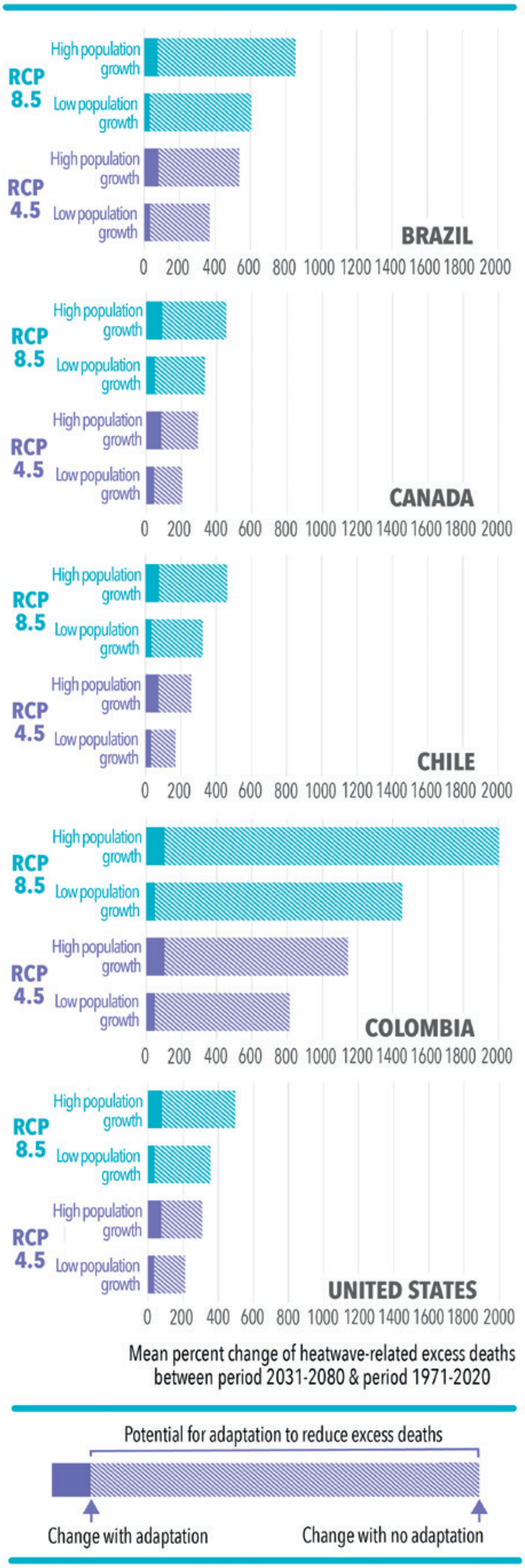

Figure 3.3 Mean percentage change of heatwave-related excess deaths between period 2031–2080 and period 1971–2020 with and without adaptation measures in Brazil, Canada, Chile, Colombia, and the United States (data to create figure from Guo et al. 2018).

change. Natural gas, which has become increasingly abundant due to wide-scale hydraulic fracturing (i.e. "fracking"), has been portrayed as a cleaner alternative with less climate impact than coal or oil (Landrigan *et al.* 2020). This claim is partly true because gas combustion generates less CO_2 per unit of energy production than combustion of coal or oil, and it produces only negligible quantities of sulfur dioxide and airborne particulate pollution. However, natural gas extraction and use make much larger contributions to climate change than are generally recognized. For example, as much as 4% of all gas produced by fracking is lost to leakage, and massive amounts of gas leakage from fracking seem to have contributed to recent sharp increases in atmospheric methane concentrations (Howarth 2019). Methane is a potent driver of global warming, with a heat-trapping potential 30 times greater than that of CO_2 over a 100-year span and 85 times greater over a 20-year span. In addition, natural gas combustion generates CO_2 and contributes to air pollution through the production of nitrogen oxides, which are potent respiratory irritants.

More than 70% of the deaths caused by air pollution are due to non-communicable diseases: heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, diabetes, and pneumonia in adults; and premature birth and low birth weight in infants (Landrigan *et al.* 2018). Evidence is mounting that air pollution may increase the risk of disease and death from additional causes beyond those currently considered in the Global Burden of Disease study, suggesting that current estimates may be conservative undercounts of the full toll of air pollution on human health. Most worrisome are reports that airborne particulate pollution may increase the risk of neurocognitive and neurobehavioral diseases, such as reduced IQs and increased risk for attention deficit/ hyperactivity disorder and autism spectrum disorder in children (Perera *et al.* 2019; Volk *et al.* 2021); and increased risk of dementia in adults (Heusinkveld *et al.* 2016).

AMBIENT AIR POLLUTION DEATHS IN THE AMERICAS, 2019

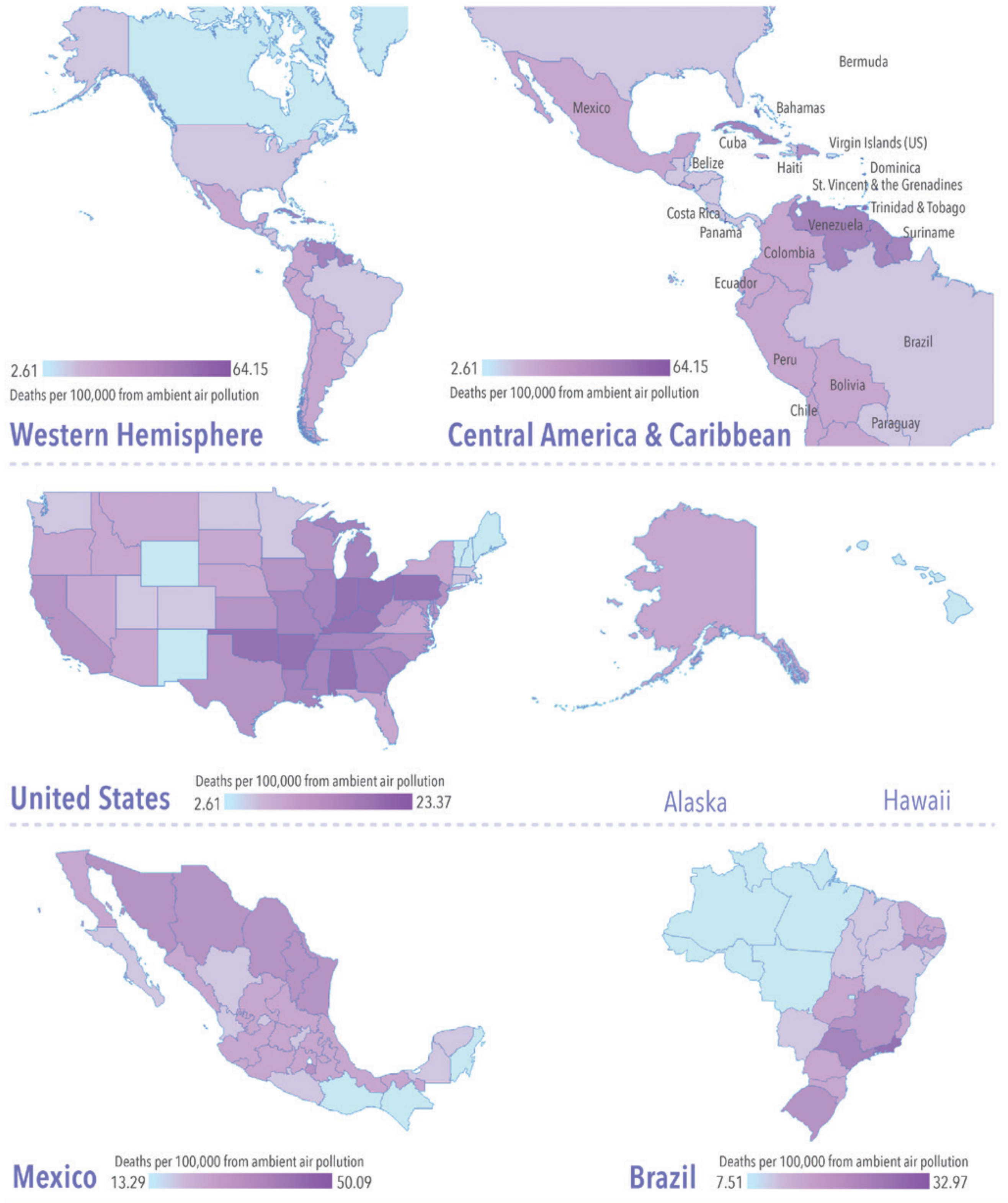

Figure 3.4 Deaths per 100,000 people attributable to ambient air pollution by country, Western Hemisphere, Central America, and the Caribbean, 2019, as well as by state for the United States, Mexico, and Brazil (data to create figure from GBD 2019 Risk Factors Collaborators 2020).

Table 3.1 Mortality attributable to ambient air pollution by country in the Americas, 2019 (data from GBD 2019 Risk Factors Collaborators 2020)

Country	Number of deaths (95% confidence interval)	Deaths per 100,000 people (95% confidence interval)
Antigua and Barbuda	30 (12–50)	34 (14–57)
Argentina	12,590 (7,871–17,879)	28 (17–40)
Bahamas	99 (29–183)	26 (8–49)
Barbados	175 (83–276)	59 (28–93)
Belize	93 (35–159)	23 (9–39)
Bermuda	8 (1–16)	12 (2–24)
Bolivia	3,885 (2,406–5,610)	32 (20–47)
Brazil	43,575 (31,146–57,276)	20 (14–26)
Canada	3,765 (1,767–6,033)	10 (5–17)
Chile	5,808 (4,598–6,939)	32 (25–38)
Colombia	13,033 (8,864–18,222)	27 (19–38)
Costa Rica	938 (643–1,271)	20 (14–27)
Cuba	5,845 (2,901–9,669)	51 (26–85)
Dominica	33 (14–55)	48 (21–80)
Dominican Republic	3,798 (1,791–6,777)	35 (16–62)
Ecuador	4,236 (2,782–5,921)	24 (16–34)
El Salvador	1,901 (1,176–2,913)	30 (19–47)
Greenland	6 (1–17)	11 (1–30)
Grenada	51 (21–85)	50 (20–82)
Guatemala	3,734 (2,228–5,564)	21 (13–31)
Guyana	411 (180–731)	53 (23–95)
Haiti	1,822 (709–3,681)	15 (6–30)
Honduras	1,783 (1,052–2,686)	18 (11–27)
Jamaica	938 (586–1,336)	33 (21–48)
Mexico	36,582 (27,288–46,596)	29 (22–37)
Nicaragua	1,002 (575–1,581)	15 (9–24)
Panama	650 (383–963)	16 (9–23)
Paraguay	1,045 (636–1,604)	15 (9–23)
Peru	8,905 (5,923–12,790)	26 (17–38)
Puerto Rico	427 (93–800)	12 (3–23)
Saint Kitts and Nevis	11 (5–18)	18 (8–30)
Saint Lucia	80 (36–131)	46 (21–75)
Saint Vincent and the Grenadines	62 (26–104)	55 (23–91)
Suriname	261 (127–426)	45 (22–74)
Trinidad and Tobago	890 (326–1,535)	64 (23–111)
United States of America	47,787 (26,056–71,528)	15 (8–22)
United States Virgin Islands	31 (15–48)	30 (15–46)
Uruguay	733 (367–1,164)	21 (11–34)
Venezuela	12,384 (8,086–17,903)	44 (29–64)
Total	**219,407**	

Climate change will worsen ambient air pollution and increase the burden of air pollution-related disease and death through multiple mechanisms. For example, higher mean temperatures and an increased frequency of heatwaves will increase the need to produce electricity to power air-cooling systems, which in turn will increase fossil fuel combustion and generate more GHGs. Climate change may also increase sensitivity to airborne pollutants. For example, high summer temperatures will likely increase cardiovascular sensitivity to airborne particulate pollution and increase mortality from cardiovascular diseases and stroke (Balbus *et al.* 2013).

Ambient air pollution and its health effects are distributed very inequitably and are closely correlated with poverty (Landrigan *et al.* 2018). Ninety-two percent of all pollution-related mortality occurs in low and middle income countries, with the greatest numbers of deaths from pollution-related disease occurring in rapidly developing and industrializing lower middle income countries—reflecting environmental injustice on a global scale. In all countries, irrespective of level of income, the health effects of air pollution are most frequent and severe among the poor and the marginalized. In North America, minority communities, Indigenous Peoples, and communities of color experience disproportionately high levels of exposure to air pollution and suffer disproportionately high rates of pollution-related disease (Academy of South Africa *et al.* 2019; Finkelstein *et al.* 2003; Hajat *et al.* 2015).

3.3.2 What adaptation and mitigation options are available to reduce the risk of air pollution-related illnesses?

Because climate change and air pollution are so closely related, action taken against either of these threats has high potential to be synergistic and to produce multiple benefits. Experience gained over the past half century in high income countries and some middle income countries shows that air pollution can be controlled and air pollution-related disease and death prevented (Landrigan *et al.* 2018). This is proof positive that pollution is not the inevitable price of economic progress. The key to controlling air pollution has been cities, states/provinces, and countries adopting pollution control strategies that are based in law, policy, regulation, and technology, that are science-driven, and that focus on the protection of public health. Targets and timetables are essential, as are both enforcement and incentives. In the United States, concentrations of six common air pollutants have been driven down by about 70% since the passage of the Clean Air Act in 1970. Similar declines have been documented throughout the Americas as gasoline use transitions from leaded to unleaded gasoline (Thomas *et al.* 1999).

Prevention of air pollution has proved highly cost-effective. In the United States, gross domestic product increased by nearly 250% in the same 45-year span over which air pollution fell by 70% (Samet *et al.* 2017). During this time, every dollar invested in the control of ambient air pollution yielded an

Case Study 5 COVID-19 and air pollution-related mortality

Marked reductions in ambient air pollution were observed in 2020 during the early stages of the COVID-19 pandemic, as economic activity and fossil fuel combustion fell precipitously around the world. In northern India, concentrations of fine airborne particulate matter ($PM_{2.5}$) declined by more than 50% (Gautam 2020). In Europe, nitrogen dioxide concentrations fell by 40% and $PM_{2.5}$ concentrations fell by 10% (Myllyvirta and Thieriot 2020). In New York City and Los Angeles, $PM_{2.5}$ concentrations fell by 25–30%.

These COVID-19-related improvements in air quality translated into fewer deaths from pollution-related disease. An estimated 77,000 lives in China were saved in January and February 2020, and 11,000 lives (95% confidence interval 7,000–21,000) were saved in Europe in April 2020 (Auffhammer *et al.* 2020). In subsequent months, as economic activity and energy use resumed, air pollution levels rebounded, so these reductions in rates of air pollution-related mortality are likely to be temporary.

Although these COVID-related improvements in air quality were short-lived, they have enabled us to imagine a world in which improvements in air quality are permanent, skies are blue, and the numbers of premature deaths caused by air pollution are greatly diminished.

estimated US$30 (95% confidence interval $4–88) in benefits, due to the increased economic productivity of healthier, longer-lived populations and to averted healthcare costs (EPA 2011). These findings rebut the common but fallacious claim that pollution control stifles economic growth. The authors of the 2018 *Lancet* Commission on Pollution and Health argued that these highly successful, cost-effective air pollution control strategies are ready to be used on a global scale. They provided a blueprint for the development of climate mitigation strategies related to air pollution reduction (Landrigan *et al.* 2018).

Enduring reductions in air pollution will require both regulations that focus on controlling airborne concentrations of pollutants and those that focus on the control of pollution at its sources. The most effective strategy for achieving this goal is a rapid, government-incentivized transition away from all fossil fuels (coal, gas, and oil) to clean, renewable energy sources (Lelieveld *et al.* 2019a). Governments have access to multiple tools to accelerate such a transition, including the creation of incentives and tax structures that favor renewable energy sources, ending current taxpayer-supported subsidies and tax breaks for the fossil fuel industry (estimated at US$35 billion annually in the United States), and taxing pollutant emissions through the application of the "polluter-pays" principle.

Two recent developments support the feasibility of a swift, society-scale transition to renewable energy. The first is an unexpectedly rapid, nearly fivefold increase (4% to nearly 20%) in the fraction of the world's electricity generated from wind and solar power over the past decade (UNEP and Bloomberg NEF 2019). The second is the steep decline in the cost of producing electricity from solar cells and wind turbines (81% and 45% reductions, respectively) over the same period (Phadke *et al.* 2020). As more electricity is produced from renewable sources, these costs are expected to decrease still further over the next 5 years as additional economies of scale are realized. At the same time, investment in renewable energy is increasing sharply, and in 2021 was expected to exceed spending on oil and gas exploration for the first time (Murtaugh 2020). As a result of these developments, it is now cheaper in many places to produce electricity from wind and solar power than from any fossil fuel. The consequences of this shift include climate change mitigation, pollution prevention, health improvement, and advances in social justice.

3.4 Waterborne illnesses

3.4.1 How does climate change increase the risk of waterborne illnesses?

Associations between warming temperatures and increased water insecurity (Case Study 6) and waterborne illness have been documented globally (Carlton *et al.* 2016; Guzman Herrador *et al.* 2015; Levy *et al.* 2016); however, the effect size or strength of the association varies and is often mediated by other factors. One global study found that all-cause diarrhea increases by 7% for every degree of warming (Carlton *et al.* 2016) regardless of income or geographical location, illustrating the widespread risk. These associations, however, are complex and not always linear. For example, in Peru, cases of diarrhea increased more during warmer winter weather compared with a relatively smaller increase in case numbers during warmer summers (Checkley *et al.* 2000). The evidence base linking warming temperatures to higher incidence of bacterial diarrhea is particularly strong (Carlton *et al.* 2016; Levy *et al.* 2016); however, less evidence is available for viral and parasitic diarrhea (Carlton *et al.* 2016; Young *et al.* 2015b), although evidence suggests that parasitic diarrhea (e.g. cryptosporidiosis and giardiasis) increases with increasing temperatures (Jagai *et al.* 2009; Lal *et al.* 2013). Conversely, the available data suggest that increased risk of norovirus- and rotavirus-related diarrhea is associated with colder temperatures (Carlton *et al.* 2016; Levy *et al.* 2016).

Climate change-related increases in the duration, intensity, and occurrences of heavy rainfall events also increase the risk of waterborne illness throughout the Americas (Guzman Herrador *et al.* 2015; Levy *et al.* 2016; Young *et al.* 2015b). There are many different pathways through which rainfall alters the risk of waterborne illness: for example, rainfall can transport pathogens from livestock, from manure applied to crops, from human wastewater, and from industrial wastewater into drinking water sources. Heavy rainfall events can also challenge and exceed sewage treatment capacity, resulting in untreated and potentially contaminated wastewater being discharged into drinking water sources, which has been associated with increased rates of diarrhea (Guzman Herrador *et al.* 2015; Levy *et al.* 2016). In addition, heavy rainfall can also contaminate drinking water through pathogens infiltrating aging, poorly maintained, and/or inadequately constructed drinking water distribution systems, as well as systems that are placed in high-risk locations that do not provide the level of treatment needed to cope with heavy rainfall events (Exum *et al.* 2018; Jagai *et al.* 2015; Uejio *et al.* 2017). Heavy rainfall leading to flooding can also damage treatment infrastructure or interrupt electricity (Cashman 2014; Kohlitz *et al.* 2017). Conversely, a lack of rainfall and drought can lead to pathogens accumulating or concentrating in the environment, which has also been associated with increased diarrhea cases (Kraay *et al.* 2020). For example, low rainfall can decrease river water levels and flow rates, resulting in higher concentrations of wastewater effluent and increasing the risk of exposure to pathogens for downstream users (Guzman Herrador *et al.* 2015; Levy *et al.* 2016). Additionally, drought conditions can also decrease the efficacy of water and wastewater treatment system processes (White *et al.* 2017). Concurrent, cumulative, and cascading environmental conditions are complex but important in the context of waterborne illness (Levy *et al.* 2016, 2018). For instance, since dry periods can lead to concentrated pathogen levels in the environment, heavy rainfall after dry periods can substantially increase the transportation of pathogens into drinking water, which has been reported in Ecuador (Carlton *et al.* 2014) and in Canada (Chhetri *et al.* 2017). Other components of the hydrological system also create important diarrheal illness risks in the context of climate change. For example, flooding is an important driver of diarrheal diseases for many locations in South America, such as Brazil (Cesa *et al.* 2016) and Peru (Colston *et al.* 2020). Moreover, in the North American Arctic, periods of rapid snowmelt have been associated with increased cases of diarrhea (Harper *et al.* 2011).

Other factors, such as socioeconomic conditions, changing recreational and consumption behaviors in warmer weather, adequate and appropriate access to water and sanitation, population demographics, local pathogen distribution patterns, and land-use patterns, not only modify the risk of waterborne illness but also underpin the adaptive capacity of governments, communities, and households to reduce these risks in a changing climate (Levy *et al.* 2016, 2018; Semenza 2020). Despite the important role that these factors play in altering the risk of climate-related waterborne illness, less than 10% of studies globally include variables related to socioeconomic conditions, access to water, type of source water, land use, population density, education, or human mobility (Lo Iacono *et al.* 2017).

There is clear evidence that climate change increases the risk of waterborne illness; however, the mechanisms underlying this risk are complex and research gaps exist. First, diarrhea is not a single disease: it can be caused by several different pathogens (e.g. bacteria, viruses, parasites) through several different transmission pathways (e.g. water, food, person-to-person contact), which makes the causal pathway from climate change to waterborne illness challenging to study. Furthermore, it is difficult to make comparisons across studies (Guzman Herrador *et al.* 2015; Kraay *et al.* 2020). Therefore, there is a need to go beyond studying all-cause diarrhea and to examine specific pathogens when possible (Levy *et al.* 2016).

Furthermore, although we focus on diarrhea in this section, it is important to note that some waterborne pathogens cause other symptoms, such as vomiting, and do not cause diarrhea or cause other symptoms in addition to diarrhea; this further highlights the importance of conducting analysis specific to pathogens when possible. Additionally, the local context matters when assessing the causes of diarrheal illness, so the geographical disparities in research that exist between North America and Central and South America (Carlton *et al.* 2016; Guzman Herrador *et al.* 2015; Lo Iacono *et al.* 2017) present important challenges for understanding the context-specific exposure–response pathways for climate change-related waterborne illness in the Americas. The effect of local conditions also complicates comparisons. For instance, extreme precipitation and temperatures need to be defined according to local conditions, and therefore a wide variety of exposure variables should be considered in analyses and will likely vary by study (Guzman Herrador *et al.* 2015). The local nature of contamination events can also mask associations between extreme weather events in regional and national analyses (Guzman Herrador *et al.* 2015). Finally, data challenges exist, including concerns about data quality (e.g. spatial and/or temporal resolution of data, data accuracy), differences in environmental–social–health data integration capabilities, reporting biases, and collinearity in exposures (Lo Iacono *et al.* 2017; Mellor *et al.* 2016). For instance, waterborne illness is known to be substantially underreported in surveillance systems, which can be a source of bias when the cause of underreporting is correlated with weather variables (e.g. during extreme events, healthcare provision can be impacted) (Guzman Herrador *et al.* 2015; Lo Iacono *et al.* 2017). Future research should examine how factors such as the type of microorganism, geographical region, season, type of water supply, water source, and/or water treatment measures modify the effect of warming temperatures and changing precipitation on waterborne illnesses (Guzman Herrador *et al.* 2015). Finally, changing precipitation patterns due to climate change can be more challenging to project than temperature, which has important implications for health (e.g. see Case Study 7).

