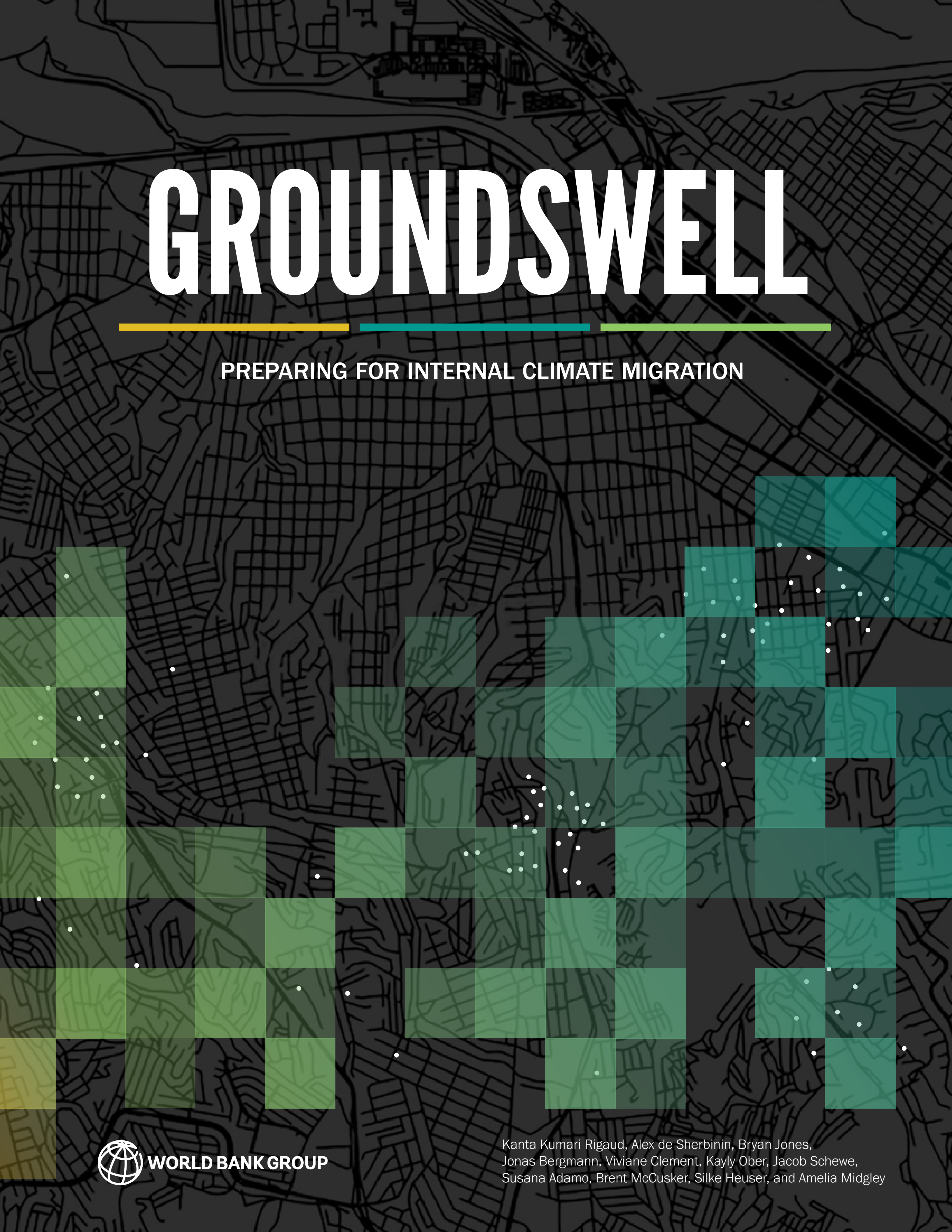

GROUNDSWELL

PREPARING FOR INTERNAL CLIMATE MIGRATION

WORLD BANK GROUP

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GROUNDSWELL

PREPARING FOR INTERNAL CLIMATE MIGRATION

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