3.4.2 What adaptation and mitigation options are available to reduce the risk of waterborne illnesses?

There is strong evidence that access to water, sanitation, and hygiene infrastructure reduces the risk of waterborne illness and has contributed to reducing the global burden of disease; it is, therefore, important in the context of climate change adaptation (Case Study 9). For example, in Guatemala, rainfall was associated with fecal contamination in wells, especially where pigs were reared nearby (Eisenhauer *et al.* 2016). In Ecuador, inadequate access to safe drinking water was associated with increased rates of diarrhea after heavy rainfall, whereas inadequate access to sanitation was associated with increased diarrhea rates after dry periods (Bhavnani *et al.* 2014). In Canada and the United States, untreated drinking water is associated with increased waterborne illnesses during heavy precipitation events, which are projected to increase with future climate change (Galanis *et al.* 2014; Harper *et al.* 2020; Uejio *et al.* 2017). Strategies to improve access to safe water and sanitation include institutional adaptation options, such as conducting more assessments of water resources, implementing climate-resilient water safety plans, investing in disaster risk reduction, improving delivery of services to the underserved, and using microfinance and microinsurance mechanisms to build small-scale infrastructure (Howard *et al.* 2016; Levy *et al.* 2018). Other adaptation options include technical interventions to reduce pathogen growth in drinking water. For example, sourcing water from cooler depths, designing systems to reduce the time that water remains in pipes, and painting exposed pipes and tank roofs white to reduce heat absorption can all reduce the risk of waterborne illnesses (Levy *et al.* 2018). Importantly, the alignment of the engineered solution with the local social, cultural, and environmental context will ultimately determine the success or failure of adaptation options (Mellor *et al.* 2016). More research is needed to investigate the extent to which adaptations such as improved water and sanitation access can reduce waterborne disease risks under future climate change scenarios (Levy *et al.* 2016).

Climate change mitigation should be considered alongside adaptation efforts that improve access to safe water and sanitation, as water and sanitation services contribute to GHG emissions (Dickin *et al.* 2020; Howard *et al.* 2016). There are opportunities to reduce emissions when implementing new systems, maintaining existing systems, and developing new technologies, for example by improving pumping efficiency, optimizing aeration in wastewater treatment, reducing emissions during removal of nutrients from wastewater, using renewable energy sources, and developing within-system energy generation (Howard *et al.* 2016). There is also potential to capture methane from wastewater treatment plants, which could potentially confer multiple benefits including GHG mitigation, cleaner water, and reduced tropospheric ozone, as methane is an ozone precursor (GMI 2013).

Case Study 6 Climate change, water, and health in the Caribbean

The location, size, and geographical features of countries located in the Caribbean make this region of the world especially exposed and vulnerable to many of the adverse effects of climate change (Nurse *et al.* 2014). Caribbean countries are located in one of three geographical regions that have been classified by the United Nations as Small Island Developing States (SIDS) (Figure CS 6.1). This classification recognizes SIDS as countries with unique social, economic, and environmental challenges, and, in the context of climate change, these areas face heightened challenges in protecting and preserving the health of their citizens. In the three SIDS regions from 1966 to 2015, 60% of all climate-related disasters, 90% of all deaths, 79% of all affected persons, and almost 90% of all damage costs occurred in the Caribbean (PAHO 2019).

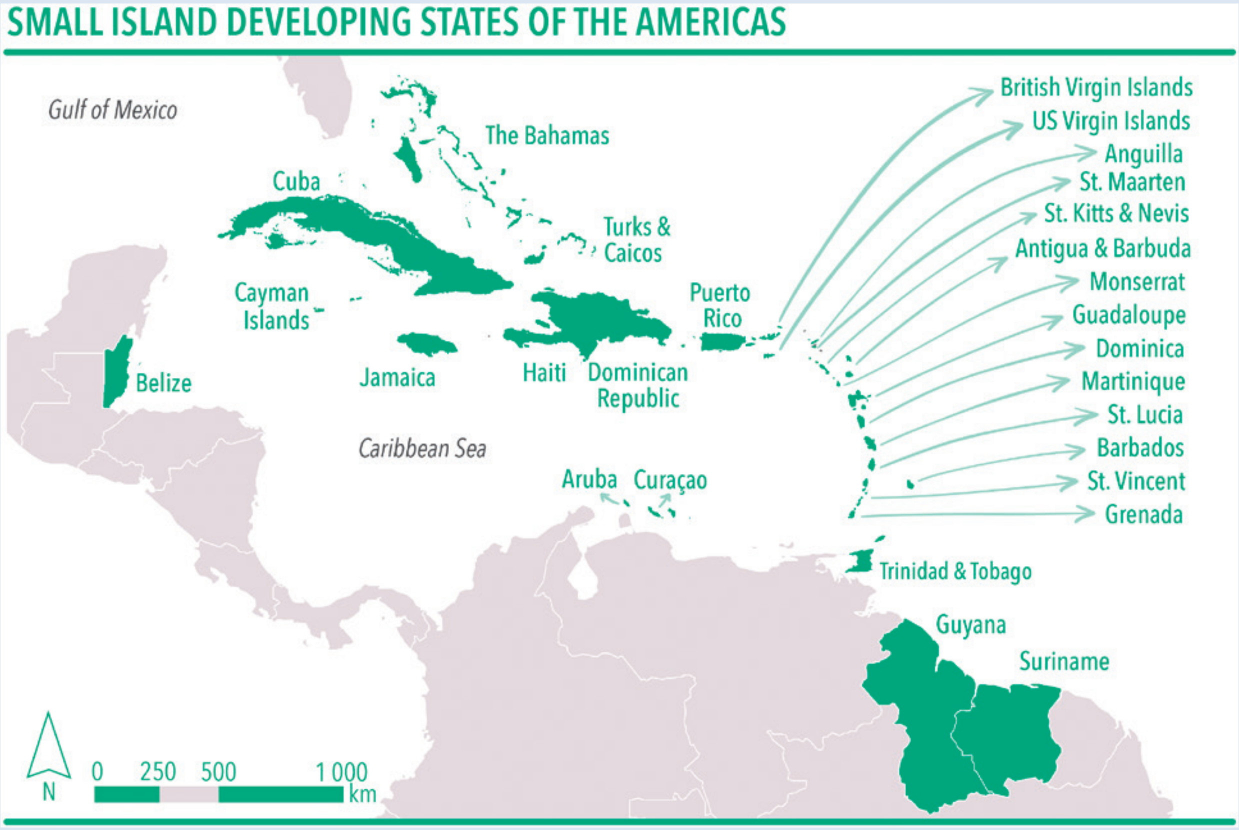

Figure CS 6.1 Map of Caribbean countries classified as SIDS by the United Nations.

Climate change-driven events, such as flash flooding and hurricanes, coupled with climate-sensitive vector-borne diseases, place additional burdens on already overburdened SIDS healthcare systems that have limited human and capital resources to adequately care for the populations they serve. This situation is further compounded by the fact that the healthcare delivery systems in many Caribbean SIDS are situated in coastal areas, which are most vulnerable to hurricanes, floods, and damage to vital supporting amenities such as water and electricity supplies (Figure CS 6.2). If a predicted sea level rise of more than 1 meter materializes by 2100, this will cause significant and profound damage to infrastructure, which in many Caribbean islands is predominately located in or near coastal areas (UNDP 2010).

Figure CS 6.2 St. Georges' General Hospital, Grenada (photograph: Martin Forde).

Ocean warming, which is one key feature of climate change, has led to an increase in the severity of hurricanes and precipitation events in the Caribbean. From 1966 to 2015, 449 severe weather events were documented that inflicted significant harm and damage to the health, livelihoods, and economies of those living in the Caribbean (EM-DAT 2018). For example, in Grenada, the total damage caused by Hurricane Ivan in 2004 was estimated to exceed 2.4 billion Eastern Caribbean dollars, an amount that was twice the value of the island's gross domestic product in that year (Government of Grenada 2017). Similarly, the passage of Hurricanes Irma and Maria in 2017 resulted in cumulative losses of at least US$5.4 billion in Anguilla, the Bahamas, the British Virgin Islands, Saint Maarten, and the Turks and Caicos Islands (Asariotis 2018).

Water insecurity is also projected to increase in the Caribbean as the impacts of climate change become more pronounced. Longer dry seasons, changing precipitation patterns, and unpredictable extreme weather events have caused severe strain on agricultural systems, leading in many instances to devastating losses. Furthermore, the occurrence of unprecedented droughts, such as the one that occurred in Grenada in 2010 or the droughts in Haiti and Jamaica since 2015, has further heightened the risk of water insecurity in many Caribbean countries (WHO *et al.* 2020).

Overall, the impact climate change will have on the health of those living in the Caribbean is anticipated to become progressively worse over time. Morbidity and mortality numbers are expected to rise because of the increased number of persons impacted by extreme weather-related events and a concomitant rise in the incidence of climate-driven waterborne and vector-borne diseases. Sadly, this is happening against the backdrop of already weakened and overburdened healthcare infrastructure that will be tasked with taking care of increasing numbers of persons adversely affected by climate change.

Case Study 7 Climate change modelling in Central America: implications for decision-makers in the context of health adaptation

Central America represents a unique climatic region of complex topography between the Pacific Ocean and the Caribbean Sea. Large-scale natural climate processes originating in these two bodies of water greatly influence the continental climate, including the El Niño–Southern Oscillation, the North Atlantic Subtropical High, the Intertropical Convergence Zone, and the trade winds that impact the Caribbean Low-Level Jet. The region experiences high levels of climate variability at different spatial and time scales, and extreme events associated with natural weather phenomena often produce severe environmental and socioeconomic impacts (Hidalgo and Alfaro 2012; Hidalgo *et al.* 2013). Temperature has increased significantly in many parts of Central America, with trends in extreme temperature indices over the past 25 years suggesting a higher frequency of warm days/nights and a lower frequency of cold days/nights (Alfaro-Córdoba *et al.* 2020; Hidalgo *et al.* 2019; Stephenson *et al.* 2014). Changes in regional precipitation trends are generally less consistent (Stephenson *et al.* 2014), but even in the absence of significant precipitation changes, increased temperatures can lead to reduced water availability, drier soils, and increased aridity (Alfaro-Córdoba *et al.* 2020; Hidalgo *et al.* 2017), which can impact agricultural activities, the environment, and the potential for wildfires—all of which have important implications for human health.

Climate and hydrological models of the region project that temperatures in Central America will increase by 1–2°C by mid-century and by as much as 4°C at the end of the century compared with the baseline period (1950–1999), whereas precipitation is not likely to change considerably over the first half of the century and may decrease by about 10% towards the end of the century, especially in the northern part of Central America (Hidalgo and Alfaro 2012; Hidalgo *et al.* 2013). Aridity has been increasing in isolated spots in Central America (Alfaro-Córdoba *et al.* 2020), and the conditions projected by these models suggest that aridity may increase significantly, particularly for northern countries. This may have important socioeconomic impacts, especially considering that agriculture is the principal productive sector in most Central American economies, which could translate into important impacts on food security, nutrition, and mental health. A north–south socioeconomic gradient already exists in the region, and climate change may exacerbate this contrast (Hidalgo and Alfaro 2012), resulting in increased inequity, higher levels of migration, and increased vulnerability to disasters and poverty (Hidalgo 2021), with compounding and cascading health impacts.

Some current adaptation strategies are guided by the results of climate model simulations. However, before investing resources in a sophisticated modelling effort, stakeholders and decision-makers must first decide whether the modelling approach is consistent with local goals, resources, and adaptative capacity (Hidalgo 2021; Nissan *et al.* 2019). It is also important to critically examine modelling results and consider the uncertainty in these estimations before using them to inform management decisions. This is especially true in a region of scarce resources such as Central America, where optimization of adaptation resources is critical (Hidalgo 2021; Nissan *et al.* 2019). If a modelling approach is justified, decision-makers should be aware that planning horizons could differ from the modelling horizons (Nissan *et al.* 2019); for example, relatively short-term decisions might be necessary, but clear climate trends may not arise until longer periods are analyzed because natural climate variability may obscure long-term trends (Hidalgo 2021).

In addition, it is also important that decision-makers consider social factors such as health status, immigration, poverty, population growth, and economic development, which can increase vulnerability to extreme weather events (Hidalgo 2021; Hidalgo and Alfaro 2012). Transdisciplinary collaboration is needed between institutions that generate climate forecasts and the end users of those forecasts to ensure that modelling exercises match the needs of decision-makers, that relevant results are made available both inside and outside the health sector, and that vulnerabilities are taken into account (Hidalgo 2021; Nissan *et al.* 2019). Climate modelling is a dynamic and constantly changing effort, and as future trends evolve and new data and techniques become available, new and ongoing analyses will need to be performed to improve the accuracy and timeliness of results to inform resource management and adaptation planning (Hidalgo 2021) to support and protect human health.

3.5 Foodborne illnesses

3.5.1 How does climate change increase the risk of foodborne illnesses?

Climatic conditions are often linked to foodborne illness, including clear associations between the prevalence of foodborne pathogens and temperature, precipitation, extreme weather events, and ocean warming and acidification (Fleury *et al.* 2006; Hellberg and Chu 2016; Lake and Barker 2018; Liu *et al.* 2013; Semenza *et al.* 2012b, 2012a). Even a 1°C increase in average ambient temperatures can result in significant food safety concerns (Smith *et al.* 2015), and increasing temperatures and extreme weather events are considered among the top factors influencing food safety (Charlebois and Summan 2015).

Agricultural activities – including gathering/catching, growing, rearing, and harvesting foods and livestock – are impacted by climate change. For instance, warming temperatures and changes in precipitation can increase the release of pathogens from livestock into the environment (Dickin *et al.* 2016; Smith and Fazil 2019). Indeed, many livestock animals carry and shed greater numbers of enteric pathogens in warmer temperatures (Keen *et al.* 2003; Pangloli *et al.* 2008; Venegas-Vargas *et al.* 2016), and changing precipitation patterns can increase manure run-off, both of which can increase pathogen abundance in the surrounding environment, crops, and, consequently, food. Increased temperature stress or alterations to livestock housing conditions in response to climate change could also prompt producers to increase antimicrobial use in food-producing animals, which could lead to increases in antimicrobial-resistant foodborne illnesses (MacFadden *et al.* 2018; WHO 2017). Climate change can also impact wildlife populations (e.g. rodents, deer, insects) in ways that can increase foodborne pathogen transmission (Agunos *et al.* 2014). For example, climate variables affect fly population density (Goulson *et al.* 2005; Ngoen-klan *et al.* 2011), and flies can be carriers of foodborne pathogens, such as *Campylobacter* spp. (Hald *et al.* 2008). In Ontario, Canada, a 28–30% increase in campylobacteriosis incidence in humans is projected by 2050 because of climate-related changes in fly population size and activity (Cousins *et al.* 2019).

Climate change can also increase the prevalence of pathogens during food processing and distribution activities. For example, warmer air temperatures are associated with the contamination of poultry with *Campylobacter* spp. in Canadian processing and retail environments (Smith and Fazil 2019). Additionally, pre-existing contamination can proliferate if food is stored at inappropriate temperatures. For instance, extreme weather events can result in power outages that disrupt refrigeration and increase foodborne illness risks (Kosa *et al.* 2011, 2012; Marx *et al.* 2006), and warming air temperatures can make traditional food storage methods unsafe in some Indigenous communities (Dudley *et al.* 2015; IPCC 2019a; Parkinson and Butler 2005). Humidity and precipitation also play important roles in food safety. For example, during the processing of maize and cereal-grain products, humidity is associated with increased prevalence of microorganisms, such as fungi that produce mycotoxins (Duarte *et al.* 2010; Patriarca and Fernández Pinto 2017). Projections indicate that the prevalence of mycotoxins will increase with climate change (Smith *et al.* 2015). Additionally, food, especially produce, can become contaminated when contaminated water is used during processing, production, irrigation, and growing (Dickin *et al.* 2016). The use of contaminated water may become more common as climate conditions lead to increases in the prevalence of waterborne pathogens and if sanitation infrastructure is overburdened or damaged because of extreme weather events (see Section 3.4).

Finally, climate change also impacts safe food preparation and consumption. For instance, climate-related behavioral changes can increase foodborne pathogen exposure through both higher-risk cooking preparation methods (e.g. barbeques) and consumption patterns (e.g. picnics, food preferences) (Liu *et al.* 2013; Milazzo *et al.* 2017; Ravel *et al.* 2010). Furthermore, the risks of climate-related foodborne illnesses will vary across the Americas due in part to regional and local consumption preferences. For example, the risk of seafood-associated foodborne illness will likely be higher in coastal regions where seafood consumption is common (IPCC 2019a) (Case Study 8).

Although increasing evidence confirms the pathways through which climate change can impact food safety, less is known about the projected magnitude of those impacts. Few studies have examined the relationships between climate change and enteric illnesses that are directly attributed to food consumption rather than other exposure pathways such as contaminated drinking water, contact with animals, and human-to-human transmission. Furthermore, the exposure pathways linking climate change to foodborne illness are complex. For instance, flooding and irrigation may be associated with increased run-off and contamination of crops; however, increased rainfall could both increase risks of contamination due to more flooding and/or reduce risks due to less irrigation. Therefore, analyses that capture the complexity of food production systems in a particular context or location are required to understand how climate change will ultimately affect foodborne public health risks under different adaptation options (Government of Canada 2017; Romero-Lankao *et al.* 2014).

3.5.2 What adaptation and mitigation options are available to reduce foodborne illnesses?

Various public health measures are known to reduce microbial contamination of food, presenting opportunities to expand climate-related monitoring and response initiatives and enhance existing programs to support climate change adaptation. Promising adaptation strategies include Hazard Analysis and Critical Control Point approaches, utilizing new scientific detection tools for various pathogen–food combinations, improved and better-integrated epidemiological surveillance, new tools for monitoring pathogens and disease (e.g. integrated environment and health monitoring, such as FoodNet in Canada), strengthened animal health surveillance, integration of food safety considerations into existing emergency preparedness plans, and improved coordination among sectors. Improved modelling techniques and better integration of climate, food, environment, and other data sources into surveillance programs can support more sophisticated analyses, enhancing the ability to predict or project emerging food safety risks. For instance, when warmer water temperatures or a strong El Niño climate pattern are predicted, this could trigger public health responses including adjustments to industrial practices, modified regulatory policies, and public outreach to reduce the risk of seafood-related illnesses (Martinez-Urtaza *et al.* 2010; Smith *et al.* 2015). Additional public health responses can include harvesting seafood from deeper and colder waters to reduce pathogen levels at harvest (Martinez-Urtaza *et al.* 2010), implementing more stringent post-harvest time–temperature controls to limit pathogen growth, and applying post-harvest processes such as mild heat, high hydrostatic pressure, and freezing that can reduce pathogen levels while generally retaining the products' original raw sensory characteristics (Martinez-Urtaza *et al.* 2010; Smith *et al.* 2015).

Case Study 8 Climate change and foodborne illness linked to seafood in the Americas

The impact of climate change on warming water temperatures is expected to increase the risk of foodborne illness due to contaminated seafood. Specifically, consumption of raw or undercooked shellfish contaminated with pathogenic *Vibrio* bacteria is projected to increase throughout the Americas as marine environments become warmer and more suitable for these pathogens. Water temperature is the predominant factor impacting *Vibrio* growth, with most species able to proliferate at temperatures of 15°C or above (Baker-Austin *et al.* 2018; Young *et al.* 2015a).

Exposure to *V. parahaemolyticus*, *V. vulnificus*, and *V. cholerae* can result in gastrointestinal illness, including diarrhea, nausea, abdominal cramps, fever, severe dehydration, and, in rare instances, sepsis. Severity of symptoms can range from self-limiting to life-threatening depending on the species and virulence of the particular strain. For example, although less common than *V. parahaemolyticus*, *V. vulnificus* infections are far more severe, accounting for 95% of fatalities associated with seafood consumption in the United States (Froelich and Noble 2016).

Outbreaks of *Vibrio* spp. infections linked to shellfish have been documented throughout coastal areas of North America and are projected to increase over time. For example, in British Columbia, Canada, models indicate that the risk of *V. parahaemolyticus* in oysters may increase by as much as 45% by 2060 (Smith *et al.* 2015), while in recent years *V. cholerae* has been detected with increased frequency in coastal areas of western Canada (Banerjee *et al.* 2018). Outbreaks of *V. parahaemolyticus* linked to oysters have also been documented in Alaska, United States, where mean water temperatures are expected to continue increasing over time, supporting the growth of *Vibrio* pathogens that historically did not thrive in this region (McLaughlin *et al.* 2005).

In South America, *V. parahaemolyticus* and *V. vulnificus* outbreaks linked to seafood have been documented since the 1970s in countries including Brazil, Venezuela, Colombia, Ecuador, Peru, Chile, and Uruguay (Fuenzalida *et al.* 2006; Raszl *et al.* 2016). However, given the lack of formal monitoring programs and the fact that *Vibrio* spp. infections are not notifiable diseases throughout most of South America, it is probable that cases have been underreported on the continent (Raszl *et al.* 2016). Importantly, El Niño events and warming ocean waters have been linked to increases in *V. cholerae* levels and to *V. parahaemolyticus* outbreaks on the Pacific coast of South America, highlighting the potential for climate change to increase the risk of foodborne illness through impacts on ocean temperatures (Gil *et al.* 2004; Raszl *et al.* 2016). In Mexico, the risk of *V. parahaemolyticus* in oysters was projected to be 11 times higher under a high emissions scenario (RCP8.5) than a low emissions scenario (RCP2.6) by the end of the century; however, this risk could be substantially lowered with adaptation measures, including improving temperature control post-harvest (Ortiz-Jiménez 2018).

3.6 Vector-borne illnesses

3.6.1 How does climate change increase the risk of vector-borne illnesses?

Vector-borne diseases transmitted by arthropod vectors (e.g. ticks, mosquitoes) have increased in incidence and distribution in the Americas. Most vectors, along with the pathogens they carry, are highly sensitive to environmental conditions, and thus will be impacted by climate change. The location, seasonal timing, and abundance of vectors directly depend on weather and climate factors, including high and low temperatures, which impact vector growth and mortality rates, as well as temperature and humidity levels, which affect the ability of vectors to find hosts (Ogden 2017). In addition, many vector-borne pathogens are zoonotic, and climate changes may impact host–pathogen–vector interactions, resulting in complex, interconnected, and multidirectional effects. However, the detection of changes in vector-borne diseases and the attribution of those changes to the effects of climate change remain challenging (Campbell-Lendrum *et al.* 2015) because of the complexity of ecological and social systems that incorporate many diverse and interconnected factors, some of which are climate-dependent (Ebi *et al.* 2017; Ogden 2017; Ogden and Lindsay 2016).

Climate change may also indirectly affect vector densities and the frequency of human–vector contact through human behavior and responses to environmental changes, particularly in Latin American countries. For example, a decrease in water availability due to climate change may require an increase in water storage during dry periods, leading to an increase in breeding sites for some vectors such as *Aedes* mosquitoes, and thus more mosquito-borne transmission of diseases (Smith *et al.* 2014). Overall, climate change is projected to increase human exposure to disease vectors; however, these projections are subject to both overestimations and underestimations (Ogden 2017). For example, when mathematical models do not control for climate-independent factors, projections may overestimate exposure increases. Conversely, projections can produce underestimates when models use current distributions of vector-borne diseases and current vector control measures that are not climate-resilient, or if models do not incorporate indirect impacts of climate change on factors affecting vector control (Ogden 2017). Furthermore, models that do not consider host distribution and subsequent changes, as well as the availability of suitable habitat, may lead to inaccurate projections.

Mosquito-borne illnesses

To date, much research has focused on the current and projected impacts of climate change on mosquito populations, given their role in the transmission of malarial parasites and the viruses causing dengue, West Nile disease, and chikungunya. The geographical range of chikungunya is projected to expand into Mexico and the United States by 2050 (Tjaden *et al.* 2017) and into southern coastal British Columbia by the end of the century (Ng *et al.* 2017).

Climate change will also have substantial impacts on the transmission of dengue (Ebi and Nealon 2016), with North America projected to experience one of the largest percentage increases in exposure to the vector globally (Messina *et al.* 2019; Monaghan *et al.* 2018; Proestos *et al.* 2015). The northern geographical range of the dengue vector in the Americas is limited in part by low temperatures (Díaz-Castro *et al.* 2017), so climate warming is projected to create a general northward range expansion (Colón-González *et al.* 2013; Eisen and Moore 2013). Specifically, northward geographical expansion into the southern United States and extended seasonal activity of the dengue vector is projected by mid-century; however, the permanent establishment of the vector in the mainland United States may be prevented by low winter temperatures (Butterworth *et al.* 2017). In Mexico, increased dengue cases are projected for most states under various climate change scenarios, particularly in currently endemic areas (Colón-González *et al.* 2013).

Southward expansion of the vector in South America is also projected by mid-century (Campbell *et al.* 2015; Messina *et al.* 2019; Proestos *et al.* 2015). Colón-González *et al.* (2018) estimated that limiting global warming to 2°C could reduce dengue in Latin America by about 2.8 million cases per year by the end the century compared with a no-policy scenario with warming of 3.7°C; limiting warming to 1.5°C could reduce dengue incidence by 3.3 million cases per year.

West Nile virus continues to spread across North America, and its geographical distribution will continue to expand throughout the century as a result climate change (Harrigan *et al.* 2014). Under various climate change scenarios, northern locations in the United States (e.g. Colorado, Connecticut, Illinois) are projected to experience increased abundance of the West Nile vector, whereas currently warm areas (e.g. El Paso, Texas, and Chandler Heights, Arizona) may become too hot for mosquito development and survival by mid-century (Brown *et al.* 2015). In the southern United States, the mosquito season is projected to start several weeks earlier and end several weeks later in most areas, although decreased population densities are projected during the summer in the southern-most areas by the middle of the century (Morin and Comrie 2013). Across various climate change scenarios, an increase in the incidence of West Nile virus infections is predicted for the Canadian prairies because of a longer mosquito season and a northward range expansion of mosquito vectors (Chen *et al.* 2013). Although West Nile virus has been found in Central and South America, the spread of the virus has not yet been accompanied by widespread cases in humans and horses nor significant avian mortality, so the current impact of climate change on West Nile disease in the region is unclear (Paz 2015).

Malarial vectors are projected to cover over 46% of the South American continent by 2070 (Laporta *et al.* 2015), but the specific impact of vector expansion will vary geographically. For example, although the length of the malaria transmission season is projected to increase in Mexico, Central America, and southern Brazil, decreases are predicted in parts of Brazil and Bolivia (Caminade *et al.* 2014). Over the next 50 years, suitable habitat for vectors that transmit malaria is generally projected to remain in the Amazon interior, on the Guiana Shield coasts, in northern Colombia, and along the southern border between Colombia and Venezuela (Alimi *et al.* 2015); the vector habitat is also expected to increase to higher altitudes (Siraj *et al.* 2014) but may decrease in parts of Brazil, Guyana, and Colombia (Alimi *et al.* 2015). However, projecting malaria disease burdens is challenging, given the complex interactions among host, vector, and environmental factors. For instance, in South America, increasing health initiatives, higher temperatures, lower water availability, and biome modifications are projected to reduce the suitable habitat for vector growth and thus decrease the distribution and abundance of the current primary malaria vector, *Anopheles darlingi* (Laporta *et al.* 2015). However, the geographical range of climate-generalist mosquitoes (*An. albitarsis* complex) is projected to significantly expand, so these mosquitoes could potentially become a more important malaria transmission vector (Laporta *et al.* 2015). For North America, climate change is expected to increase the geographical range of malaria vectors in the United States (Caminade *et al.* 2014), although future projections of malaria transmission in the country will depend on social, economic, and environmental factors, including the efficacy of health interventions. Improvements in social development and public health programming can reduce the burden of vector-borne diseases through factors such as transmission prevention and access to healthcare, but it is difficult to incorporate these developments into disease transmission models. In some models, gross domestic product per capita has been used as an indicator of socioeconomic conditions, which in combination with climatic variables have been used to project the future distribution of malaria. These models show that climate change effects may negate the future benefits of improved socioeconomic status on malaria risk (Campbell-Lendrum *et al.* 2015; Franklinos *et al.* 2019; Parham *et al.* 2015).

Tick-borne diseases

The geographical distribution and incidence of tick-borne diseases are also increasing in the Americas (Bouchard *et al.* 2019). Climate change is projected to create longer seasonal activity and generally expand the number of climatically suitable northern habitats for ticks in North America (Ogden *et al.* 2014), increasing the risk of human exposure to tick-borne diseases. The incidence and geographical distribution of Lyme disease has increased in Canada and the United States as climate change affects both the distribution and abundance of ticks (Eisen *et al.* 2016; Ogden *et al.* 2014). In Ontario, the northward expansion of the geographical range of tick populations over the past decade has been associated with observed increases in temperatures (Cheng *et al.* 2017), and increased Lyme disease cases and tick encounters have been associated with temperature changes in New York State, United States (Lin *et al.* 2019). In the United States, the season for Lyme disease transmission is projected to become longer due to climate change, with larger impacts under high emissions scenarios and more substantial impacts in the southerly mid-Atlantic states than the Northeastern and upper Midwestern states (Monaghan *et al.* 2015). In North America, there are different regional predictions for the risks of tick-borne disease under climate change. For example, in Minnesota, the risk of Lyme disease is projected to increase under a warming climate and an increasingly deciduous landscape by 2100, with the highest increase in projected risk in northeastern counties (Robinson *et al.* 2015). In Canada, tick vectors are projected to significantly increase under various climate change scenarios in Nova Scotia, areas of New Brunswick and Quebec, southern Ontario, and southern Manitoba; however, lower emissions scenarios are projected to slow tick invasion after the 2030s (McPherson *et al.* 2017). Moreover, future modelling must not only consider the impact of climate change on tick vectors, but must also include effects on the different hosts that serve as reservoirs for viruses. For example, in Quebec, the northern range of the white-footed mouse (an important reservoir host) is projected to increase by 2050 under three climate scenarios (Roy-Dufresne *et al.* 2013).

Reduviid-vectored diseases

Chagas disease is prevalent in the southern United States, Mexico, Central America, and South America. It is transmitted by triatomine bugs (commonly known as kissing bugs) infected with the protozoan parasite *Trypanosoma cruzi*. The breadth of the triatomines' niche is projected to expand under many climate change scenarios (Carmona-Castro *et al.* 2018; Garza *et al.* 2014), with significant increases in human exposure expected both in rural and in urban areas in North America (Carmona-Castro *et al.* 2018). A significant northern increase in range is also anticipated (Garza *et al.* 2014). However, there may be regional differences in exposures and range expansions, as the predicted geographical distributions of two endemic vectors of Chagas disease with different thermal preferences, *Mepraia gajardoi* and *M. spinola,* vary depending on the climate change scenario (Garrido *et al.* 2019).

3.6.2 What adaptation and mitigation options are available to reduce vector-borne illnesses?

Current adaptations to prevent climate-related increases in vector-borne diseases involve reducing environmental risk of exposure and promoting individual preventative behaviors to reduce human–vector contact, both of which rely on comprehensive vector and disease surveillance (e.g. Hinckley *et al.* 2016; Keesing and Ostfeld 2018; Sommerfeld and Kroeger 2015). In Quebec, interventions to reduce the incidence of West Nile disease that were identified as most acceptable among stakeholders include: (i) individual protection (e.g. frequently inspecting window screen integrity, wearing light-colored clothing, eliminating peridomestic mosquito larval sites, reducing outdoor activities at peak times); and (ii) regional management and mosquito-targeting interventions (e.g. larvicides, vaccination of animal reservoirs, modification of human-made larval sites) (Hongoh *et al.* 2016). New prevention, surveillance, and control efforts are needed to support adaptation to the geographical range expansions and increases in the incidences of vector-borne illness that are expected because of climate change (Ebi and Nealon 2016). For example, in Ecuador, an integrated climate–dengue surveillance system producing high-resolution risk data is currently being used to improve seasonal early warnings for dengue (Lowe *et al.* 2017; Stewart-Ibarra and Lowe 2013). On the border between Ecuador and Peru, a multinational network launched a climate–malaria surveillance system (Krisher *et al.* 2016) and achieved local elimination of malaria, demonstrating the potential and power of cross-country collaborations (WMO and WHO 2016). Infection control and prevention programs, including vector control, eradication, reliable water and sanitation services, and integrated longitudinal surveillance, are vital public health strategies that will continue to be important tools for adapting to climate change impacts on vector-borne disease (Case Study 9).

3.7 Nutrition and food security

3.7.1 How does climate change increase the risk of undernutrition and food insecurity?

Without mitigation and adaptation efforts, climate change is projected to result in a negative net impact on food systems

Case Study 9 Climate change, health, and the GEOHealth Hub Centered in Peru

Peru is highly vulnerable to the health impacts of climate change. The Peruvian National Institute of Statistics and Informatics projects that there will be a 1°C increase in temperature and a 10% increase in precipitation variability in the country by 2030. This is particularly concerning given that 71% of all tropical glaciers are located in Peru, and increases in temperature threaten to decrease the availability of water in the future. Furthermore, Peru experiences the effects of the El Niño–Southern Oscillation, a climate phenomenon that has become frequent and intense in recent decades, contributing to heavy rains and flooding on the north coast and drought in the southern areas of the country.

Given these projections, Peru is poised to experience several climate-related health impacts. For example, the habitat suitable for *Aedes aegypti*, the mosquito vector of the dengue virus, is expected to expand as a result of climate change. Dengue fever, a climate-sensitive febrile illness caused by infection with the dengue virus, is endemic in parts of Peru, with transmission of the virus being well documented since its re-emergence in the early 1990s. Epidemics of the virus linked to the El Niño–Southern Oscillation and flooding have been observed. For example, in Piura in 2017, there were 7,239 confirmed cases of dengue and 34 recorded deaths; however, it is estimated that there could have been as many as 30,000 cases, but many were likely not documented because of limited healthcare infrastructure and challenges in the public health response. In 2020, the COVID-19 pandemic imposed additional strain on healthcare resources in regions such as Iquitos in the Peruvian Amazon, which were already experiencing increased incidences of dengue fever.

Climate change may also impact diarrheal disease in Peru. A national-level impact assessment of routine rotavirus vaccination against childhood diarrhea found that the number of clinical visits for childhood diarrhea declined when rotavirus vaccinations were accompanied by improved water and sanitation initiatives (Delahoy *et al.* 2020). These findings demonstrate the success of multifaceted adaptation methods to address complex climate-related health challenges; such approaches may become increasingly important features of vulnerability assessments, mitigation planning, and public health programming as temperatures increase and El Niño–Southern Oscillation events become more intense due to climate change (Delahoy *et al.* 2020).

Further research has investigated associations between temperature changes and El Niño–Southern Oscillation events and other non-infectious health outcomes, including those related to reproductive health. In the Andean region (Molina and Saldarriaga 2017) and in Lima, Peru (Tapia *et al.* 2021), increased temperatures have been associated with lower birth weights.

Peru has several public and private institutions with dedicated climate change research initiatives, including the Universidad Peruana Cayetano Heredia (UPCH), located in the capital city of Lima. With support from the Fogarty International Center of the National Institutes of Health, UPCH developed a regional program in 2015, the "GEOHealth Hub Centered in Peru" (www.geohealthperu.org), to support collaborative research in environmental health. The program team works with partners at Emory University, Johns Hopkins University, and the University of Georgia to research health issues related to indoor and outdoor air pollution, water contamination with arsenic, and climate change. UPCH also hosts CLIMA, a center devoted to promoting and developing research at local, regional, and global scales on the impact of climate change on human, environmental, and ecosystem health in Latin America. The successes of the GEOHealth Hub Centered in Peru and CLIMA demonstrate how academic and scientific institutions can develop research capacity, both to understand climate change impacts on human health and to inform locally specific adaptation and mitigation strategies.

throughout the Americas (IPCC 2019b; Mbow *et al.* 2019; Porter *et al.* 2014; Smith *et al.* 2014; Springmann *et al.* 2016b; Zabel *et al.* 2019, 2021). Warming temperatures, changing precipitation patterns, and extreme weather are expected to lead to net reductions in staple crop yields, including yields of vegetables, legumes, fruits, nuts, and seeds, and may also hinder livestock production, lower nutrient content in agricultural commodities, and contribute to increasing global food prices (Alae-Carew *et al.* 2020; Mbow *et al.* 2019; Scheelbeek *et al.* 2018). These anticipated changes have important food and nutritional security implications (IANAS 2017a). Food insecurity is associated with many negative physical and mental health outcomes, including non-communicable disease conditions, such as obesity, type 2 diabetes, heart disease, oral health issues, and depression (Jessiman-Perreault and Mcintyre 2017; Mcleod and Veall 2006; Muldoon *et al.* 2013; Tarasuk *et al.* 2016). As such, climate change impacts on food and nutritional security are often ranked among the top climate change threats in the Americas (CCA 2019; Richards *et al.* 2016).

In the Americas, climate change is projected to reduce overall caloric availability by the year 2050 (Springmann *et al.* 2016b). In most countries, reduced availability of nutrient-dense fruits and vegetables will lead to an increase in undernutrition, particularly for children, as well as a net increase in mortality (Fanzo *et al.* 2018). These projected trends are particularly pronounced in upper middle income and high income countries such as the United States, Canada, and Brazil, where reduced fruit and vegetable consumption is expected to result in additional climate-related deaths due to coronary heart disease, stroke, and certain types of cancer (Springmann *et al.* 2016b).

Climate change-related net decreases in food availability will likely lead to increased food prices for fruits, vegetables, and cereals: for example, globally, cereal prices are projected to increase by as much as 29% by 2050 (Mbow *et al.* 2019). Increased food prices can force consumers, especially those experiencing low socioeconomic conditions, to purchase lower-cost, energy-dense foods, which often have negative nutrition and health consequences (Gibson *et al.* 2004; Lake *et al.* 2012; Lock *et al.* 2009; Marushka *et al.* 2017). Food availability is also linked to physical access to food, which can be markedly impacted by extreme weather events, for example through the disruption of transportation systems and a consequent reduction in access to retail foods (French *et al.* 2020; Palko and Lemmen 2017). In Northern Canada, winter roads provide seasonal access to important goods and services, including food. However, as a result of climate change, predicted weather conditions will no longer be suitable for seasonal construction of these roads by mid- or late-century in many locations in Ontario, Canada (Hori *et al.* 2018).

In terms of food production, climate change is projected to impact nutrient (e.g. vitamins B_1, B_2, B_5, and B_9) availability. Increasing CO_2 concentrations are expected to increase the synthesis of carbohydrates and decrease the content and density of other key macronutrients and micronutrients in agricultural, fish, and seafood products (Dong *et al.* 2018; Macdiarmid and Whybrow, 2019). For example, zinc, iron, and protein concentrations can be reduced by 3–15% when wheat, rice, and legumes are grown in conditions with elevated CO_2 (550–690ppm) (Myers *et al.* 2014, 2017). For rice, research has also shown that increased CO_2 concentrations can result in a decline of vitamins B_1, B_2, B_5, and B_9 by an average of 12–30% (Zhu *et al.* 2018). Similar trends have been observed for vegetables, with reductions in iron, magnesium, and zinc ranging from 9 to 16% in elevated CO_2 conditions (Dong *et al.* 2018). Importantly, changes in nutrient availability are expected to differ by geographical region under climate change, with some areas projected to have more substantial reductions as a result of agricultural productivity declines and CO_2-related nutrient decreases. For example, in North America, reductions in zinc availability are projected to be greater than the global average (Beach *et al.* 2019). In addition to nutrient deficiencies in food crops, elevated CO_2 also has implications for many livestock animals, which represent an important source of protein globally. Livestock are also vulnerable to the health effects of decreased nutrients in grazing crops, which in turn has impacts on the human food system, as the quality and quantity of animal-based proteins are reduced (Ebi and Loladze 2019).

These projected decreases in nutrient availability have significant health repercussions: for example, when applied to current diets, hundreds of millions of people globally will be at risk of zinc, iron, and/or protein deficiencies, and the existing deficiencies of an estimated two billion people will be exacerbated (Myers *et al.* 2017). In particular, women of childbearing age are often most affected by iron deficiency and anemia. Zinc and iron deficiencies increase the risk of several health outcomes, and modelling suggests that some countries in the Americas (e.g. Bolivia, El Salvador, Ecuador, Guatemala, Haiti, Honduras) will experience a particularly high burden of zinc and iron deficiency-related disease compared with other countries (Weyant *et al.* 2018). Several negative health impacts are also linked to vitamin B deficiencies, including neurological disorders and birth defects; and, in the absence of food products fortified with vitamins such as thiamine (B_1), riboflavin (B_2), and folic acid (B_9), there may be an increased risk of vitamin B deficiency-related health impacts. In Venezuela, where a large proportion of the population faces socioeconomic challenges and undernutrition, folic acid deficiency was documented in over 30% of participants in a nationwide study (García-Casal *et al.* 2005). Moreover, the impact of climate change on animal food sources may be experienced more acutely in regions where meat production and consumption are the greatest, including the potential for increased vitamin B_{12} deficiency. Several countries in the Americas, such as Argentina, the United States, and Brazil, are among the largest producers and consumers of meat globally (OECD 2021), and thus may be particularly vulnerable to the economic, health, and social impacts of climate change on the livestock sector. At the same time, global emissions associated with livestock production grew by 16% from 2000 to 2017, and approximately 990,000 deaths globally in 2017 were attributed to excessive red meat consumption (Watts *et al.* 2021). The connections between climate change and livestock production are, therefore, complex, and the implications of those interactions on dietary protein security require careful attention in food security and climate change response planning. Ultimately, the health impacts of reduced nutrients in foods will depend largely on overall dietary diversity as well as country-specific responses, including enrichment and fortification policies (CFIA 2014).

The impact of climate change on both pestiferous (e.g. insects, diseases) and beneficial (e.g. pollinators, biological control agents) organisms will also have important consequences for crop production and thus for nutritional security. Climate change could result in an increase in the number of generations per year and could modify the geographical range of species, with populations expanding into new areas as they become suitable and potentially declining in areas where they currently exist (Bebber *et al.* 2013; Crozier 2004; Ramirez-Cabral *et al.* 2017; Rosenzweig *et al.* 2001; Thomson *et al.* 2010). In the case of pest species moving into new areas, this could impact crop yields and lead to a potential increase in pesticide use. Additionally, climate change may also indirectly affect a given species through other species within the same food web. As one example, climate change can affect plant phenology, morphology, and physiology (Cornelissen 2011; Nicotra *et al.* 2010), which in turn could have positive or negative effects on populations of pestiferous and beneficial species at higher trophic levels. For instance, in response to herbivory, some plants release biogenic organic volatile compounds, which play a role in the upregulation of induced plant defenses (Aljbory and Chen 2018; Kant *et al.*

2015; War *et al.* 2012) and are also used as foraging cues by natural enemies of herbivores (McCormick *et al.* 2012; Vet and Dicke 1992). The release of these compounds has been shown to vary under different climate change scenarios (Arneth and Niinemets 2010; Peñuelas and Straudt 2010), and thus will influence herbivores as well as their parasitoids and predators. Similarly, the quantity and quality of nectar produced by plants can vary in response to climate change (Erhardt *et al.* 2005; Takkis *et al.* 2015), which will impact pollinator success. Furthermore, increasing levels of GHGs may reduce the persistence of plant volatiles (McFrederick *et al.* 2009), with the potential to alter interspecific interactions at all trophic levels. However, considerably more data are needed to reasonably predict effects, as the responses at all levels will vary depending on the species, especially for highly domesticated crop species with lower genetic variability.

The impacts of climate change on biodiversity loss will also increase risks to food and nutrient security (Romero-Lankao *et al.* 2014; Rose *et al.* 2001). For instance, global estimates suggest that climate-related declines in fish harvests (IPCC 2019a) will leave 845 million people vulnerable to deficiencies in iron, zinc, and vitamin A, as well as 1.4 billion people vulnerable to deficiencies in vitamin B_{12} and long-chain omega-3 polyunsaturated fatty acids by 2050 (Golden *et al.* 2016). However, such impacts will not be equitably distributed, as Indigenous Peoples who depend on the land and waters for sustenance are particularly impacted by climate-related biodiversity loss (Anderson *et al.* 2018a; Boulanger-Lapointe *et al.* 2019; Kenny *et al.* 2018; Richmond and Ross 2009; Rose *et al.* 2001). Research has shown that replacing declining food species that are locally harvested with market foods in Northern Canada would negatively impact nutrient intake (Rosol *et al.* 2016). Furthermore, replacing Indigenous local foods can have negative impacts through "nutrition transitions" whereby diets transition from healthy Indigenous food systems to often unhealthy retail alternatives (Sharma 2010; Zavaleta *et al.* 2018). This can negatively affect cultural continuity, mental health outcomes, language, self-determination, and social cohesion, which are critical determinants of Indigenous Peoples' health, thus raising important questions about the appropriateness and efficacy of market foods as an adaptation response (Marushka *et al.* 2019).

The health-related impacts of climate change on food systems and environments will vary between countries in the Americas, reflecting underlying societal, cultural, environmental, political, and economic factors and inequities. Similarly, food security levels differ within and between countries, between rural and urban locations, and across geographical features (e.g. altitude). Inequities are also generally greater for single-parent households, lower-income households, and households with lower formal education levels (PHAC 2018). At both scales, climate change will exacerbate challenges for those regions and households with existing low levels of food security. Importantly, although individual and household characteristics are associated with food insecurity trends, each individual and household experiences a range of intersecting social, political, economic, and environmental factors that contribute to differential food security status over time (Kapilashrami and Hankivsky 2018). Therefore, individuals and households experience different and changing vulnerability to climate change impacts on food systems at multiple levels over time.

3.7.2 What adaptation and mitigation options are available to reduce undernutrition and food insecurity?

Both adaptation and mitigation approaches are critical in the context of food and nutritional security in a changing climate (Mbow *et al.* 2019) (see also Chapter 4). The IPCC identified food security response options that have significant adaptation and mitigation potential, including the following (Mbow *et al.* 2019):

- Improving crop management (e.g. increasing soil organic matter content, changing crop varieties, improving water management, biochar application, agroforestry, switching from monocultures to crop diversification, changing cropping areas, land rehabilitation (enclosures, afforestation), perennial farming, tillage and crop establishment, improving residue management, crop–livestock systems).

- Improving livestock management (e.g. implementing silvo-pastoral systems, introducing new livestock breeds, livestock fattening, shifting production to small ruminants or drought-resistant livestock or fish farming, establishing feed and fodder banks, seasonal feed supplementation, improving animal health through parasite management and thermal stress control).
- Improving food supply chains (e.g. developing food storage infrastructure, shortening supply chains, improving food transport and distribution, improving the efficiency and sustainability of the food processing, retail, and agrifood industries, improving energy efficiencies of agriculture, reducing food loss, promoting urban and peri-urban agriculture).
- Food demand management (e.g. promoting dietary changes (see Chapter 4 for details), reducing food waste, reducing packaging, changing selling and retail methods (e.g. to direct sales), improving the transparency of food chains (including through labelling), external costs).

To be effective, these response options should consider the potential health benefits and/or unintended adverse health consequences of the strategy. Effective responses will work across sectors and include nutrition-sensitive adaptation and mitigation strategies, as well as considerations of climate-resilient, nutrition-sensitive, and sustainable agricultural development. Furthermore, response strategies should consider the role of social support, inclusion, and capacity development, as well as maternal and child care and health, and increased policy coherence that supports institutional and cross-sectoral collaboration (Mbow *et al.* 2019; Tirado *et al.* 2013). Finally, addressing social inequities must be a part of an effective adaptation and mitigation response. Importantly, responses that consider equity will vary depending on the socio-cultural and political context (Halvey *et al.* 2021; Horst *et al.* 2017). For example, Indigenous Peoples, farmworkers, and women with low incomes often face discrimination and inequity in access to resources, both of which contribute to higher rates of food insecurity and undernutrition in the Americas (Carr and Thompson 2014; Greene 2018). Thus, addressing discrimination and inequity, which affect their food security and nutrition, must be part of an inclusive and effective adaptation and mitigation response (Bacon *et al.* 2021). For example, rights-based approaches are one strategy for explicitly incorporating social inequity considerations into climate change adaptation and mitigation planning.

3.8 Mental health and wellbeing

3.8.1 How does climate change impact mental health?

There is strong evidence linking climate change and the resulting environmental shifts to a diverse range of complex and often-overlapping negative mental health outcomes in the Americas. Climate change will not only exacerbate pre-existing mental health conditions and challenges but it will also create new threats, stressors, and mental health outcomes (Benevolenza and DeRigne 2019; Clayton *et al.* 2017; Cunsolo and Ellis 2018; Dodgen *et al.* 2016; Hayes *et al.* 2018; Kim *et al.* 2019; Middleton *et al.* 2020b; Obradovich *et al.* 2018; Rataj *et al.* 2016; Rifkin *et al.* 2018; Vins *et al.* 2015). The published literature on the mental health impacts of climate change in the Americas is predominantly focused on Canada and the United States; there is growing, yet still limited, evidence from Mexico, and very limited research in the Caribbean or Central and South America.

There are four main causal pathways through which climate change affects mental health: acute, chronic, anticipatory or vicarious, and through disruptions to other determinants of health.

- **Acute and short-term weather events**, such as severe storms, heatwaves, and corresponding events such as flooding and wildfires (Case Study 10), are linked to a wide range of mental health outcomes in the Americas, including depression and anxiety (e.g. Clayton 2020; Cunsolo and Ellis 2018; Cunsolo *et al.* 2020b; Obradovich *et al.* 2018), unhealthy substance usage (Clayton *et al.* 2017; Cunsolo Willox *et al.* 2013a, 2013b; Morrison 2011), family stress and violence (Clayton *et al.* 2017; Cunsolo Willox *et al.* 2013a, 2013b; Younan *et al.* 2018), suicidal thoughts and suicide (Burke *et al.* 2018; Kim *et al.* 2019), post-traumatic stress disorder (Rataj *et al.* 2016; Schwartz *et al.* 2017), behavioral and mood disorders and increased rates of psychiatric hospitalization (Xu *et al.* 2020c), and strong emotional reactions (e.g. fear, stress, distress, grief, anxiety) (Cunsolo *et al.* 2020b; Middleton *et al.* 2020b). There is a growing body of research in the United States linking heatwaves to a range of negative mental health outcomes, including increased rates of violence and aggression, suicide, emergency room visits and hospitalizations, and self-reported poor mental health days (Burke *et al.* 2018; Fernández-Arteaga *et al.* 2016; Fuhrmann *et al.* 2016; Guirguis *et al.* 2014; Kim *et al.* 2019; Obradovich *et al.* 2018; Sherbakov *et al.* 2018; Younan *et al.* 2018).
- **Chronic exposures to subacute climate change events and related environmental alterations** (e.g. drought, heatwaves, temperature fluctuations, sea level rise, sea ice loss, ecosystem changes) are linked to strong emotional responses, as well as to increased family stress and violence, disrupted sleep, and maladaptive coping behaviors including substance usage (Clayton *et al.* 2017; Coêlho *et al.* 2004; Middleton *et al.* 2020b; Rifkin *et al.* 2018; Vins *et al.* 2015). For example, multi-year research from Nunatsiavut, Labrador, Canada, indicated that long-term chronic exposure to slow and creeping sea ice loss, changes in precipitation, and changes in wildlife populations were disrupting Inuit lives, livelihoods, and wellbeing. These changes led to diverse mental health outcomes, including feelings of sadness, fear, distress, depression, and grief, as well as increases in self-reported depression and anxiety, drug and alcohol usage, family stress, the magnification of already-present trauma and underlying mental health conditions, and losses of place attachment, sense of identity, and intergenerational knowledge sharing (Cunsolo Willox *et al.* 2012, 2013a, 2013b; Harper *et al.* 2015; Middleton *et al.* 2020a, 2020b; Petrasek MacDonald *et al.* 2015).
- **Anticipatory** (i.e. anticipating future changes and what may result) and **vicarious** (i.e. witnessing the pain and suffering of others) **experiences** lead to emotional stress, sadness, stress, distress, fear, anxiety, and depression, even in the absence of direct acute or chronic exposure to climate hazards (Clayton 2020; Clayton *et al.* 2017; Middleton *et al.* 2020b). One study in Florida found that exposure to, and consumption of, media coverage of impending hurricanes led to increased negative mental health outcomes, including post-traumatic stress, depression, and anxiety, and that attempts to mitigate hurricane-based anxiety through more media consumption often led to higher levels of anxiety (Thompson *et al.* 2019).
- **Disruption, degradation, or alteration of other determinants of health**, including physical health, infrastructure, occupation, social connections, place-based attachments, knowledge systems, and cultural practices, can lead to negative mental health outcomes (Middleton *et al.* 2020b). For example, a systematic review of mental health disorders related to extreme weather events in Mexico, Nicaragua, Honduras, and Grenada found that displacement, the destruction of homes and infrastructure, and physical

injury led to increased rates of depressive and anxiety disorders and post-traumatic stress disorder (Rataj *et al.* 2016).

The currently available evidence shows that climate-sensitive mental health outcomes in the Americas are unevenly and inequitably distributed. Those who live in ecologically sensitive areas, those who rely closely on the environment for livelihoods, food, and culture, those with chronic physical and mental health challenges, and those who are systematically marginalized and disadvantaged are the most affected (Clayton *et al.* 2017; Cunsolo *et al.* 2020b; Hayes *et al.* 2018; Middleton *et al.* 2020b). Groups at high risk for mental health outcomes related to climate change include Indigenous Peoples, particularly those living in remote locations and relying on the land for sustenance, livelihoods, and wellbeing (Middleton *et al.* 2020b), agricultural communities (Greene 2018; Yusa *et al.* 2015), those living in drought-, flood-, and/or wildfire-prone areas (Dodd *et al.* 2018; Stanke *et al.* 2013; Vins *et al.* 2015), children and young people (Clayton *et al.* 2017; Majeed and Lee 2017; Sanson *et al.* 2019; Sugg *et al.* 2019; Wu *et al.* 2020a), women, seniors, and economically disadvantaged peoples (Clayton *et al.* 2017; Xu *et al.* 2020c), and those living with chronic physical and mental health challenges (Clayton *et al.* 2017).

Although there has been little research developing future risk projections for mental health outcomes, one study indicated that suicide is projected to increase in the United States and Mexico by 2050 under RCP8.5 (Burke *et al.* 2018). Another study, analyzing data from Canada, the United States, Mexico, and Brazil, found that higher ambient temperatures are associated with an increased risk of suicide (Kim *et al.* 2019). With current climate projections predicting increased ambient temperatures throughout the Americas, negative mental health outcomes such as suicidal thoughts, suicide attempts, and deaths by suicide linked to climate change and related environmental alterations will likely continue to increase in incidence, prevalence, and severity in the coming decades.

3.8.2 What adaptation and mitigation options are available to reduce mental health risks?

Climate change is an urgent threat to the mental health of individuals and communities in the Americas. As such, active, responsive, coordinated, and place-specific mental health adaptation policies are required to proactively protect, support, and improve individual and community mental health. Relevant and appropriate mental health adaptations might include the following:

- Applying a mental health lens to policies related to mitigation and adaptation of both the direct and indirect effects of climate change. This will help to ensure that the full health costs are considered in adaptation and mitigation planning, and that the potential for mental health impacts is reflected in decision-making.
- Developing and implementing climate-sensitive mental health, intangible loss, and damage metrics and indicators, as well as creating national and international public health surveillance systems to track those indicators (Middleton *et al.* 2020b).
- Developing, enhancing, and/or scaling up climate-sensitive mental health training and resources for health providers to support patient care and advocacy, which is essential to support mental health resilience in individuals and groups. This could include curriculum development in educational programs, toolkits, train-the-trainer approaches, web-based resources and communities, and ongoing professional development opportunities (Clayton *et al.* 2017; Cunsolo *et al.* 2020b).
- Enhancing clinical assessments and supports for climate-sensitive mental health outcomes for patients, both at point-of-entry to the healthcare system and during ongoing healthcare connections (Cunsolo *et al.* 2020b).
- Learning from already-proven individual and group therapy approaches, and adding

a climate-sensitive mental health lens to these supports and coping strategies. This could include activities that enhance social, physical, and mental health by promoting a connection to the natural world, such as increased time in nature and active, sustainable transportation choices (Clayton *et al.* 2017; Cunsolo *et al.* 2020b; Heinz *et al.* 2021; Reed *et al.* 2021; Verstraeten *et al.* 2020).

- Ensuring that the nuances of location-specific contexts are recognized by creating and implementing locally appropriate and culturally relevant mental health resources, programming, and policy. This can provide opportunities to further support and enhance positive mental health outcomes among those experiencing the direct and indirect effects of climate change (Cunsolo *et al.* 2020b; Cunsolo and Ellis 2018).

- Understanding that mental health outcomes from climate change are unequally distributed and therefore require examination through a health equity lens, which should consider equity-based indicators including ethnicity, class, gender identity, access to mental health services, and geographical location (Cunsolo *et al.* 2020b).

Although research on climate-sensitive mental health outcomes continues to grow, there are important priorities and gaps. First, there is extremely limited published research examining climate-sensitive mental health outcomes in the Americas, particularly in the Caribbean and in Central and South America. More research is urgently needed, particularly among Indigenous Peoples and those groups that are most socially, economically, and politically marginalized. Second, there are limited population-level, longitudinal, and/or risk projection studies assessing and projecting exposures to climate hazards and the resultant mental health outcomes. Third, more research analyzing the nuances of the incidence rates and severity of short-, medium-, and long-term indirect and direct exposures to climate change hazards and the related mental health outcomes is needed to support mental health programming, resource development, and decision-making. Fourth, there is limited research on the short-, medium-, and long-term effects of climate change on the mental health of children and young people, and on their overall growth and development, scholastic achievement, and ability to handle long-term stress; however, emerging evidence indicates that children and young people are at risk for long-term impacts on mental health and cognitive function due to climate change (Clayton *et al.* 2017; Majeed and Lee 2017; Sanson *et al.* 2019). Fifth, research has not yet evaluated mental health adaptation strategies to cope with and reduce the risks of climate change, including strategies and therapies already proven to treat other forms of mental illness. Finally, multi-country and multi-population comparative studies, complemented by localized case studies, are needed to understand local, national, and international mental health threats, as well as to identify related adaptation opportunities and to determine how mitigation efforts (e.g. transitioning to sustainable cities, changes to

Case Study 10 Climate migration and health in the Americas

Migration in the context of climate change is highly context-specific and often exemplifies climate injustice. The reasons for, and impacts of, migration depend on several factors related to specific climate impacts and the adaptive capacity of the affected population. Individuals, households, or larger communities may migrate as a direct result of a climate hazard (e.g. destruction of homes and/or assets by a flood or extreme weather event), or because of indirect impacts of climate change (e.g. crop failure and subsequent loss of income/livelihood due to drought conditions) (McLeman *et al.* 2021). Mobile populations may migrate when local responses are insufficient to reduce climate-related risk, although the outcomes of migration are uncertain and may be adaptive or maladaptive. Furthermore, the level of agency plays an important role in mobility outcomes, depending on whether the migration is voluntary or forced (e.g. because of a climate disaster); forced migration is also referred to as displacement (McLeman *et al.* 2021). In addition, some populations may be considered immobile due to a lack of resources needed to move or strong connections to place. Immobile populations and mobile populations with low agency often have lower adaptive capacity and poorer mobility outcomes than mobile populations with high agency (McLeman *et al.* 2021).

Climate migrants are vulnerable to health impacts at all stages of the migration process, including the pre-departure stage, during transit (i.e. during short and/or long journeys), at the destination, and, in some cases, during the return journey (Abubakar *et al.* 2018). Circumstances surrounding migration are often very challenging and require individuals and/or families to make difficult decisions, which can have important implications for mental health, wellbeing, and social cohesion. Depending on the distance and mode of transport, some migrants also face unique health risks during transit, including reduced access to food and water, disruptions to healthcare access, and exposure to dangerous environments. Women and children in particular face an increased risk of violence and exploitation during transit (Abubakar *et al.* 2018). Moreover, discriminatory policies, racism, and/or social exclusion at the destination can limit access to healthcare, housing, education, and economic opportunities, which can both directly and indirectly impact the long-term health of migrants.

Climate hazard-induced migration is already occurring throughout the Americas, both internally and internationally, and is projected to worsen with climate change. The following are some examples:

- Wildfire evacuations in British Columbia, Canada, and the long-term relocation of residents from communities entirely destroyed during the 2021 wildfire season.
- Voluntary migration away from coastal homes in Florida, United States to avoid the future impacts of sea level rise on housing.
- Displacement of all Barbuda residents during the 2017 Atlantic hurricane season, including evacuations to Antigua after Hurricane Irma.
- Relocation of residents in Newtok, Alaska, because of erosion and the increasing risk of flooding in the community.
- International migration due to crop failure and the loss of agricultural livelihoods and economic opportunities in Central America.

Frameworks and policies that focus on mitigation and adaptation, such as the Paris Agreement, will be important for preventing some level of climate migration by reducing climate hazards and the related displacement. However, despite mitigation efforts, migration is projected to increase substantially in the coming years. It is therefore critical for local, regional, and federal governments to improve and/or adopt new policies to accommodate and protect the health of those who are displaced by climate change. Currently, no nation has a system for migrants to seek asylum on the basis of climate displacement, demonstrating a need for governments to formally recognize and provide climate migrants with legal protections (McLeman 2019). Ratifying existing non-binding Compacts, such as the United Nations Global Compact for Safe, Orderly, and Regular Migration (United Nations General Assembly 2018), will improve international co-operation and ensure consistent legal protections and avenues of migration for those displaced by climate change. Adequately supporting, enforcing, and investing in policies and frameworks such as the SDGs (e.g. Goal 3: Good health and wellbeing) (United Nations 2020), "health in all policies" approaches (WHO 2014a), and universal health coverage (WHO and World Bank Group 2019) will also be important in building more resilient healthcare systems that respect human rights and reduce barriers to healthcare access for climate migrants.

food and transportation systems) might impact mental health.

3.9 Respiratory health

3.9.1 How does climate change increase the risk of respiratory illnesses?

Particulate matter and ozone

The combustion of fossil fuels results in air pollutants and emissions of GHG, both of which contribute to the public health burden of air pollution (Kinney 2018; Orru *et al.* 2017) (see Section 3.3). Fine particulate matter includes non-CO_2 inhalable pollutants, which are formed by combustion of fossil fuels and other chemical reactions. Ozone, another pollutant that can result from the combustion of fossil fuels, is produced by reactions between sunlight and other air pollutants, and at ground level is a contributor to smog and respiratory irritation (Fann *et al.* 2016). Climate change can increase these types of air pollution by accelerating the chemical reactions that lead to pollutant formation, including ozone formation, which has important health impacts (Kinney 2018). Climate change can also increase energy demands (e.g. through the use of air conditioning during heatwaves), further increasing GHG and air pollutant emissions (Abel *et al.* 2017, 2018). The impacts of air pollutants are expected to be exacerbated by climate change given the climate-sensitive nature of their formation and exposure pathways. For example, higher temperatures may increase the formation and effects of pollutants such as ozone, and changing weather patterns may alter the distribution of fine particles by wind and may lead to increasing stagnation of ground-level ozone (Fann *et al.* 2016).

There is no doubt that air pollution associated with fossil fuel burning results in large numbers of premature deaths annually, although there is considerable uncertainty about the exact number of deaths globally (Lelieveld *et al.* 2019a; McDuffie *et al.* 2021; Vohra *et al.* 2021). Coal combustion is a major cause of air pollution, accounting for a large number of the worldwide premature deaths attributable to particulate matter exposure in 2018 (Watts *et al.* 2021). A multi-city study in Latin America found an increased risk of mortality as ambient concentrations of particulate matter and ozone increased (Romieu *et al.* 2012). Despite anticipated improvements in air quality standards and reduced fossil fuel use, overall ozone-related mortality is projected to increase in North America due to more favorable climatic conditions for ozone formation (Fann *et al.* 2016; Smith *et al.* 2014; U.S. Energy Information Administration 2021). In the United States alone, some projections estimate thousands of climate change-attributable ozone-related deaths, respiratory illnesses, and hospital admissions annually by 2030 (Cheng *et al.* 2008; Fann *et al.* 2016; Kinney 2018; Orru *et al.* 2017). However, the health impacts resulting from particulate matter attributable to climate change are less certain than the health effects of increased ozone exposure (Cheng *et al.* 2008; Fann *et al.* 2016; Kinney 2018; Orru *et al.* 2017). Importantly, climate change, air pollution, and respiratory health outcomes may interact through several pathways that could exacerbate disparities for vulnerable populations, including children, the elderly, and those experiencing low socioeconomic conditions. With climate change, more people will seek cooling indoors. High-income populations may have access to air conditioning and filtration, whereas those in lower socioeconomic conditions may have to rely on opening windows, thus increasing their exposure to outdoor air pollution. Those with air conditioners but without air filtration may be exposed to higher concentrations of indoor air pollutants, since closing windows can cause the accumulation of such pollutants (Fann *et al.* 2016; Watts *et al.* 2021).

Climate change is also increasing the frequency, intensity, and distribution of wildfires, and wildfire smoke contains particulate matter that impacts respiratory health throughout the Americas (Case Study 11). Wildfires occurring in the deforestation arc in the southern and western Brazilian Amazon episodically expose approximately 10 million people to smoke, with important health impacts and costs to public health systems (de Oliveira Alves *et al.* 2017; Ignotti *et al.* 2010; Machin *et al.* 2019).

Important research gaps remain, with implications for decision-makers. Many studies in the United States have examined a wide range of health impacts related to air pollution exposure (Beelen *et al.* 2014; Landrigan *et al.* 2018) or changing temperatures (Abrahamson *et al.* 2009; Åström *et al.* 2013; Reid *et al.* 2012; Xu *et al.* 2014), but few have investigated combined and/or synergistic effects (Cheng *et al.* 2008; Kinney 2018; Orru *et al.* 2017). There are even fewer studies that focus on projections for Central and South American countries (Smith *et al.* 2014). Regional effects must be a critical consideration in air pollution research, as the causes and effects may be location-specific (e.g. drought-related forest fires in Brazil and parts of Canada) (Case Study 11) (Dang and Unger 2015; Menezes *et al.* 2018; Sotto *et al.* 2019). For example, in South America, air pollution downwind of wildfires is sometimes higher than air pollution observed in large urban centers, and has resulted in increasing hospital admissions for respiratory concerns, primarily among children and the elderly (Aragão *et al.* 2016; de Oliveira Alves *et al.* 2017; Paralovo *et al.* 2019). Furthermore, although a growing body of literature examines ozone-related health impacts and projections under climate change, less certainty and understanding exists around climate impacts on particulate matter pollution. For example, household solid fuel combustion and the transport sector are major sources of black carbon, which is both a component of $PM_{2.5}$ and a potent short-lived climate pollutant, highlighting a need for additional research to evaluate integrated actions to address multiple forms of pollution, including black carbon. Compounding these issues is a lack of reliable and extensive air quality monitoring and limited oversight of local climate actions in many Central and

South American countries (Riojas-Rodríguez *et al.* 2016; Sotto *et al.* 2019). Evaluation of existing decarbonization efforts in the region will also be critical (AMS 2020; Coronel Carbo and Marzo Páez 2017; Crawford-Brown *et al.* 2012).

Aeroallergens

Climate change will impact the distribution, severity, and effects of aeroallergens, including fungal spores and plant pollen, which contribute to a large global burden of allergies. Aeroallergen production and release are sensitive to environmental conditions, including temperature, precipitation, humidity, wind, and atmospheric CO_2 concentrations (Beggs 2004; Fann *et al.* 2016; Sierra-Heredia *et al.* 2018; Smith *et al.* 2014). Thus, climate warming may contribute to increased pollen production and a longer pollen season in some regions, as seen over several decades with ragweed pollen throughout North America, particularly at higher latitudes (Ziska *et al.* 2011). Projected increases in atmospheric CO_2 concentrations are also expected to favor increased pollen production, although CO_2 impacts on fungal spores are less understood (Albertine *et al.* 2014; Beggs 2004; Cecchi *et al.* 2010).

The health impacts of aeroallergens include asthma, rhinitis, dermatitis, and conjunctivitis. Spores and pollen can also exacerbate pre-existing respiratory conditions such as chronic obstructive pulmonary disease, and allergenicity levels can increase with exposure to air pollutants (Fann *et al.* 2016; Sierra-Heredia *et al.* 2018; Smith *et al.* 2014). Studies have demonstrated associations between increased pollen concentrations and more frequent allergy-related ambulance calls and hospital visits (Breton *et al.* 2006; Héguy *et al.* 2008; Sapkota *et al.* 2020). However, there is a paucity of research projecting future health impacts related to aeroallergen changes, particularly for Central and South America, emphasizing a need for additional research to understand these climate-sensitive health outcomes.

3.9.2 What adaptation and mitigation options are available to reduce respiratory health risks?

Future trends in energy and carbon emissions are currently extremely contingent on economic trajectories after the recovery from the COVID-19 pandemic, and deliberate policy action to guide economic recovery may be needed to ensure that emission reductions continue (IEA 2020). Air pollution control both through mitigation efforts and through climate change policies will play an important role in the projected reduction of air pollution-related mortality and morbidity (Bell *et al.* 2006; Cifuentes *et al.* 2001; Crawford-Brown *et al.* 2012; Landrigan *et al.* 2018; Lelieveld *et al.* 2019a). Several policy recommendations center around mitigation through investments in renewable energy, promoting active travel, and clean air that will benefit health through multiple pathways (AMS 2020; Crawford-Brown *et al.* 2012; Haines *et al.* 2007; Watts *et al.* 2019a). Direct and indirect co-benefits (i.e. double benefits and even triple benefits) should also be considered when evaluating the costs and benefits of such policies (Crawford-Brown *et al.* 2012; EEA 2020; Nemet *et al.* 2010; Portugal-Pereira *et al.* 2018). Region-specific air pollution epidemiology and monitoring programs should be implemented to evaluate the health and environmental impacts of mitigation policies. The development and expansion of adaptation strategies, such as local air quality indices and improved indoor air quality management, will also be important given anticipated increases in air pollutants.

Climate change policies and air pollution management strategies may not always align (Crawford-Brown *et al.* 2012). For example, air pollution control measures can increase temperatures by removing cooling sulfate aerosols from the atmosphere (Lelieveld *et al.* 2019a). This highlights both the importance of reducing air pollution through climate change mitigation actions and the necessity of considering climate impacts in planning air pollution control.

With carefully designed goals and priorities, both air pollution control and climate change policies can play an important role in reducing projected air pollution-related mortality and morbidity due to climate change (Bell *et al.* 2006; Cifuentes *et al.* 2001; Crawford-Brown *et al.* 2012; Dang and Unger 2015; Landrigan *et al.* 2018).

Case Study 11 Climate change, wildfires, and health in Canada and the United States

Climate change is contributing to warmer and drier environments in many regions throughout North America, creating more favorable conditions for larger and more severe fires and longer wildfire seasons. In Canada and the western United States, the number of large wildfires and land area burned has been increasing in recent decades (Gauthier *et al.* 2014; Hanes *et al.* 2019; USGCRP 2017, 2018), with research attributing increases in the area burned to climate change (Gillett *et al.* 2004).

The burning of organic materials produces large quantities of particulate matter and ozone precursors (Fann *et al.* 2016), so smoke from wildfires can impact the respiratory health of exposed individuals. Wildfire smoke can be transported long distances: for example, in 2016, smoke from the wildfires in Fort McMurray, Alberta, increased the particulate matter and ground-air ozone above acceptable quality standards in New York City, over 3,000 kilometers away (Wu *et al.* 2018).

Climate change is projected to increase the intensity and duration of wildfires, resulting in increased exposure to fire-related particulate matter (Matz *et al.* 2020; Sun *et al.* 2019; Wotton *et al.* 2017). For example, it is estimated that smoke exposure will more than double by the mid-century in the western United States (Liu *et al.* 2016a). Additionally, wildfire-related morbidity and mortality, as well as respiratory-related hospitalizations, are expected to increase (Liu *et al.* 2016b). Inhalation of smoke and air pollutants from wildfires has been linked to respiratory infections, healthcare visits and hospitalizations for respiratory problems, exacerbation of asthma and chronic obstructive pulmonary disease, and all-cause mortality (Reid *et al.* 2016). In Canada, several thousand premature deaths have been attributed to short- and long-term smoke exposure annually (Matz *et al.* 2020), and the number of annual premature deaths due to smoke from wildfires is projected to double by the late century in the United States compared with the early 21st century (Ford *et al.* 2018). Current and future projections highlight the need for mitigation and adaptation response strategies that consider and prepare for increased respiratory health impacts linked to wildfires and climate change.

Wildfires not only impact physical health; they can also negatively impact individual and community mental health and wellbeing (see Section 3.8). Direct exposure to wildfires increases the risk for numerous mental health concerns, such as depression, anxiety, post-traumatic stress disorder, insomnia, suicidal ideation, and substance abuse (Belleville *et al.* 2019; Brown *et al.* 2019; Silveira *et al.* 2021; Xu *et al.* 2020a). Wildfire-induced psychological trauma and emotional distress may persist long after the initial threat subsides. For example, a study in Fort McMurray, Alberta, found evidence of probable post-traumatic stress disorder, depression, anxiety, and alcohol or substance use disorder among grade 7–12 students 18 months after a devastating wildfire caused the forced evacuation of the city's 88,000 residents (Brown *et al.* 2019). These stress-related disorders can be exacerbated by pre-existing mental health and wellbeing concerns, which was observed following exposure to the Camp Fire of 2018, the deadliest wildfire in California's history (Silveira *et al.* 2021). Wildfires can also indirectly impact mental health by undermining the social and environmental determinants of health. For example, the 2014 wildfire season in the Northwest Territories, Canada, caused prolonged periods of smoke and reduced air quality, disrupting residents' ability to safely participate in outdoor and culturally significant land-based activities, which subsequently impacted their livelihoods and mental wellbeing (Dodd *et al.* 2018). Qualitative interviews with workers participating in recovery efforts for the 2017–2018 California wildfires further highlighted the interconnected nature of wildfire-induced social issues, such as displacement-related housing and employment concerns, with mental and emotional health (Rosenthal *et al.* 2021). Lastly, similar to other extreme weather events, current and anticipated risks of wildfire-related losses of property, beloved places, livelihoods, and loved ones may evoke strong emotional reactions, such as ecological anxiety and grief.

Case Study 12 Climate change and Indigenous Peoples' health in the Americas

Although everyone in the Americas is affected by climate change impacts on health, Indigenous Peoples are often the most affected (IPCC 2019b, 2019a; Status of Tribes and Climate Change Working Group 2021). Many Indigenous Peoples have strong cultural, spiritual, and emotional ties to the land and waters of their territories; therefore, climate change impacts on the environment can have important health implications. Indigenous Peoples often face socioeconomic, infrastructural, political, and health inequities, which are rooted in historical and ongoing colonial legacies, and which can further increase climate change risks (Anderson *et al.* 2016; Greenwood and Lindsay 2019; Whyte 2016, 2019). Despite these challenges, Indigenous Peoples are actively adapting and responding to climate change in many ways, including through actions, advocacy, and political engagement that range from local to international in scale (Etchart 2017; Ford *et al.* 2020; IPCC 2018, 2019a, 2019b). As Indigenous scholar Margot Greenwood and colleagues wrote:

"*Colonialism violently disrupted relational ways, criminalizing cultural practices, restricting freedom of movement, forcing relocation, removing children from families, dismantling relational worldviews, and marginalizing Indigenous lives. However, Indigenous peoples have never been passive in the face of colonialism. Now more than ever, Indigenous knowledge in three critical areas—food and water security, climate change, and health—is needed for self-determination and collective survival in a rapidly changing world.*" (Greenwood and Lindsay 2019).

It is important to note that although Indigenous Peoples across the Americas share many climate change exposures, vulnerabilities, and risks, they are also extremely diverse in terms of Peoples, cultures, languages, colonial experiences, and knowledges. Herein, we provide examples of climate change impacts on Indigenous health in the Americas, and we outline examples of ongoing climate change adaptation led by Indigenous Peoples (Table CS 12.1).

Changing access to availability of nourishing, accessible, and preferred food and water

Many Indigenous Peoples throughout the Americas depend on local agriculture, gathering, hunting, fishing, and water sources. These activities and sources provide not only food, nutrition, and water security, but are also essential for cultural continuity and for emotional, mental, and spiritual health; this reflects the deep connection that many Indigenous Peoples have with the land and waters (e.g. Hofmeijer *et al.* 2013; Middleton *et al.* 2020b; Parraguez-Vergara *et al.* 2018; Torres-Slimming *et al.* 2020; Wilson *et al.* 2019). Consequently, rising temperatures, altered precipitation patterns, and increasing incidents of extreme weather events due to climate change negatively impact Indigenous Peoples' access to, and quality of, nourishing and preferred resources (Cozzetto *et al.* 2021; Donatuto *et al.* 2014; FAO *et al.* 2021; Jacob *et al.* 2010; Reid *et al.* 2014; Schlinger *et al.* 2021; Torres-Slimming *et al.* 2020; Whyte *et al.* 2021a; Zavaleta *et al.* 2018). These climate-related changes not only exacerbate the existing food and water insecurity experienced by many Indigenous Peoples (Anderson *et al.* 2016; FAO *et al.* 2021), but have also been linked to increased incidences of negative health outcomes such as malnutrition, cardiovascular disease, acute gastrointestinal illness, vector-borne illness, mental health concerns, and a lack of cultural health resources (Middleton *et al.* 2020b; Mitchell 2018; Reid *et al.* 2014).

Climate change is affecting Indigenous Peoples' planting, harvesting, fishing, and hunting practices in many ways. For example, decreased rainfall has resulted in soil salinization, desertification, and decreased agricultural productivity, thus compromising food security and nutritional outcomes for the Mapuche Peoples in the Chilean Andes (Parraguez-Vergara *et al.* 2016). Climate change is also impacting the abundance, distribution, and health of wildlife species hunted by Indigenous Peoples (Cunsolo *et al.* 2020a; Kronik and Verner 2010; Zavaleta *et al.* 2018). For example, in the Arctic, climate change is an important contributor to the declining caribou population, which has led to a ban on caribou hunting in Labrador, Canada. However, as caribou are an important food source and cultural keystone species for Inuit in the region, this ban has significant negative food security and wellness implications for the affected communities (Borish *et al.* 2021; Cunsolo *et al.* 2020a; Kenny *et al.* 2018). Furthermore, increased winds, melting and thawing of the cryosphere, and changing ocean currents are expected to enhance the transport and uptake of organic pollutants and toxic heavy metals in Arctic ecosystems. This will not only compromise the quality and safety of Inuit food systems, but will also increase the risk of neurodevelopmental disorders and cardiovascular disease (Alava *et al.* 2017, 2018; Donaldson *et al.* 2010). Additionally, rising temperatures are expected to increase the incidence of foodborne diseases. For example, increasing temperatures in Alaska, United States, are negatively affecting the preparation of traditional fermented foods, increasing the risk of botulism among Indigenous Peoples (Fagan *et al.* 2011; Parkinson and Butler 2005).

The quantity, quality, and accessibility of freshwater resources upon which Indigenous Peoples rely are also being threatened by climate change (Berner *et al.* 2016; Cozzetto *et al.* 2013, 2021; Doyle *et al.* 2013; Goldhar *et al.* 2014; Harper *et al.* 2011, 2015, 2020; Patrick 2018; Schlinger *et al.* 2021; Torres-Slimming *et al.* 2020). Changes in water resources affect not only water security but also Indigenous Peoples' mental, emotional, and spiritual wellbeing, as many communities maintain intimate spiritual and cultural connections with bodies of water (Cozzetto *et al.* 2013; Cunsolo Willox *et al.* 2012; Harper *et al.* 2015; Mitchell 2018; Torres-Slimming *et al.* 2020; Wilson *et al.* 2019). For example, in the United States, droughts are becoming more common and are forcing members of the Navajo Nation to travel over 14 miles to obtain water for household use (Cozzetto *et al.* 2013). Similarly, as glaciers continue to retreat in the high Andes, water scarcity is increasing for Indigenous communities that depend on snowmelt for water (Kronik and Verner 2010). Lastly, in addition to decreased water quantity, changing temperature and precipitation regimes across the Americas are increasing the risk of waterborne diseases, leading to increased cases of acute gastrointestinal disease, cholera, and leptospirosis (Doyle *et al.* 2013; Harper *et al.* 2011, 2020; Hofmeijer *et al.* 2013; Kronik and Verner 2010; Parkinson and Butler 2005; Wang *et al.* 2018). These challenges can exacerbate existing water access, scarcity, and safety concerns, as well as inequitable access to adequate water treatment infrastructure (Cozzetto *et al.* 2021; Harper *et al.* 2020; Wilson *et al.* 2019).

Increasing risks of chronic and infectious illnesses due to climate change

Climate change is also projected to exacerbate the already high burden of chronic illnesses and infectious diseases that affect many Indigenous Peoples (Anderson *et al.* 2016; Gracey and King 2009). For example, in the Arctic, higher temperatures are contributing to increased air pollution and production of pollens, worsening allergy and asthma symptoms (Albert *et al.* 2018; Driscoll *et al.* 2016; Harper *et al.* 2015). Similarly, as heatwaves increase in frequency, heat-related stresses are also increasing: reports of respiratory distress on hot summer days have already been reported by Indigenous Elders (Bolton *et al.* 2011; Driscoll *et al.* 2016). In addition, such health impacts will likely be further compounded for those Indigenous Peoples who have limited access to quality healthcare services (Brierley *et al.* 2014; Bussalleu *et al.* 2021).

The risks of vector-borne and zoonotic diseases are also expected to increase as a result of climate change (Ellwanger *et al.* 2020; Ford *et al.* 2010; Parkinson and Butler 2005; Parkinson *et al.* 2008). For example, higher temperatures in the Arctic and Andes regions are expected to increase the range of insect vectors and alter the types and incidence of vector-borne and zoonotic diseases, such tick-born encephalitis, malaria, and dengue (Albert *et al.* 2018; Kronik and Verner 2010; Parkinson *et al.* 2008). In the Amazon, decreased precipitation levels have led to more stagnant water reservoirs, thus increasing the prevalence of vector-borne diseases such as leishmaniasis (Hofmeijer *et al.* 2013). In the Arctic, there is also concern about emerging pathogens from thawing permafrost (EASAC 2019).

Increasing injuries and mortality as a result of changing climate conditions

Extreme and rapidly changing weather conditions, including heatwaves, storms, droughts, flooding, and changing water, ice, and sea ice conditions, continue to pose challenges for many Indigenous Peoples, particularly those who engage in activities on the land (IPCC 2019a, 2019b; Wilson *et al.* 2021). In the Arctic, decreasing sea ice thickness and increasingly unpredictable weather have contributed to more unintentional injuries, such as hypothermia and frostbite, while out on the land in both the United States and Canada (Clark and Ford 2017; Driscoll *et al.* 2016; Fleischer *et al.* 2014). In Montana, Crow Tribal Elders have expressed concerns that outdoor ceremonial practices such as sundances are being threatened by high temperatures, which increase the risk of heat stroke, particularly among fasting participants (Doyle *et al.* 2013). In the Amazon, Indigenous Peoples report the need to be more cautious in rivers following heavy rainfalls because of strong currents bringing unseen debris that could cause them harm (Torres-Slimming *et al.* 2020). Furthermore, in Peru, high floods are often accompanied by the arrival of dangerous animals such as boas, vipers, and eels into communities (Langill 2018).

Changing and uncertain environmental conditions impact mental health and wellbeing

Climate change has direct effects on Indigenous Peoples' mental health and wellbeing (Cunsolo and Ellis 2018; Middleton *et al.* 2020b). For example, Awajún communities in northern Peru have reported that growing water insecurity is contributing to increased stress and depressive symptoms (Tallman 2019). In the Arctic, higher temperatures were associated with mental health-related clinic visits for Nunatsiavut Inuit (Middleton *et al.* 2021). Moreover, for many Indigenous Peoples, the ability to safely engage in land-based activities is essential to their mental wellbeing (Cunsolo Willox *et al.* 2013b; Middleton *et al.* 2020a) and physical health (Akbar *et al.* 2020); as such, disruption of water-, ice- and land-based activities due to climate change, combined with other factors such as the loss of cultural sites caused by erosion or flooding, are contributing to psychosocial stresses (Cunsolo Willox *et al.* 2013a; Donatuto *et al.* 2014; Middleton *et al.* 2020a). For example, in Indigenous communities the Arctic, the reduced ability to safely engage in land-based activities and access important cultural sites has led to increased anxiety, fear, distress, anger, and grief (Cunsolo Willox *et al.* 2013a, 2015; Petrasek MacDonald *et al.* 2015). Lastly, in some cases climate change may alter landscapes to such a degree that Indigenous Peoples are forced to relocate, which is associated with stress, grief, and depression due to the loss of meaningful places, social networks, and cultural links (Albert *et al.* 2018; Kronik and Verner 2010; Maldonado *et al.* 2021; Middleton *et al.* 2020b; Parry *et al.* 2019).

Declining access to quality healthcare due to climate change

Across the Americas, Indigenous Peoples' access to allopathic healthcare is often limited and can require extensive travel, especially if their home community is remote (Anderson *et al.* 2016; Brierley *et al.* 2014; Parry *et al.* 2019). Consequently, Indigenous Peoples' access to healthcare can be vulnerable to climate change and is often disrupted by extreme weather conditions. For example, in some Peruvian villages, community members reported that they typically lack access to the nearby health post for several weeks if flood waters rise to a certain level (Langill 2018). In Arctic Canada, many Indigenous Peoples rely primarily on air transportation and telecommunication in emergency medical situations, both of which are vulnerable to extreme weather events (Ford *et al.* 2010; Harper *et al.* 2015). Furthermore, changing seasonality, flooding, and drought, combined with deforestation and other anthropogenic changes, have also decreased the accessibility of plants and other medicines harvested from the local environment for many Indigenous Peoples (Hofmeijer *et al.* 2013; Lynn *et al.* 2013). For example, many Indigenous Peoples rely on medicinal plants (e.g. Vandebroek *et al.* 2004) and foods (FAO *et al.* 2021), which are considered key for fostering climate change adaptation.

Adaptation and responses to the impacts of climate change on health

Despite these challenges, Indigenous Peoples across the Americas have been leading health-related adaptation strategies, which are often grounded in strong social networks, extensive Indigenous knowledge systems, and deep connections to place (Table CS 12.1). To reduce the health effects of climate change for Indigenous Peoples, decision-makers must apply a rights-based approach and support Indigenous self-determination in identifying, developing, and implementing adaptation and mitigation strategies that reflect their specific socio-cultural, economic, environmental, and geographical contexts. This requires acknowledging, upholding, and reaffirming Indigenous Rights (e.g. the United Nations Declaration on the Rights of Indigenous Peoples) and providing resources to address both non-climatic and climatic factors that increase climate–health risks, as well as recognizing the critical role that Indigenous knowledges play in climate–health solutions (Cameron *et al.* 2021; Gahman and Thongs 2020; ITK 2019; Jones 2019; McGregor 2021; Ratima *et al.* 2019). Ultimately, addressing climate–health risks for Indigenous Peoples requires not only examining and dismantling the broader context of colonialism, racism, and dispossession but also supporting Indigenous self-determination (Cameron *et al.* 2021; Gahman and Thongs 2020; ITK 2019; Jones 2019; McGregor 2021; Ratima *et al.* 2019).

Table CS 12.1 Examples of health risks experienced by Indigenous Peoples in the Americas due to climate change, and associated Indigenous-led adaptation measures

Impacts of climate hazards on health	Adaptation measures
Food and water insecurity	
• Gitga'at Nation in British Columbia, Canada, expect that the salmon and clams upon which they rely will be negatively impacted by warmer and more acidic waters (Reid *et al.* 2014).	• Gitga'at Nation maps and surveys historic and new harvesting sites to adapt to changes in food access. They also organize communal harvesting efforts (Reid *et al.* 2014).
Chronic and infectious diseases	
• Shawi and Shipibo communities in Peru report concern over increasing vector-borne diseases and parasitic infections (Hofmeijer *et al.* 2013).	• Shawi and Shipibo Peoples use nets, boil their water, and build raised homes that offer protection from animals carrying diseases (Hofmeijer *et al.* 2013).
• Climate change is projected to cause changes in the incidence and geographical distribution of infectious diseases in the Arctic (Parkinson *et al.* 2008).	• The International Circumpolar Surveillance system was established to monitor infectious diseases in the Arctic to help formulate prevention and control strategies (Parkinson *et al.* 2008).
Injury and mortality	
• Inuit in Northwest Territories, Canada, report that early and rapid spring melt, less predictable weather, and changing sea ice dynamics are causing more hunters to become stranded or injured (Fawcett *et al.* 2018).	• Inuit take extra supplies and gas out on the land, travel in groups, stay closer to town, and use communication and/or navigation technology (Fawcett *et al.* 2018).

Table CS 12.1 *(continued)*

Injury and mortality	
• Shawi communities in Peru report that heavy rainfall creates dangerously strong water currents which carry debris that could injure bathers (Torres-Slimming *et al.* 2020).	• Shawi exercise greater caution when bathing, and actively reforest the riverbank to minimize erosion (Torres-Slimming *et al.* 2020).
Mental health and wellbeing	
• In Nunatsiavut, Canada, less predictable weather and decreasing sea ice render it more challenging to safely engage in traditional activities, which are central to Inuit mental wellbeing (Hirsch *et al.* 2016).	• 'Going Off, Growing Strong' is a community-led youth outreach program that aims to enhance the mental, physical, and spiritual health of youth by participating in land-based activities with harvesters and Elders (Hirsch *et al.* 2016).
Access to quality healthcare	
• First Nations in the Yukon, Canada, report that changing temperatures, precipitation, and seasonality impact the harvesting and practice of traditional medicine (Climate Telling 2021).	• The First Nations community developed an action plan to sustain traditional medicine practices through climate changes, which includes documenting traditional medicine knowledge and identifying gathering areas sensitive to climatic changes (Climate Telling 2021).

4 What are the overarching adaptation and mitigation response options?

Given the range, magnitude, and pace of current climate change impacts, together with heightened future risks, both climate change adaptation and mitigation strategies are critical to protect public health. Whereas in Chapter 3 we examined some adaptation options specific to each health outcome category, here we synthesize the overarching mitigation and adaptation options, with a focus on those strategies that cut across sectors, health outcomes, and geographies. Case studies are incorporated throughout the chapter to provide local and/or regional context and to highlight in-depth examples of climate–health impacts and response strategies across the Americas.

4.1 Adaptation strategies, policies, and programs

Climate change is already affecting population health and healthcare infrastructure, requiring adaptation policies and measures to increase the resilience of individuals, communities, and health systems. Adaptation is "*the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities*" (IPCC 2014a).

The risks of a changing climate arise from the intersection of the hazards directly and indirectly created by climate change, the populations and regions exposed to these hazards, their vulnerability to exposure, and the capacities of communities, health systems, and healthcare infrastructure to understand and prepare for changes in the magnitude and pattern of climate-sensitive health outcomes. Vulnerabilities to climate change are shaped by complex spatial, social, political, and economic factors. Therefore, iterative risk management is needed to manage the health risks of climate change, through which effective adaptation policies address the underlying inequalities and injustices that create differential vulnerabilities (Eriksen *et al.* 2011).

Adaptation strategies, policies, and programs aim to build climate-resilient and environmentally sustainable health and healthcare systems (WHO 2020b). Figure 4.1 illustrates how shocks and stresses associated with climate change can affect the capacity and resilience of health systems and healthcare facilities, and how adaptation and disaster risk management can affect preparedness, response, and recovery (WHO 2020b). Improving climate–health education will also be critical in developing and implementing effective adaptation strategies (Case Study 13).

To build resilience, adaptation approaches need to address the building blocks of health and healthcare systems: (i) leadership and governance; (ii) the health workforce; (iii) health information systems, including vulnerability, capacity, and adaptation assessments, integrated risk monitoring, and early warning and response systems; (iv) service delivery, including climate-informed health policies and programs and management of the environmental determinants of health; (v) the availability and accessibility of complementary social services; (vi) climate-resilient and sustainable technologies and infrastructure; and (vii) financing and investment (WHO 2020b).

4.1.1 Policy options for managing the health risks of climate change

Vulnerability, capacity, and adaptation (V&A) assessments are critical for establishing a knowledge base of current and projected health risks, identifying particularly vulnerable populations and regions, and detailing the capacity of systems and communities to prepare for and manage changes in the magnitude and pattern of risks. These

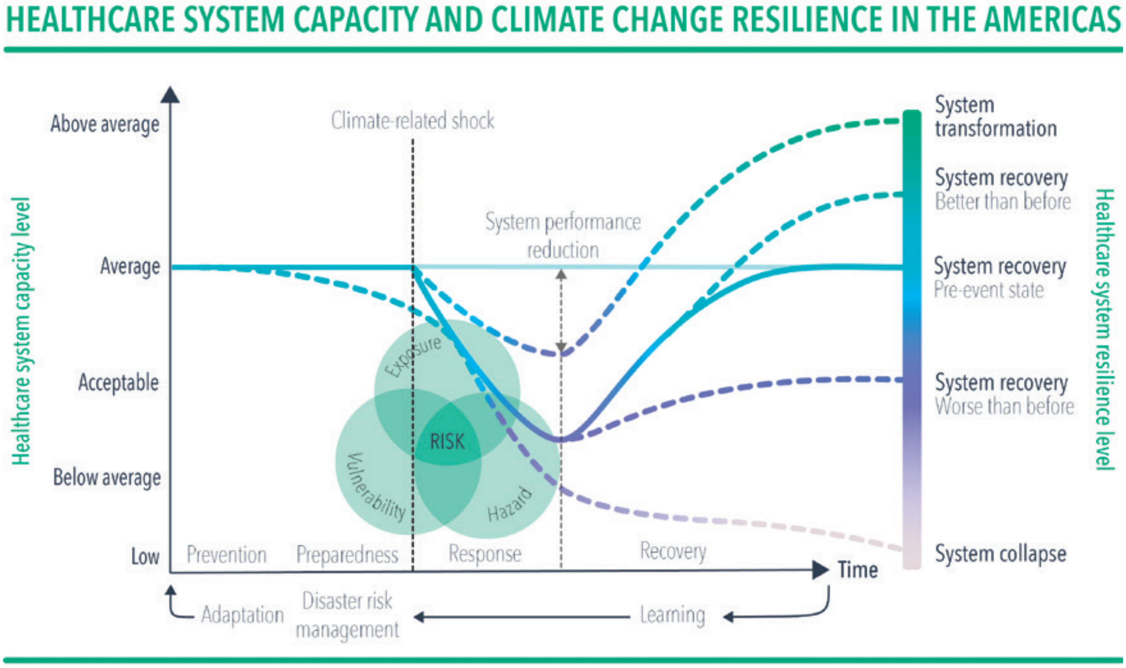

Figure 4.1 Recovery scenarios for healthcare systems after climate shocks, which are influenced by prevention, preparedness, response, and recovery actions, as well as by learning cycles and adaptation measures (adapted from WHO 2020b).

assessments often build partnerships within the health sector to ensure that climate change is integrated into current policies and programs, as well as partnerships across non-health sectors that facilitate collaborations on adaptation tools such as early warning systems. These assessments typically identify and prioritize a range of adaptation strategies, policies, and programs over short to longer terms (Berry *et al.* 2018). Many countries follow the World Health Organization guidelines for conducting such assessments (WHO 2013, 2021) (Figure 4.2). Countries in the Americas with national V&A assessments include Antigua and Barbuda, Barbados, Bolivia, Brazil, Canada, Costa Rica, Dominica, Grenada, Mexico, Panama, St. Lucia, and the United States (Berry *et al.* 2018). Specific guidelines have been developed for regions in Canada (e.g. Ontario) (Berry *et al.* 2018) and the United States (e.g. CDC Building Resilience for Climate Effects (BRACE; https://www.cdc.gov/climateandhealth/BRACE.htm)), and guidelines are also being prepared for SIDS in the Caribbean (Scheske *et al.* 2018). Subnational assessments are useful in large countries where the health impacts of climate change are diverse and can vary significantly between regions (Berry *et al.* 2018).

A V&A assessment is a core element supporting the development of the health component of a national adaptation plan (HNAP) (WHO 2014c). An HNAP builds on existing national efforts towards health adaptation to climate change, including existing assessments, policies, and programs, to ensure that health adaptation is integrated into national health planning strategies, processes, and monitoring systems. HNAPs also maximize synergies across sectors, such as food, water, energy, and housing, by building health considerations into their adaptation planning, which is critical in addressing the upstream drivers of health.

Examples of health adaptation options

Prioritizing adaptation options in any location requires an understanding of the magnitude and pattern of current and projected risks, the vulnerabilities of populations and infrastructure to these risks, the effectiveness of policies and programs to manage these risks, and the strengths and challenges that are unique to communities and health systems. Table 4.1 illustrates the range of adaptation options that can be effective in managing climate-sensitive health outcomes (Smith *et al.* 2014).

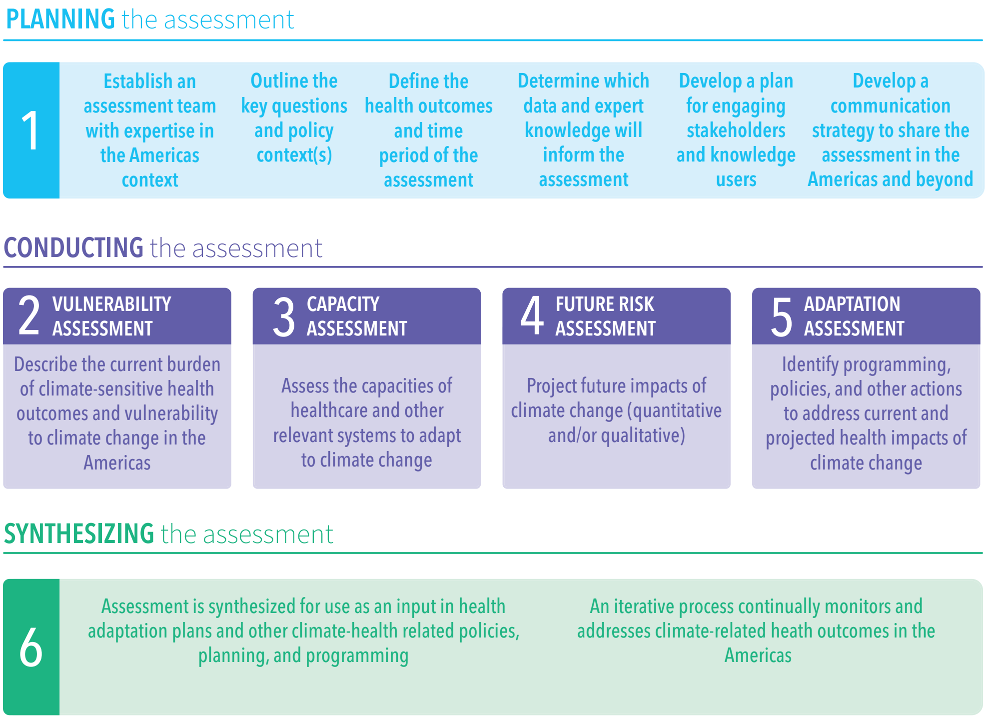

Figure 4.2 Steps for conducting a climate change and health vulnerability and adaptation (V&A) assessment (adapted from WHO 2021).

Table 4.1 Examples demonstrating the range of adaptation options that are available to manage climate-sensitive health outcomes (Smith *et al.* 2014)

Climate-sensitive health risk	Example adaptation options
Heat-related morbidity and mortality	Education to increase awareness of the hazards of high ambient temperature; heat action plans, including heatwave early warning and response plans and longer-term planning; built environment modifications to address higher temperatures and more frequent heatwaves with progressing climate change
Injuries, illnesses, and deaths from extreme weather and climate events	Explicitly incorporating health into disaster risk management plans; stress testing of disaster response plans to ensure effectiveness in a warmer future; early warning and response systems; incorporating mental health impacts into disaster risk management
Illnesses and deaths associated with poor air quality	Early warning and response systems; education to increase awareness of the hazards of ozone, aeroallergens, and wildfire smoke
Infectious diseases	Integrated vector management; integrated disease surveillance; early warning and response systems; improved water, sanitation, and hygiene systems
Undernutrition	Integrated surveillance and monitoring systems; early warning and response systems; improved water, sanitation, and hygiene systems

4.1.2 Indicators for assessing health adaptation

Monitoring and evaluating climate change adaptation progress will be increasingly critical. What constitutes successful adaptation will vary over time with shifts in vulnerability and climate-related exposures, and those adaptation strategies implemented today may not show effectiveness for several years. Consequently, the *Lancet Countdown* established an international collaboration to provide an independent, global monitoring system dedicated to tracking four groups of indicators of adaptation, planning, and resilience for a health profile of a changing climate (Watts *et al.* 2017):

1. Adaptation planning and assessment
   a. National adaptation plans for health
   b. National assessments of climate change impacts, vulnerabilities, and adaptations for health
   c. City-level climate change risk assessments

2. Climate information services for health

3. Adaptation delivery and implementation
   a. Detection, preparedness, and response to health emergencies
   b. Air conditioning
   c. Urban green space

4. Spending on adaptation for health and health-related activities

Two of the indicators on adaptation and planning are drawn from the World Health Organization Health and Climate Change Survey. This is a voluntary national survey completed by Ministry of Health focal points. In 2021, 47 (52%) of 91 countries participating in the survey reported having national health and climate change strategies or plans in place (Romanello *et al.* 2021). The main findings of the survey are relevant for all regions: (i) national planning on health and climate change is advancing, but the comprehensiveness of strategies and plans needs to be strengthened; (ii) implementing action on key health and climate change priorities remains challenging; (iii) results from vulnerability and adaptation assessments are influencing policy prioritization; and (iv) multisectoral collaboration on health and climate change policy is evident, with uneven progress (Watts *et al.* 2021).

The third indicator on adaptation and planning is derived from the Carbon Disclosure Project reporting platform (https://www.cdp.net/en/climate), which was established to assist investors, companies, cities, states, and regions with the management of their environmental impacts. As of July 2021, 36 of 859 subnational adaptation measures reported to the Carbon Disclosure Project in the United States (4%), 13 of 250 measures in Canada (5%), and 3 of 131 in Mexico (7%) focused on public health and safety (https://data.cdp.net/d/feaz-9v5k/visualization). These findings are consistent with data showing very limited climate financing for health-related climate change adaptation, and equally limited research funding in biomedical sciences for climate change and health (UNEP 2018). The evidence base for effective adaptation strategies to protect public health in low and middle income countries is particularly inadequate. A recent systematic review identified 99 studies (1,117 reported outcomes) from 66 low and middle income countries, and only two studies were *ex ante* formal evaluations of climate change adaptation responses (Scheelbeek *et al.* 2021). This gap in the evidence base reflects a broader knowledge gap in the adaptation literature. A global review of research on implemented climate–health adaptations found that few studies have assessed the effectiveness of adaptation actions (Berrang-Ford *et al.* 2019, 2021a). Although adaptation assessments often rely on indicators of adaptation policy processes, evaluating the effectiveness of these processes also requires policy attribution frameworks for assessing risk and vulnerability reduction outcomes. Our understanding of whether or how adaptations are reducing key climate change risks and vulnerabilities would benefit from further development, and highlights the need for more robust monitoring and evaluation of adaptation policies, programs, and projects.

Adaptation options need to be co-designed and co-implemented by health systems, vulnerable populations, and other sectors to effectively incorporate local vulnerabilities, priorities, and strengths. This means that the specifics of an adaptation option, such as early warning and response systems or improvements to water, sanitation, and hygiene infrastructure, will vary from location to location. For example, indicators of the health risks of and capacity to respond to climate change in Nunavut, Canada, were selected taking into consideration the territory's atmosphere, habitats, and peoples (Healey Akearok *et al.* 2019). Individuals from multiple sectors participated in a consensus-building process, identifying 20 indicators for environmental health, morbidity and mortality, population vulnerability, and mitigation, adaptation, and policies. The highest priority indicator was determined to be food security, including access to food and weather-related food shortages. Other priority indicators included mental health, specifically in terms of the incidence of depression and anxiety related to climate change, as well as the number of health surveillance systems related to climate change, numbers of injuries and deaths related to extreme weather events and to sea ice instability, the number of heatwave early warning systems, human cases of environmental infectious diseases such as Lyme disease, the vulnerability of elderly individuals living alone and other population groups susceptible to climate change impacts, the size of the public health workforce available and trained in the effects of climate change, indicators of water security and air quality, and the presence of harmful algal blooms and shellfish poisonings. There are still challenges when it comes to identifying indicators that effectively reflect the intended metric, but the development and measurement of appropriate indicators may be improved as additional data are collected over time. Furthermore, it is important that governments provide the resources and supports needed to identify, implement, and sustain the continued monitoring of these metrics and responses.

4.1.3 Coordinating health adaptation across scales and sectors

Adapting to the health impacts of climate change will require coordinated efforts between the health sector and other sectors such as water and sanitation, food production, transportation, housing, education, and land-use planning. The design of coherent adaptation policies based on cross-sectoral collaboration to maximize synergies between different policy goals and minimize trade-offs or conflicts is generally considered an essential condition to achieving successful risk and vulnerability reduction (Austin *et al.* 2016). National and regional adaptation plans can be supported by cross-sectoral and multi-scalar working groups that bring a health lens to adaptation planning in related sectors and at different levels of government.

4.1.4 Limits to adaptation

The changing nature of climate risks means that currently effective adaptations may become inadequate over the medium to longer term. An important concern is that adaptations designed without sufficient attention to equity and the needs of the most vulnerable may actually increase risks or shift risks to certain groups (Juhola *et al.* 2016). A key research question is to determine whether there are situations in which health systems will no longer be able to avoid intolerable risks even with adaptation strategies in place. These limits to adaptation may result from climate change and/or physiological, institutional, technological, behavioral, or economic factors. For example, hospitals and other health facilities built on permafrost or on floodplains face limits to adaptation as the hazards associated with these locations increase with climate change. More than 5% of Canadian health facilities are located on floodplains (Clark *et al.* 2021); consequently, these facilities have a reduced capacity to respond and provide health services to those injured or otherwise impacted during a flooding event.

The limits to adaptation will depend on both the rate and magnitude of temperature increases. If global temperatures only reach 2°C above pre-industrial temperatures by 2100, then health systems and critical infrastructures have time to prepare for the consequences; however, global increases greater than 2°C will pose much more significant adaptation challenges. Research is needed to better understand the range of plausible future climate and adaptation scenarios to inform policies and programs and to increase resilience in an uncertain future.

As temperature and precipitation patterns continue to change, numerous important thresholds could be crossed; for example, increased rainfall could result in significant increases in the geographical range of vectors carrying climate-sensitive infectious diseases. Similarly, outdoor workers are particularly vulnerable to global temperature increases, especially where they are already working at the limits of thermal tolerance for part of the year (Smith *et al.* 2014). Several Latin American countries could experience extreme heat conditions that exceed the threshold for safe moderate physical labor during the hottest month of the year if average global temperature increases exceed 2°C. This is likely to increase poverty and inequalities in health and wealth, as those in limited socioeconomic circumstances may be forced to accept unsafe, low-paying working conditions, further damaging their health and material resources (Andrews *et al.* 2018). Further, such increases could negatively impact agricultural practices by reducing crop yields and the available agricultural labor pool, resulting in potentially detrimental impacts on both the availability and quality of food (Smith *et al.* 2014).

Ebi *et al.* (2021a) applied a synthesis approach used in the IPCC assessment reports for health outcomes to illustrate how health risks are projected to change with further temperature increases under three adaptation scenarios (Figure 4.3). The health risks illustrated in the figure are heat-related morbidity and mortality; ozone-related mortality; malaria incidence rates; incidence rates of dengue and other diseases spread by *Aedes* spp. mosquitoes; Lyme disease; and West Nile fever. Adaptation can reduce the magnitude of risks as they continue to increase with climate change. Transitions from detectable and attributable risks to severe and widespread risks related to heat could manifest even at warming of less than 1.5°C above pre-industrial temperatures and will continue to develop at warming levels up to about 2.5°C, depending on the extent to which adaptation is proactive, timely, and effective. The Shared Socioeconomic Pathway SSP1 adaptation scenario, which emphasizes international co-operation towards achieving sustainable development, has the greatest potential to avoid significant increases in risks under all but the highest warming scenarios. The SSP2 adaptation scenario assumes that current trends in adaptation continue, with medium challenges to adaptation and mitigation. Finally, the SSP3 scenario describes a world with a high level of challenges to adaptation and mitigation (Ebi *et al.* 2021a).

Figure 4.3 provides insight into possible limits for adaptation. For example, additional warming may lead to expansion or northern range shifts of tick species carrying vector-borne diseases such as Lyme disease and encephalitis, which, combined with underprepared or overburdened health systems, could lead to communities in certain regions being overwhelmed by disease outbreaks (Smith *et al.* 2014).

A key challenge for decision-makers is that health adaptation research tends to be organized by health outcome, yet health systems and communities will need to manage multiple health risks simultaneously. The challenge of managing multiple risks is increasingly difficult when risks are compounding and cascading, such as simultaneous heatwaves and drought or repeated floods. This challenge highlights the importance of bolstering both the emergency response and surge capacities of health systems. Therefore, additional research is needed to identify effective and feasible health adaptation measures that target multiple risks simultaneously, as well as appropriate strategies in instances where compounding or cascading risks are likely.

4.1.5 Critical next steps for adaptation

As highlighted in this chapter, there are very significant needs for research into and implementation of health adaptations across the Americas. There is a significant adaptation gap, given that recent and current funding amounts are well below the estimated

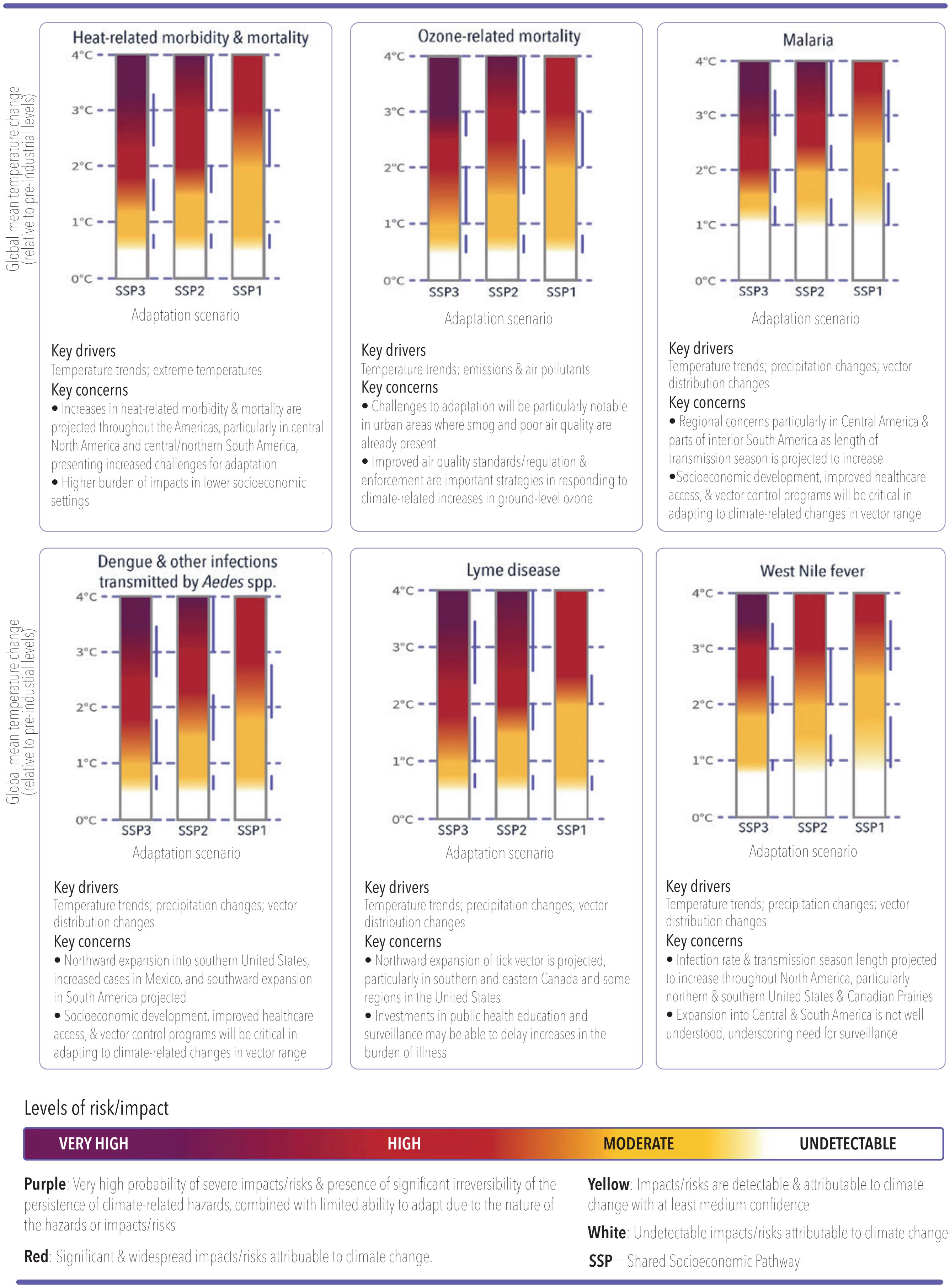

Figure 4.3 Change in risks for six climate-sensitive health outcomes in the Americas by increases in temperature above pre-industrial levels under three different adaptation scenarios (adapted from Ebi et al. 2021a).

Case Study 13 Climate–health education for health professionals

Health education programs have a responsibility to integrate climate–health teaching into curricula to equip current and future doctors, nurses, and public health practitioners with the knowledge and skills necessary to provide effective healthcare at a patient level within a changing climate (Leffers *et al.* 2017; Mantilla and Li 2019). In addition, climate–health education will expand the ability of health professionals to advocate for climate change research and policies that will benefit population health outcomes and improve the climate resiliency of healthcare systems (Adlong and Dietsch 2015; Leffers *et al.* 2017; Mantilla and Li 2019; Maxwell and Blashki 2016; Shaman and Knowlton 2018; Vogel 2019; Wasco 2019; Yang *et al.* 2018).

Given the urgent need to prepare health professionals to address climate–health impacts across the Americas, many national and international health associations, including the American Medical Association, the Canadian Public Health Association, and the International Council of Nurses, have called for the integration of climate–health education into health professional curricula (AACN 2011; AMA 2019; Buka and Shea 2019; Castleden *et al.* 2020; CPHA 2019; Health Workforce Advocacy Initiative 2009; ICN 2008; Shea *et al.* 2020; Wellbery *et al.* 2018; WMA 2009). Additionally, an editorial recently published in more than 200 medical and public health journals declared climate change to be the "greatest threat to global public health" and made a clear call for "emergency" responses (e.g. Atwoli *et al.* 2021). In 2015, 118 public health, medical, and nursing schools around the world, 103 of which are in the Americas, signed the Health Educators Climate Commitment agreeing to train the next generation of health professionals to address climate–health issues (The White House; Office of Press Secretary 2015). Despite this commitment, there remains a substantial gap in climate–health preparation for health professionals in the Americas (Bell 2010; Leffers *et al.* 2017; Polivka *et al.* 2012; Shea *et al.* 2020; Silverman 2019; Trajber and Mochizuki 2015; Wellbery *et al.* 2018). For example, in 2019, less than 3% of public health programs in the United States required a specific course on climate change, and less than 25% offered a climate–health elective opportunity (Silverman 2019). Similarly, in 2017, although half of medical schools in Colombia introduced a climate–health session into the curriculum, the topic was not prioritized and was not taught by qualified professionals (Mantilla and Li 2019). Therefore, health professionals across the Americas lack the preparedness and confidence to effectively assess, mitigate, and adapt to climate–health threats, which is recognized as one of the main barriers to optimizing the public health response to climate change (Bell 2010; Cabrera and Tomey 2010; Castleden *et al.* 2020; Leffers *et al.* 2017; Maxwell and Blashki 2016; Polivka *et al.* 2012; Silverman 2019; Vogel 2019).

Given this recognized gap, extensive literature has explored how to effectively incorporate climate–health education into health curricula (Bell 2010; Castleden *et al.* 2020; Gehle *et al.* 2011; Jagals and Ebi 2021; Leffers *et al.* 2017; Maxwell and Blashki 2016; Shea *et al.* 2020). Key challenges to operationalizing climate–health education include a lack of faculty with climate–health expertise, limited curriculum-development funding, overcrowded curricula, institutional inertia and politics, and the absence of climate–health education as a strategic focus of institutions (Castleden *et al.* 2020; Gehle *et al.* 2011; Leffers *et al.* 2017; Maxwell and Blashki 2016; Shea *et al.* 2020; Trajber and Mochizuki 2015; Walpole *et al.* 2017; Wasco 2019; Yang *et al.* 2018). However, several educational strategies, frameworks, and resources have been developed to help overcome these barriers and facilitate the implementation of climate–health education (Cantell *et al.* 2019; Gehle *et al.* 2011; IFMSA 2016; Jagals and Ebi 2021; Leffers *et al.* 2017; Maxwell and Blashki 2016; Mckeown and Hopkins 2010; Teherani *et al.* 2017; Walpole *et al.* 2017; Wasco 2019). Common principles include the following:

- **Integration into the existing curriculum:** climate–health competencies could be feasibly integrated as cross-cutting themes into existing elements of health curricula (e.g. environmental health, social determinants of health) to enhance learning without requiring major changes in already overpacked curricula (Bell 2010; CFMS HEART 2020; Gehle *et al.* 2011; Leffers *et al.* 2017; Walpole *et al.* 2017; Wellbery *et al.* 2018).
- **Application of climate–health knowledge:** climate–health courses must extend beyond climate–health science and include problem solving, critical thinking, and practical competencies, so as to cultivate knowledgeable health professionals who are empowered as competent actors and leaders in climate change action (Bell 2010; Cantell *et al.* 2019; CFMS HEART 2020; Mckeown and Hopkins 2010; Shapiro Ledley *et al.* 2017; Silverman 2019; Vaughter 2016; Walpole *et al.* 2016; Yang *et al.* 2018).
- **Emphasis on self-efficacy:** climate–health teaching should emphasize individuals' capacity to achieve positive outcomes, as feelings of hope and efficacy are correlated with individuals' likelihood to engage with climate change issues (Cantell *et al.* 2019; Castleden *et al.* 2020; Myers *et al.* 2012; Shapiro Ledley *et al.* 2017; Yang *et al.* 2018).
- **Regional considerations:** climate–health curricula must reflect the regional variability of climate change impacts (Bell 2010; Cantell *et al.* 2019; Castleden *et al.* 2020; Maxwell and Blashki 2016; Mckeown and Hopkins 2010; Silverman 2019).
- **Continuing education:** climate–health resources must evolve with new evidence and emerging needs, and be available for established health practitioners as continuing professional education (Bell 2010; Maxwell and Blashki 2016; Teherani *et al.* 2017; Wellbery *et al.* 2018).
- **Collaboration and use of existing resources:** implementing climate–health education amid resource constraints warrants inter-institutional collaboration (CFMS HEART 2020; Madden *et al.* 2018; Mantilla and Li 2019; Shaman and Knowlton 2018; Shea *et al.* 2020). The Global Consortium on Climate and Health Education was established to enact the Health Educators Climate Commitment and to unite health professional schools worldwide by sharing best practices, core competencies, and free resources to build evidence-based climate–health curricula and training (Columbia University Mailman School of Public Health 2019). Additional curricular resources have been developed by health organizations across the Americas (ANHE 2016; CFMS HEART 2019; NHI). Institutions should capitalize on these available resources to facilitate and accelerate the implementation of climate–health education (Shea *et al.* 2020).

Although climate change is the greatest health threat of the 21st century, action to address the threat is also one of the greatest public health opportunities (Watts *et al.* 2017). However, capitalizing on this opportunity will require health professionals to understand climate–health impacts and responses (Castleden *et al.* 2020; Leffers *et al.* 2017; Madden *et al.* 2018; Maxwell and Blashki 2016; Walpole *et al.* 2017; Yang *et al.* 2018). Therefore, it is imperative that programs for health professionals across the Americas continue to collaborate to establish robust climate–health curricula that will equip health professionals with the expertise to provide effective care for patients and lead action in climate change mitigation and adaptation (Castleden *et al.* 2020; Yang *et al.* 2018).

levels required to minimize negative health outcomes (e.g. UNEP 2018). Unless adaptation investments are considerably strengthened, the burden of climate-sensitive health outcomes will continue to increase with climate change. Adaptation is becoming a greater policy priority for many countries in the Americas, and, consequently, governments can more fully use the policies and strategies available at their disposal to reduce vulnerabilities and risk.

4.2 Mitigation options

4.2.1 Health co-benefits

Even if drastic and immediate actions are taken to meet current emissions targets, global warming is likely to exceed or "overshoot" 1.5°C. This will result in years, if not decades, of higher global temperatures before response efforts are able to stabilize temperatures at the 1.5°C level (IPCC 2021). There are clear benefits to meeting the emissions targets set out in the Paris Agreement, especially in terms of reducing health risks in the coming decades (see Chapter 3 and Case Study 14); however, decision-makers are often working within shorter time horizons, and therefore it can be helpful to recognize the nearer-term benefits of climate change action (Figure 4.4). Indeed, the near-term health benefits (co-benefits) of reducing emissions across sectors can provide important rationales for climate responses, and can substantially offset the costs for decision-makers to take more aggressive and immediate climate action (Chang *et al.* 2017; Haines 2017; Haines *et al.* 2009). For example, in the United States, where air pollution levels are relatively lower than in many other countries, emissions policies to limit warming to 2°C could prevent 175,000 premature deaths by 2030, and 22,000 additional deaths annually thereafter (Shindell *et al.* 2016). In Mexico, climate change mitigation policies that reduce ozone and particulate matter could reduce mortality by 3,000 deaths per year (Crawford-Brown *et al.* 2012). Using case study examples, we further outline the co-benefits of reduced air pollution, increased physical activity, and dietary changes, which are the most widely studied co-benefits to date. Furthermore, these climate actions are projected to result in some

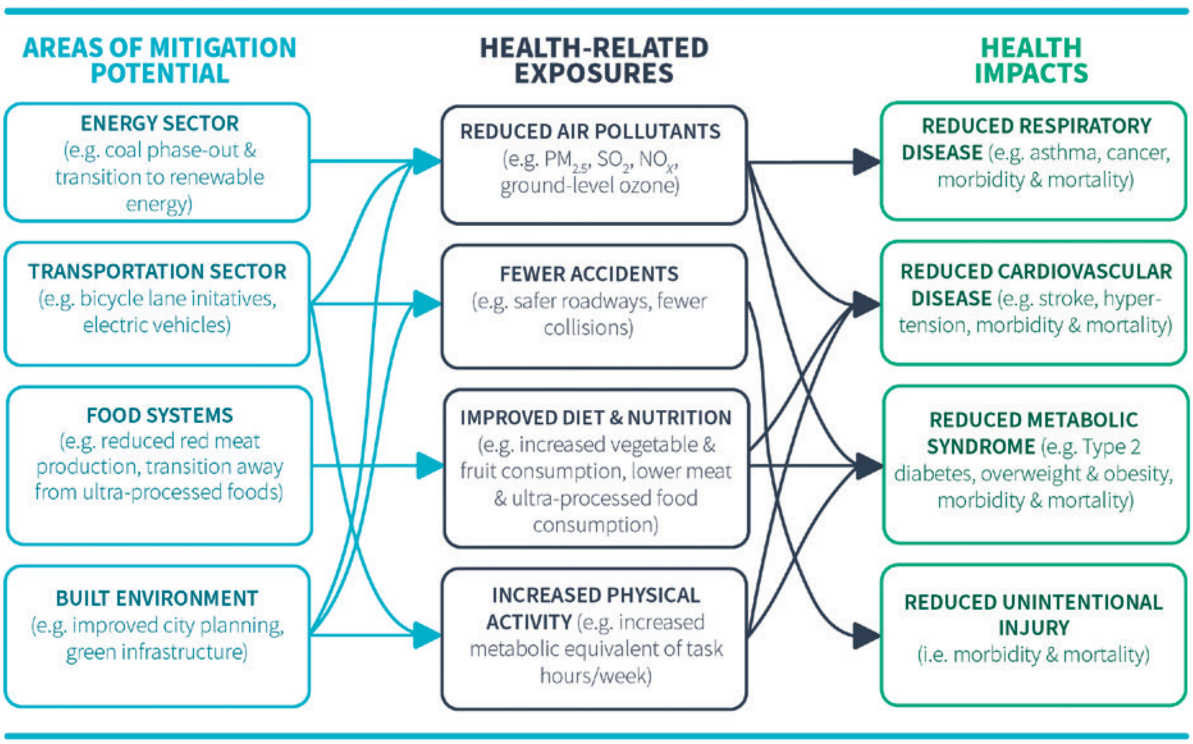

Figure 4.4 Examples of how mitigation efforts can have immediate co-benefits for health in the Americas (adapted from Hess et al. 2020).

of the largest reductions in climate-sensitive health outcomes compared with other possible climate responses, although multiple strategies will be necessary and the most appropriate strategies will vary by time and location (Milner *et al.* 2020).

Coal phase-out has co-benefits for the environment and human health

Coal-fired power generation remains one of the largest sources of GHG emissions and other air pollutants globally (Oberschelp *et al.* 2019). Addressing the issue of coal-based power will therefore be essential to meeting global emission reduction targets. To align with the goals of the Paris Agreement, near total phase-out of coal-fired power plants, in combination with carbon sequestration efforts, must be achieved by 2050 (IPCC 2018; Sampedro *et al.* 2021).

Although necessary to reduce global GHG emissions, coal phase-out will also have immense additional benefits due to the negative environmental implications of every stage of the coal continuum. Coal mining requires the use of heavy diesel-powered machinery; and in the case of surface coal mining, clearcutting of forests and the use of large quantities of explosives are common, which degrade the environment and contribute to air pollution (Hendryx *et al.* 2020; Palmer *et al.* 2010). Coal processing creates large volumes of chemically contaminated wastewater, which, if managed incorrectly, can permeate local water supplies (Hendryx *et al.* 2020). Burning coal for electricity production releases air pollutants including CO_2, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and other particulate matter (Hendryx *et al.* 2020; Oberschelp *et al.* 2019). Finally, coal ash, the waste product from coal burning, contains radioactive elements and heavy metals that can have long-lasting impacts on the environment (Hendryx *et al.* 2020). For example, coal combustion is the second-highest source of mercury exposure worldwide (after small-scale and artisanal mining) (EPA 2021).

Each stage of the continuum from extraction to coal ash disposal poses important health risks through air, soil, and water pollution. Studies have associated coal mining processes with increased all-cause mortality and elevated incidences of cardiovascular disease, respiratory disease, lung cancer, and negative infant and child health outcomes (Kravchenko and Lyerly 2018), highlighting the co-benefits of coal phase-out for human health in addition to the environmental benefits. Research has shown that phasing out the most polluting coal plants (top 10% of polluters globally) could reduce related health impacts by up to 64% (Oberschelp *et al.* 2019), whereas cancelling all newly proposed coal projects could lead to 210,000 fewer premature deaths per year related to air quality by 2030 (Sampedro *et al.* 2021).

The co-benefits of coal phase-out are highly relevant for the Americas. The United States is one of the largest producers of coal-fired electricity, ranking as the world's third-largest producer in 2018 (Watts *et al.* 2021). Other countries, including Chile and Guatemala, also have more than 25% of their total electricity generation sourced from coal (Watts *et al.* 2021). Importantly, however, investments in new coal capacity are declining in some regions; for example, compared with 2006 levels, new investments have decreased by 50% and 95% in Brazil and the United States, respectively, (Watts *et al.* 2021). Continued divestment and phase-out of coal will have important implications for human health in the Americas. For instance, in the Appalachia region of the eastern United States, mountaintop removal mining (a form of surface coal mining) has become increasingly common since the 1990s (Hendryx *et al.* 2020). Research studies and systematic reviews have documented increased violations of water quality (Hendryx *et al.* 2012) and the negative physical and mental health impacts for residents living near surface mines in Appalachia (Boyles *et al.* 2017). Reductions in mining activities may, therefore, improve the health and water security of Appalachian communities.

In northeast Brazil, a cost–benefit analysis found that stricter PM_{10} (particulate matter of sub-10 μm size) guidelines for coal plants would result in health-related cost savings far greater than the costs of emissions controls, demonstrating the potential benefits of coal phase-out not only for ecosystems and human health, but for economies as well (Howard *et al.* 2019).

Changing transportation systems have co-benefits for human health

Road traffic accounts for approximately three-quarters of transport-related emissions, and these emissions, which are the fastest-rising within the energy-using sectors, are projected to increase by 80% by 2030 (IPCC 2014b). Therefore, reducing emissions from road traffic will be critical to meet the Paris Agreement goals. Possible mitigation measures include promoting bicycle and foot travel, encouraging carpooling, building effective public transit infrastructure, and expanding electric vehicle use. These mitigation actions can have important health co-benefits, including increased physical activity, lower morbidity and mortality due to reduced air pollution, and reduced risk of road traffic injuries. In particular, the health benefits of increased walking and cycling are substantial, and have been associated with significant reductions in the prevalence of ischemic heart disease, cerebrovascular disease, depression, dementia, and diabetes (Woodcock *et al.* 2009, 2018). Recognition of these health co-benefits has led to efforts to expand, improve, and create safe urban environments for active travel (Milner *et al.* 2020; Watts *et al.* 2021).

A study in the Midwestern United States found that riding a bicycle rather than using a car for short-distance trips could result in decreased air pollution, increased levels of physical activity, and reduced healthcare costs (Grabow *et al.* 2012). There have been several initiatives throughout the Americas to promote active travel, such as bicycle lanes that transform city streets into safe and vehicle-free spaces for residents to use for recreational and transportation purposes. A study assessing the health and economic benefits of bicycle lanes across 15 Latin American cities (INSPIRES 2020) reported significant reductions in annual mortality and morbidity from certain diseases (i.e. cardiovascular diseases, type 2 diabetes, cancer, and dementia), in addition to economic benefits. A study in São Paulo (SP 2040) examining different transportation scenarios for the city found that increased levels of walking and cycling and lower levels of car and motorcycle use would confer substantial health benefits, particularly from reduced heart disease as a result of increased physical activity and reduced air pollution (Hérick de Sá *et al.* 2017). Conversely, a scenario favoring private cars resulted in worse health outcomes, including increased road injuries (Hérick de Sá *et al.* 2017). Improving public transportation systems improves social cohesion and supports efforts to reduce inequities by improving mobility and access to services for those who would otherwise have fewer travel options (Watts *et al.* 2021). As such, expanding equitable and green transportation initiatives not only has important co-benefits for climate change and health but also provides opportunities for advancing the SDGs.

Low emission diets can have co-benefits for human health

The food production system contributes an estimated 20–30% of global GHG emissions, and thus represents a critical area of focus for mitigation efforts (Guillaumie *et al.* 2020; Vermeulen *et al.* 2012). In addition to emissions from food production, processing, and distribution, agricultural practices contribute to large-scale environmental stress and degradation; for example, up to 80% of global water use is attributed to the agricultural sector (Jägerskog and Jønch Clausen 2012). It has become increasingly clear that food system transitions are needed to reduce environmental impacts and meet the emissions targets set by the Paris Agreement. Livestock production, particularly red meat production, contributes substantially to GHG emissions, far exceeding the emissions impacts associated with plant-based food products (Gerber *et al.* 2013; Poore and Nemecek 2018; Springmann *et al.* 2016a). Argentina, Brazil, and the United States are some of the largest producers and consumers of red meat globally (OECD 2021), emphasizing the importance of food system transitions in the Americas.

Importantly, evidence also points to health co-benefits of "low emission diets", which contain fewer animal products and more nutrient-dense plant-based foods (Mbow *et al.* 2019). The diets of many people living in high income nations are high in ultra-processed foods with inadequate consumption of fruits and vegetables (Guillaumie *et al.* 2020). However, studies have found that healthier diets low in red and processed meats and high in fruits, vegetables, and legumes are associated with reduced premature deaths and lower risks of developing conditions such as cardiovascular disease, coronary heart disease, type 2 diabetes, and colorectal cancer (Aleksandrowicz *et al.* 2016; Hallström *et al.* 2017; Jarmul *et al.* 2020; Mbow *et al.* 2019; Springmann *et al.* 2018). Other research has found that the adoption of a healthy diet lower in red and processed meats reduces the relative risk of coronary heart disease and colorectal cancer in the United States by 20–45% (Hallström *et al.* 2017). These risk reductions can also result in substantial economic benefits by reducing healthcare costs by up to US$93 billion per year (Hallström *et al.* 2017). In Canada, the updated Food Guide promotes a lower emissions diet, serving as a tool to help consumers make healthy and environmentally sustainable food choices (Government of Canada 2019). However, in addition to guidelines at the individual level, system-level changes and government support will be needed to drive large-scale change.

When discussing the benefits of more sustainable, lower-emission diets at a global scale, it is important to consider these diets in the context of equity and diverse geographical and socioeconomic conditions. Dietary transitions may not look the same, or be appropriate, in all settings. At the core of more sustainable and healthy diets is the intensified production of plant-based, nutrient-dense foods, which are more expensive to produce than many other foods with lower nutrient density, such as refined sugars and oils (Hirvonen *et al.* 2020). Although generally affordable in high income nations, diets such as the EAT-*Lancet* reference diet[1] are estimated to exceed household income per capita for more than 1.5 billion people in low and middle income countries (Hirvonen *et al.* 2020). Therefore, considerable attention must be given to improving income status and nutritional supports and lowering the costs of nutrient-dense plant-based foods in low and middle income settings, so that diets such as the EAT-*Lancet* reference diet can be feasible at a global scale. There are also specific issues of affordability and equity in the Americas, as 11.6% of people in Latin America and the Caribbean live on a daily income lower than the cost of the EAT-*Lancet* reference diet, compared with 1.2% of people in North America (Hirvonen *et al.* 2020). Furthermore, dietary transitions may not be appropriate for some populations, such as Indigenous Peoples and those living in remote communities. For instance, commercially produced foods must be flown into remote communities in the Canadian Arctic, contributing to emissions and resulting in added costs for consumers (ITK 2019). Inuit in Northern Canada rely heavily on subsistence hunting and the consumption of local country foods, which are nutrient-dense, preferred, and vital to cultural and community wellbeing, in addition to having a lower emissions impact than commercial foods (ITK 2019; QIA 2019). It is therefore critical

[1] A "universal" healthy reference diet based on dietary patterns, food types, and health outcomes in the scientific literature, developed by the EAT-*Lancet* Commission. The reference diet incorporates many vegetables, fruits, whole grains, legumes, nuts, and unsaturated oils; modest amounts of poultry and seafood; and little-to-no red and processed meats, refined grains, added sugar, or vegetables high in starch (Willett *et al.* 2019).

to consider the context-specific nature of sustainable and healthy diets to avoid unintended consequences (e.g. the health and environmental impacts of ultra-processed foods (Seferidi *et al.* 2020)).

To support relevant and appropriate dietary transitions, commitment and effective governance will be needed at national and international scales to refocus food systems on the production of nutrient-dense foods with lower environmental impacts (Willett *et al.* 2019). This transition will involve innovation and investment along the food production, processing, and distribution chain. In addition, opportunities to diversify protein sources and reduce red meat consumption must be identified wherever feasible. In Canada, promoting poultry-based animal proteins over those from beef and pork could satisfy nutritional protein requirements while reducing emissions from livestock production by up to 31% (Dyer *et al.* 2020). Food waste reduction will also be critical in improving food production efficiency, reducing the impacts of food waste on energy consumption and landfills, and aligning with Sustainable Development Goal 12: Responsible production and consumption (Vermeulen *et al.* 2012; Willett *et al.* 2019). Research in the United States suggests that shifting towards more sustainable diets while simultaneously addressing food waste could not only reduce food production-related emissions by 11%, but would also have additional positive impacts for emissions related to land use and land fill (Birney *et al.* 2017). Importantly, context, affordability, and other issues of equity must be kept at the core of all response options and impact assessments.

Decarbonizing the healthcare sector can improve and protect human health

The healthcare sector contributes approximately 4.4% of total GHG emissions (Karliner *et al.* 2019), with the United States and Canada among the top 10 emitting nations globally (Pichler *et al.* 2019). These emissions are predominantly derived from energy use in health centers and from supply chain activities, including the manufacture, transport, and disposal of medical products, pharmaceuticals, and equipment (Karliner *et al.* 2019; Salas *et al*. 2020a).

Given the goal of the healthcare sector to improve and protect health, as well as the health co-benefits of mitigating climate change, the sector faces increasing calls to achieve net zero emissions by: (i) reducing consumption within healthcare facilities and promoting cultures of awareness and sustainability; (ii) advocating and investing in renewable energy at local and national scales; (iii) decarbonizing the supply chain; and (iv) prioritizing disease prevention to reduce overall reliance on the healthcare sector (Karliner *et al.* 2019; Salas *et al.* 2020a). Importantly, decision-makers and governments will play a vital role in supporting the healthcare sector in the development and implementation of net zero emissions plans (EASAC and FEAM 2021).

Nature-based adaptation and mitigation solutions can have co-benefits for human health

Nature-based solutions refer to an array of adaptation and/or mitigation responses to climate change that are inspired by natural environments (ECDG 2015). Examples in urban settings include green roofs, parks, wetland development for flood control, and other forms of environmental restoration and protection. There have also been examples of social and nature "prescribing" in the Americas, which involves health professionals proposing nature-based activities in response to physical and mental health challenges. These "prescriptions for nature" can include activities such as community gardening and nature walking groups, which are supported by research that demonstrates the health benefits of green time and spaces (Sherman *et al.* 2021).

These projects can directly help to mitigate climate hazards such as flooding or extreme heat, and may also provide additional economic, social, and health benefits. In their review, van den Bosch and Ode Sang (2017) found that nature-based solutions may contribute to improved public health in many ways, including the following: (i) stress reduction and improved mental health and wellness; (ii) increased physical activity resulting in a reduced burden of overweight/obesity and cardiovascular disease; (iii) decreased heat-related morbidity and mortality due to mitigation of heat island effects; (iv) improved reproductive health and childbirth outcomes; and (v) reductions in all-cause mortality. Moreover, by preventing illness and reducing the need for healthcare services, nature-based solutions not only confer economic benefits through reduced healthcare expenditures but also result in emission reductions within the healthcare sector (ECDG 2015; MacKinnon *et al.* 2019; van den Bosch and Ode Sang 2017). It is important to note, however, that some nature-based solutions do have limits in their ability to protect human health. For example, although urban forests can make important reductions in local ambient temperatures by several degrees, during extreme heatwaves this temperature reduction may be insufficient to protect human health.

Transforming cities to achieve net zero emissions can protect human health

Widespread transformation in all sectors and at all scales is needed to reach a net zero economy. As global urbanization increases, opportunities exist to accelerate this transformation through city planning that simultaneously considers economic, social, health, and environmental needs and aligns with the SDGs for building sustainable cities (United Nations 2020). Given the scale and pace of the necessary transformation, coordination efforts aligning city governance, infrastructure development, technological and social innovations, and behavioral change are essential. Importantly, these changes must draw on scientific evidence and must be implemented considering both bottom-up and top-down approaches in different contexts (Crane *et al.* 2021).

4.2.2 Health benefits and trade-offs

Health benefits and trade-offs of energy-efficient buildings

Energy-efficient homes and buildings have several direct and indirect impacts on health. For instance, properly insulated buildings with adequate heating and/or cooling systems reduce potential morbidities and mortality linked to extreme cold and heat, whereas effectively maintained gas heating systems can reduce the risk of carbon monoxide leaks and related illnesses or deaths (Kuholski *et al.* 2010; Levy *et al.* 2003). Energy-efficient homes provide indirect benefits through lower utility bills, reducing financial strain on low-income households and thus decreasing the risk of health outcomes related to food insecurity and the inability to pay for essential medical services (Brown *et al.* 2020; Kuholski *et al.* 2010). In addition, research in the United States has shown that retrofitting homes for improved energy efficiency can significantly reduce annual air pollutants, substantially lowering respiratory morbidity and mortality and resulting in billions of dollars in healthcare and economic savings (Levy *et al.* 2003). However, it is also important to consider potential trade-offs when designing energy-efficient buildings; for example, inadequate ventilation in well-sealed buildings can worsen the indoor environment and contribute to mold growth and poor air quality (Ahmad *et al.* 2017; Ortiz *et al.* 2020). Furthermore, there must be government policies that support retrofitting buildings for low-income households, who are often at higher risk of heat-related mortality and morbidity.

Trade-offs in the food production and renewable energy sectors

Land allocation for food, biofuels, and mining can create competition between sectors, so decision-makers must consider potential trade-offs and other unintended consequences of all mitigation and adaptation response options. Feeding an estimated population of 10 billion people by 2050 will require a transformation of the food system, as well as consideration of key trade-offs in sustainability, food safety, and food security (Vågsholm *et al.* 2020). Reducing post-harvest food loss and food waste, which may account for approximately one-third of all foods produced globally each year, is one of the most impactful ways to improve the sustainability of food systems and decrease demand on agricultural/ livestock land use (FAO 2011, 2019). Reducing alternative uses of agricultural land is also critical, given increasing land demands for biofuels in the renewable energy sector (Goswami and Choudhury 2019). Trade-offs in the renewable energy sector are becoming more evident as the demands for lithium, copper, cobalt, silver, and other rare-earth elements increase to meet battery and renewable energy production needs (Sovacool *et al.* 2020). Plans to meet these demands must consider the ecological impacts of mining as well as the social challenges and potential conflicts related to mine and resource management, and should include elements aimed at improving supply chain efficiency and recycling (Giurco *et al.* 2019; Sovacool *et al.* 2020).

4.2.3 How will socioeconomic development shape future scenarios?

The climate change research community has developed tools known as Shared Socioeconomic Pathways (SSPs) to examine how future socioeconomic developments may influence climate change impacts, mitigation, and adaptations, including at the climate–health nexus. Social development modifies levels of exposure and vulnerability to climate hazards through processes such as strengthened governance and climate policies, advances in technologies, better infrastructure and built environments, and advances in education, gender equity, and other SDGs (Ebi *et al.* 2014). Different SSPs represent alternative futures, in which these scenarios of development either increase or decrease climate–health risks and challenges to mitigation and adaptation.

Five SSP narratives have been developed, qualitatively describing a set of the most to least optimistic development pathways (O'Neill *et al.* 2017; Sellers 2020).

Importantly, SSPs are a tool that help decision-makers assess the impacts of development on different mitigation and adaptation responses, which is imperative given the wide array of potential approaches to adaptation and mitigation in the Americas and globally (O'Neill *et al.* 2020). Regions that undergo different development pathways will have differing capacities to implement emissions reduction and/or adaptation strategies (O'Neill *et al.* 2014) For instance, under SSP5, investments in health, education, and other social capital may result in fewer challenges to adaptation, although continued heavy reliance on fossil fuels to grow economies will result in challenges for mitigation through emission reductions (O'Neill *et al.* 2017).

Decision-makers in government, and increasingly in other sectors, require clear and relevant response option assessments to make recommendations about specific mitigation and adaptation policies and about programming to protect health. To add additional layers of information, SSPs can also be integrated with other models of future policy assumptions and climate projections, such as the SSP-RCP frameworks (O'Neill *et al.* 2020). For example, the relationship between the incidence of mosquito-borne illnesses, which are of particular relevance to Latin America, and climate change-related temperature increases will not necessarily be linear due to the important role of other factors such as infection and pest control programs, poverty reduction, and future land-use changes (Ebi *et al.* 2018a; Wilbanks and Ebi 2014). Therefore, SSPs in combination with RCP projections can provide valuable information on the ways in which the burden of vector-borne diseases could be altered under different socioeconomic pathways and for specific climate scenarios (Wilbanks and Ebi 2014). Indeed, many mortality outcomes are at least partly dependent on trajectories

Case Study 14 Scorecard analysis: Health content in the Nationally Determined Contributions

In response to the ambitious goal of the Paris Agreement to restrict global temperature increases to below 1.5 or 2°C, countries have made climate commitments in the form of Nationally Determined Contributions (NDCs) (GCHA 2021). Governmental commitments, as outlined in their respective NDCs, have been evaluated and ranked through the Global Climate & Health Alliance Healthy NDCs Scorecard analysis (GCHA 2021). The evaluation criteria included the extent to which NDCs considered and incorporated human health impacts, health in climate change adaptation initiatives, health co-benefits, health with respect to finance and economics, and general consideration and inclusion of health (GCHA 2021). The NDC Scorecards also included a Climate Action Tracker rating for some countries, which evaluated the climate change ambition of each respective country on the basis of certain factors, such as national climate change policy, commitments to reducing emissions, and climate change finance (Climate Action Tracker 2021; GCHA 2021). It is important to highlight that "low and middle income countries secured the top scores" despite "hav[ing] contributed least to the emissions responsible for climate change" (GCHA 2021).

In North America, the United States received the lowest overall score of 6/15, whereas Canada and Mexico received overall scores of 7/15 and 10/15, respectively. The United States was found to be on track for 3°C of warming and received a Climate Action Tracker rating of *Insufficient*, with Canada and Mexico, on track for 4°C of warming, being rated as *Highly Insufficient* (Climate Action Tracker 2021; GCHA 2021). Although all three countries received the highest possible scores in the health co-benefits category (3/3), the overall levels of warming projected for each country exceed the tolerable thresholds established in the Paris Agreement and are likely to be to be catastrophic for human health in the longer term (GCHA 2021).

In Central America, Costa Rica, Panama, Honduras, Belize, and Nicaragua received NDC Scorecard rankings. Costa Rica's NDC received a score of 13/15, which is the highest for all evaluated countries in the Americas, with full scores in all health categories except for economics and finance, which received a score of 1/3 (GCHA 2021). Overall, Costa Rica was the only country in the Americas to receive the second-highest Climate Action Tracker rating of *Almost Sufficient,* as it is on track to limit warming to 2°C (Climate Action Tracker 2021; GCHA 2021). Panama received an overall score of 12/15, followed by Belize and Honduras, which both received scores of 9/15. The lowest score was given to Nicaragua (5/15) (GCHA 2021).

For countries in the Caribbean, NDC Scorecard rankings ranged from 4/15 to 10/15. Scores were given to the Dominican Republic (10/15), Saint Lucia (6/15), Grenada (5/15), Jamaica (5/15), Antigua and Barbuda (4/15), Barbados (4/15), and Cuba (4/15) (GCHA 2021). These countries have not received Climate Action Tracker ratings (GCHA 2021).

In South America, Columbia (12/15), Argentina (11/15), Chile (10/15), and Paraguay (9/15) all received NDC Scorecard rankings of 9 or higher (GCHA 2021), whereas Suriname (4/15), Peru (2/15), and Brazil (0/15) received scores below 5 (GCHA 2021). None of the South American countries included in the Climate Action Tracker analysis were compliant with the Paris Agreement (i.e. have adequate climate ambition to limit warming to 1.5°C). In terms of the Climate Action Tracker ratings, Brazil, Argentina, and Columbia were rated as *Highly Insufficient*, as they are on track for 4°C of warming, whereas Peru and Chile, on track for 3°C of warming, were rated as having *Insufficient* climate change action (Climate Action Tracker 2021; GCHA 2021).

of mitigation and adaptation capacity, and understanding how future mortality burdens are likely to change with socioeconomic development will be critical in making decisions about the allocation of resources (Sellers 2020).

4.3 On whom should decision-makers focus?

Climate change affects the health of everyone. Although the nature and scale of climate hazards vary by location, climate change affects people in high, middle, and low income countries across all socioeconomic conditions, livelihoods, and cultures. Several factors are generally considered to increase climate-related health risks, including biological and physiological factors, current health status, social and economic conditions, and governance, although the ways in which these factors interact are complex and highly dependent on location and population characteristics (Smith *et al.* 2014). For example, the priorities, decisions, and allocation of resources by local governments have a direct impact on the populations under their administration (Bowen *et al.* 2012; Ebi 2020), but those decisions and their impacts may look very different depending on geography and on the physical and financial resources available. Baseline levels of health outcomes and disease risk are also considered to be among the most important drivers of current and future vulnerability in all populations: in areas already experiencing a high burden of climate-sensitive illness, an increase in disease risk will have a much more profound impact than a similar risk increase in an area with low baseline levels of disease (Smith *et al.* 2014).

Although climate change has consequences for all people globally, it is important to highlight the fact that some populations, for a variety of reasons, are more vulnerable to the health impacts of climate change than others. These disparities must be recognized and prioritized in climate change mitigation and adaptation responses to avoid deepening existing health inequities.

4.3.1 Aging populations

Older individuals typically have a reduced ability to avoid and/or respond to physiological stressors, including temperature extremes, physical injuries, and infectious diseases (Gamble *et al.* 2013). Moreover, socio-cultural factors play an important role in increasing vulnerability in older people: for instance, in some cultures it is common for older people to live alone, often with reduced sources of income, resulting in increased isolation and a limited ability to receive assistance from social contacts or other service providers (Gamble *et al.* 2013; Smith *et al.* 2014). In Latin America and the Caribbean, the proportion of the population over age 65 is expected to grow from the current 9% to over 30% by 2100 (ECLAC - UN 2019), highlighting the need for improving availability and access to healthcare infrastructure for the aging population.

4.3.2 Children

Children are highly susceptibility to certain climate-sensitive health outcomes, such as infectious diseases and extreme heat. Pneumonia and diarrheal illness remain leading causes of mortality in the Americas, particularly in the middle and low income nations, representing 14% of child deaths in 2015 (PAHO 2017). Food insecurity also tends to disproportionately impact households with children, leading to important short- and long-term health impacts from inadequate nutrition in childhood (Smith *et al.* 2014).

4.3.3 Gender

Gender can impact the opportunities and resources people have to cope with and adapt to climate change, with disproportionate disadvantages typically being experienced by women and girls (Vincent *et al.* 2014). For example, traditional gender roles can put women and girls at an increased risk of exposure to, and mortality from, certain climate hazards (WHO 2011), while also reducing their ability to adapt to climate change due to limited economic resources and social exclusion (Vincent *et al.* 2014). Additionally, more work is needed to understand the intersection of climate change with LGBTQ2S+ peoples, as well as non-binary/ gender-fluid peoples.

4.3.4 Indigenous Peoples

Indigenous Peoples are disproportionately impacted by climate change because of several factors that are rooted in past and ongoing impacts of colonialism, exclusion, racism, and marginalization (Anderson *et al.* 2016; IPCC 2018, 2019a, 2019b; Status of Tribes and Climate Change Working Group 2021; Whyte 2016; Whyte *et al.* 2021b). Climate–health impacts, vulnerability, and resiliency in the context of Indigenous Peoples are discussed in depth in Case Study 12. There is clear evidence that some of the most effective adaptation responses in Indigenous nations are underpinned by Indigenous knowledge, are systemic in nature, and address political and economic inequities. Critically, recognition of Indigenous Rights, including Indigenous self-determination in climate change research, response, and governance, as well as adequate funding and resources will be essential to effectively reduce climate–health risks for Indigenous Peoples (Case Study 12).

4.3.5 Those living in challenging socioeconomic settings

At individual, household, and national scales, those living in more challenging socioeconomic settings are more vulnerable to the negative health consequences of climate change (Smith *et al.* 2014). Those with access to fewer socioeconomic resources may be less able to prevent or respond to climate hazards (e.g. less able to access to air conditioning to prevent heat-related morbidity and mortality) (Ostro *et al.* 2010), whereas at a national level, regions with fewer public services can result in increased susceptibility in the general public.

Ethnicity also has important implications for socioeconomic-related vulnerabilities, as many marginalized and racialized communities continue to face disproportionate burdens of illness that are often rooted in injustice and inequities, as well as reduced access to healthcare and other essential services (Ostro *et al.* 2010; Zimmerman and Anderson 2019). In the United States, "redlining" is the "historical practice of refusing home loans or insurance to whole neighborhoods based on a racially motivated perception of safety for investment" (Hoffman *et al.* 2020). Hoffman *et al.* (2020) found that 94% of formerly redlined areas had temperatures as much as 7°C higher than their non-redlined neighbors, emphasizing the role that policies, racism, and other social factors can play in creating disproportionate exposures to climate change.

4.3.6 Geographically vulnerable populations

Geography impacts vulnerability through differing exposures to climate hazards and access to climate-resilient infrastructure and health services. Certain locations face particularly high risks from specific climate hazards; for instance, the North American Arctic is experiencing warming at a faster rate than more southern regions, exposing populations living in the Arctic to increased risks from sea ice reductions and permafrost thawing (Larsen *et al.* 2014). Meanwhile, low-lying coastal and island populations face particularly high risks from worsening storms, hurricanes, and flooding. Severe hurricanes have an enormous economic impact, particularly for small island nations in the Caribbean, where economic losses from natural disasters can far exceed national annual gross domestic product (Ötker and Srinivasan 2018). Remote populations are also typically more vulnerable to climate hazards due to reduced access to climate-resilient health infrastructure and public services. For example, residents of some communities in Northern Canada are required to fly to the nearest urban center for specialized health services, presenting barriers to accessing healthcare and other essential services (ITK 2014).

4.4 Equity in all climate–health actions

The significance of incorporating justice and equity in responses to climate change impacts has been emphasized in IPCC reports and international treaties, including the Paris Agreement (de Coninck *et al.* 2018; Roy *et al.* 2018; UNFCCC 2015). Climate change impacts are distributed unfairly, and they further exacerbate insecurities and injustices that are already affecting vulnerable populations, many of which are founded in historical injustices such as colonialism, racism, oppression, and development challenges (Adger *et al.* 2006; Coggins *et al.* 2021b). For Indigenous Peoples in the Americas, recognizing, reaffirming, and upholding Rights (e.g. the United Nations Declaration on the Rights of Indigenous Peoples) are critical for successful responses to climate change. It has been argued that the integrity and legitimacy of decisions made by governing bodies in response to climate change rely on the extent to which equity and justice are incorporated into decision-making processes and their respective outcomes (Adger *et al.* 2006). Here, we present an overview of key climate justice considerations following the broad classifications of distributional, capabilities, procedural, and recognition aspects of justice theory (Schlosberg 2007). Singular approaches to justice (e.g. focusing exclusively on distributional justice) are often insuffcent, as many different forms of injustice may be in play in any given situation (Coggins *et al.* 2021a). Including a balance of these four interconnected aspects allows for a more comprehensive justice approach (Coggins *et al.* 2021a; Schlosberg 2007). These categories of justice have been used widely; however, given the complexity and diversity of justice conceptualizations in the literature, it is acknowledged that there may be definitions of justice that do not fit precisely into these classifications, as well as opportunities for further distinctions within each category (Coggins *et al.* 2021a). We apply this climate justice framework by focusing on the climate–health context and present these considerations as questions.

1. Address issues of climate justice with respect to fair distributions and capabilities.

Decision-makers should consider issues of climate justice with respect to fair distributions (Adger *et al.* 2006) and capabilities (Nussbaum 2000, 2007; Nussbaum and Sen 1993; Pressman and Summerfield 2002; Schlosberg 2007; Sen 1985, 1999a, 1999b) by answering the following questions for all climate change actions:

- How are the adverse impacts and benefits of climate change currently distributed (Adger *et al.* 2006)? How are they likely to be distributed in the future? How will the distribution of impacts likely affect human health?

- How do these impacts intersect with existing insecurities and vulnerabilities facing vulnerable populations or groups (Adger *et al.* 2006)? How are these impacts likely to intersect with vulnerabilities in the future?

- How are the capabilities of individuals to maintain good health, wellbeing, and the ability and freedom to live as they choose being impacted by climate change (Nussbaum 2000; Pressman and Summerfield 2002; Schlosberg 2007; Wolff 2019)? How might these capabilities be impacted in the future? Which individuals, groups, or populations are likely shoulder the greatest burden of these impacts?

- Is climate adaptation assistance being distributed fairly? Are those who are the most vulnerable to climate change impacts prioritized in adaptation initiatives, plans, and interventions (Adger *et al.* 2006)?

- Do the potential negative consequences of mitigation actions outweigh the benefits? Are the negative consequences of mitigation disproportionately shouldered by some individuals, communities, or nations?

2. Address issues of climate justice with respect to fair procedures and recognition.

It would be prudent for decision-makers to consider issues of climate justice with respect to fair procedures and recognition (Anderson 1999; Schlosberg 2007) by answering the following questions for all climate change actions:

- Are any individuals and/or groups not recognized as being equal in relation to one another (Anderson 1999)? Are cultural differences recognized and respected?

- Does a lack of recognition for certain groups or individuals impede their participation in decision-making and institutional processes (Schlosberg 2007)? Do any groups or individuals face barriers to participating in decision-making processes? If so, how might these barriers be eliminated?

- To what extent are individuals and groups able to shape the decisions that impact them (Coggins *et al.* 2021b)?

- Are decision-making and institutional processes equitable and just (Schlosberg 2007)?

5 What are this report's conclusions and recommendations?

5.1 What do we know and why are we concerned?

The global climate is changing, and it is attributable to human activities. Throughout this report, we have assessed and synthesized the available evidence to understand the climate–health nexus in the Americas, from which we have arrived at the following key conclusions:

- **Climate change is already impacting human health in the Americas.** Climate–health research in the Americas demonstrates that across South, Central, and North America, people are already experiencing the health impacts of climate change.
- **Climate change is already impacting everyone, everywhere—but the magnitude and distribution of impacts vary.** Certain populations face increased vulnerability to climate change and experience a disproportionate burden of health impacts because of several biological, social, and geographical factors. Older individuals, children, women and girls, Indigenous Peoples, those living in challenging socioeconomic settings, and geographically vulnerable populations face additional health risks and challenges related to climate change.
- **Every degree of heating matters in the Americas.** This reiterates the importance of taking all actions possible to limit warming well below 2°C in accordance with the Paris Agreement. It is clear from the evidence-based data that health risks will be substantially lower in the Americas at 1.5°C degrees compared with 2°C of warming, and the capacity of individuals, communities, health systems, and governments to adapt is reduced with every increment of additional warming (IPCC 2018).
- **Equity is at the core of effective responses.** Socially, politically, and geographically excluded groups are at the highest risk of health impacts from climate change but are not adequately represented in the evidence base, which has implications for effective policy-making. These inequitable health risks and exclusions from climate change responses persist in the Americas. Equity must be at the forefront of future research and policy responses from local to international scales.
- **Actions taken now to build climate–health resilience in the Americas will limit future risks.** Investing in climate-resilient infrastructure, programming, and healthcare systems will support adaptation and reduce future health risks from climate change. Conducting vulnerability and adaptation assessments, integrating health into Nationally Determined Contributions, and investing in climate–health education are examples of immediate actions that policy-makers can take.
- **Climate change and health considerations must be integrated into educational opportunities.** It is imperative that programs across the Americas continue to collaborate to establish robust climate–health curricula to equip health professionals with the necessary expertise to provide effective patient care and lead action in climate change mitigation and adaptation.
- **A "health in all policies" approach will support adaptation, mitigation, and health co-benefits.** Climate change affects many aspects of human health and wellbeing; consequently, health must be considered in all aspects of the climate change response. A "health in all policies" response will not only support climate change adaptation and mitigation actions to meet the goals of the Paris Agreement but will also have co-benefits for health

and will support the achievement of key international initiatives such as the SDGs.

- **Research momentum in the Americas must continue to build.** The climate–health literature in the Americas is growing, yet it is still understudied compared with other areas of climate research (Harper *et al.* 2021a; Hosking and Campbell-Lendrum 2012; Verner *et al.* 2016). Continued efforts to build the evidence base are needed, particularly for regions of the Americas that are currently underrepresented in the literature.

- **Cross-sectoral collaboration is needed.** Filling research gaps and acting on the current evidence base will require intersectional, intersectoral, and interdisciplinary approaches (Levy *et al.* 2018) that bring together microbiologists, epidemiologists, social scientists, ecologists, environmental scientists, engineers, economists, demographers, urban and rural planners, and climatologists with decision-makers from the Americas and beyond (Lo Iacono *et al.* 2017; Mellor *et al.* 2016).

- **Climate change intersects with, and exacerbates, other global challenges.** The COVID-19 pandemic highlights intersections between climate, the environment, and society, and demonstrates how these factors can contribute to the exacerbation of existing health and social inequities. COVID-19 also provides us with important lessons about responding to grand global challenges through co-operation and rapid mobilization at a large scale (Belesova *et al.* 2020; Klenert *et al.* 2020; Krieger 2020).

5.2 Building and utilizing the evidence base

5.2.1 Engaging with the climate–health evidence base to shape policy

Utilizing the evidence base to promote a "health in all policies" approach will result in more relevant, sustainable, and effective climate response actions. Such an approach will include the following benefits:

- Integrating health impact assessments into all potential response options allows decision-makers to weigh the health benefits, risks, unintended consequences, and trade-offs of different approaches.

- A "health in all policies" approach can be used to inform the assessment and revision of environmental standards. For example, research has shown that stricter air quality standards (i.e. beyond current WHO guidelines) have health and economic benefits, resulting in fewer hospitalizations and lower healthcare spending (Howard *et al.* 2019).

- The climate–health evidence base adds value to local and national climate assessments. In the Americas, some countries have conducted national vulnerability and adaptation assessments (Berry *et al.* 2018), and as more nations work to undertake such assessments, access to the best available climate–health evidence will be vital.

- A "health in all policies" approach ensures that issues of equity remain at the forefront of climate response discussions, and it promotes engagement with different audiences in climate–health discussions (Case Study 15). Critically,

Case Study 15 Youth engagement in climate action in the Americas

Young people are proving to be key players in the climate–health nexus by responding to climate risks in diverse and unique ways. From organizing events, such as summits, marches, and school strikes, to designing innovative resources to build knowledge and skills, they are mobilizing and turning their concerns about climate change into collaborative action. Indeed, it is critical to recognize youth as climate leaders, not simply as a group to be consulted and engaged.

Across the Americas, youth organizations are urging their governments to implement climate-related policies. For example, the International Indigenous Youth Council, created through the efforts of womxn and two-spirit peoples during the Standing Rock Indigenous Uprising in 2016, is using education, spiritual practices, and civic engagement to strive towards a sustainable future. The power of youth voices is also evident in other stories of successful government lobbying. For example, in 2018, the Supreme Court sided with youth plaintiffs in Colombia, supporting their argument that deforestation and increasing temperatures threatened their constitutional rights to a healthy environment, life, health, food, and water. In 2019, Jóvenes por el Clima lobbied the Argentinian Government to declare a Climate and Ecological Emergency and enact the first Climate Change Law.

Peer-support groups provide resources for youth who are feeling emotionally burdened by the climate crisis. For example, the Community Climate Council based in the Regional Municipality of Peel, Ontario, is hosting Climate Change Cafés, which are virtual spaces where youth can meet and discuss anxiety and grief related to climate change. Another initiative is the Fraser Basin Council's "My Climate Story" project, which, in addition to providing toolkits and educational resources, allows young people to share stories of climate anxiety including those related to health. In 2021, the Royal Society of Canada and Let's Talk Science announced a partnership to engage over 600,000 youth across Canada in climate science education and action through events, action projects, and digital resources.

Young people are also using their voices to address the intersectionality of the climate crisis. For example, Climate in Colour highlights systemic racism in climate movements, offering workshops on environmental racism, environmental justice, and the colonial history of climate. In Latin America and the Caribbean, the Sail for Climate Action movement involved a group of young people sailing to Europe, striving to have their voices represented in decision-making spaces. Their journey included capacity-building and knowledge sharing programs, and was meant to end at the 52nd session of the subsidiary bodies to the UNFCCC in Germany before being interrupted by COVID-19.

To support these and other important climate-related initiatives that young people are championing, decision-makers can take several actions:

- Engage young people early in decision-making efforts.
- Provide young people with platforms to express their concerns and incorporate their health priorities into climate-related policies and programs.
- Invest in youth-designed and youth-led initiatives. Consult young people and provide them with the capital and resources they need to mobilize and respond to climate–health impacts.
- When consulting with young people, prioritize Indigenous and other frequently excluded voices who may be disproportionately impacted by climate–health risks.

care must be taken to avoid diluting responsibility and diminishing the quality of responses when health and equity considerations are mainstreamed into decision-making.

5.2.2 Synthesis of evidence and identification of knowledge gaps

Research based on rigorous, transparent, and multidisciplinary methods is, and must continue to be, at the core of the climate–health evidence base. However, the increasing number of publications on climate change and health (Berrang-Ford *et al.* 2021b) means that decision-makers and researchers must sort through large amounts of information, presenting barriers to effective action (Ebi *et al.* 2018a; Hosking and Campbell-Lendrum 2012; Verner *et al.* 2016). Thus, the information we have provided in this report can serve as a useful synthesis tool to inform action and future research based on themes identified in the report, including the following areas:

More research is needed to project future climate–health impacts in the Americas

Although a growing body of literature examines current health impacts related to environmental and climatic factors, there is a notable lack of projection research across many of the health outcomes assessed in this report. Climate–health projections in future research projects must consider demographic changes, socioeconomic factors, social development, and adaptation interventions that are likely to change over time and across locations. Given the complex interactions between non-climatic factors and climate-sensitive health outcomes, such considerations will be essential in modelling future trends.

An increased focus on understudied health outcomes is needed

Some climate-sensitive health outcomes remain relatively understudied in the Americas.

For example, a relatively small base of literature exists in North America examining mental health outcomes, nutrition, injuries, and aeroallergens compared with other health outcomes such as heat-related morbidity and mortality and respiratory illness (Harper *et al.* 2021a).

Additional research is needed to fill gaps in the Caribbean, Central America, and South America

Published literature on climate change and health is heavily focused on North America, and particularly the United States. It is evident from this report that research gaps exist in the Caribbean, Central America, and South America, representing an important area of future focus. Filling these locational gaps will be critical for establishing baseline information on context-specific exposure–response relationships, developing regionally specific projections, and informing relevant mitigation and adaptation responses for these regions. Supporting interdisciplinary efforts, implementing data-sharing agreements, and expanding regional research resources and collaborations will be key to addressing these gaps. Critical to more equitable geographical coverage of research is improving funding mechanisms for the Caribbean, Central America, and South America. The available funding is too often skewed towards mitigation, despite the clear benefits of research focusing on adaptation in many low and middle income countries.

More research is needed to connect climate change impacts with adaptation and mitigation options

Much of the climate–health literature to date is focused on current health impacts. This provides important baseline information, which must be continuously built upon to improve our understanding of the available mitigation and adaptation options and the implications of those options across climate-sensitive health outcomes in the Americas.

Future research must be self-determined and led by vulnerable populations to address and prevent health inequities

As is evident from this report, certain populations are at greater risk for experiencing the health impacts of climate change; however, research and responses often do not adequately consider socially, geographically, economically, and politically marginalized groups. Additional research will be important for informing responses that approach climate–health mitigation and adaptation through a health equity and justice lens. Such research will also contribute to global initiatives such as the SDGs and the World Health Organization goal of establishing universal healthcare by 2030 (United Nations 2020; WHO and World Bank Group 2019). It will be critical to provide the resources and support needed for communities to self-determine research priorities, processes, and responses, especially regarding the risks of climate change for Indigenous Peoples' health.

5.2.3 The ongoing role of IANAS and other Academy networks

Academy networks, such as IANAS, play an important role in building the climate–health evidence base; however, the responsibilities of academic networks extend beyond the development of research knowledge, and include the following important roles:

- Providing objective information that is independent of political and commercial interests.
- Engaging with governments, organizations, media outlets, and public audiences to convey information and actively counter misinformation and misinterpretation of data.
- Providing a platform that brings together global experts and promotes cross-sectoral collaboration and innovation.
- Working with partners to establish future research priorities and calls for funding.

IANAS plays a critical role by engaging with local, national, and international communities both within and outside the Americas to communicate research findings and priorities. Moreover, IANAS and its member academies have developed several frameworks and agendas focused on improving scientific communication and educational engagement with science, including the following:

- *Communicating Science Effectively: A Research Agenda* (National Academies of Sciences, Engineering, and Medicine 2017);
- *Inquiry Based Science Education: Promoting changes in science teaching in the Americas* (IANAS 2017b);
- *A Framework for K-12 Science Education: Practices, crosscutting concepts, and core ideas* (National Research Council of the National Academies 2012).

Important next steps following this report include using the findings to engage with regional decision-makers. There will also be a subsequent global report that synthesizes findings and key messages from each of the InterAcademy Partnership regional reports, including IANAS (the Americas), NASAC (Africa), EASAC (Europe), and AASSA (Asia).

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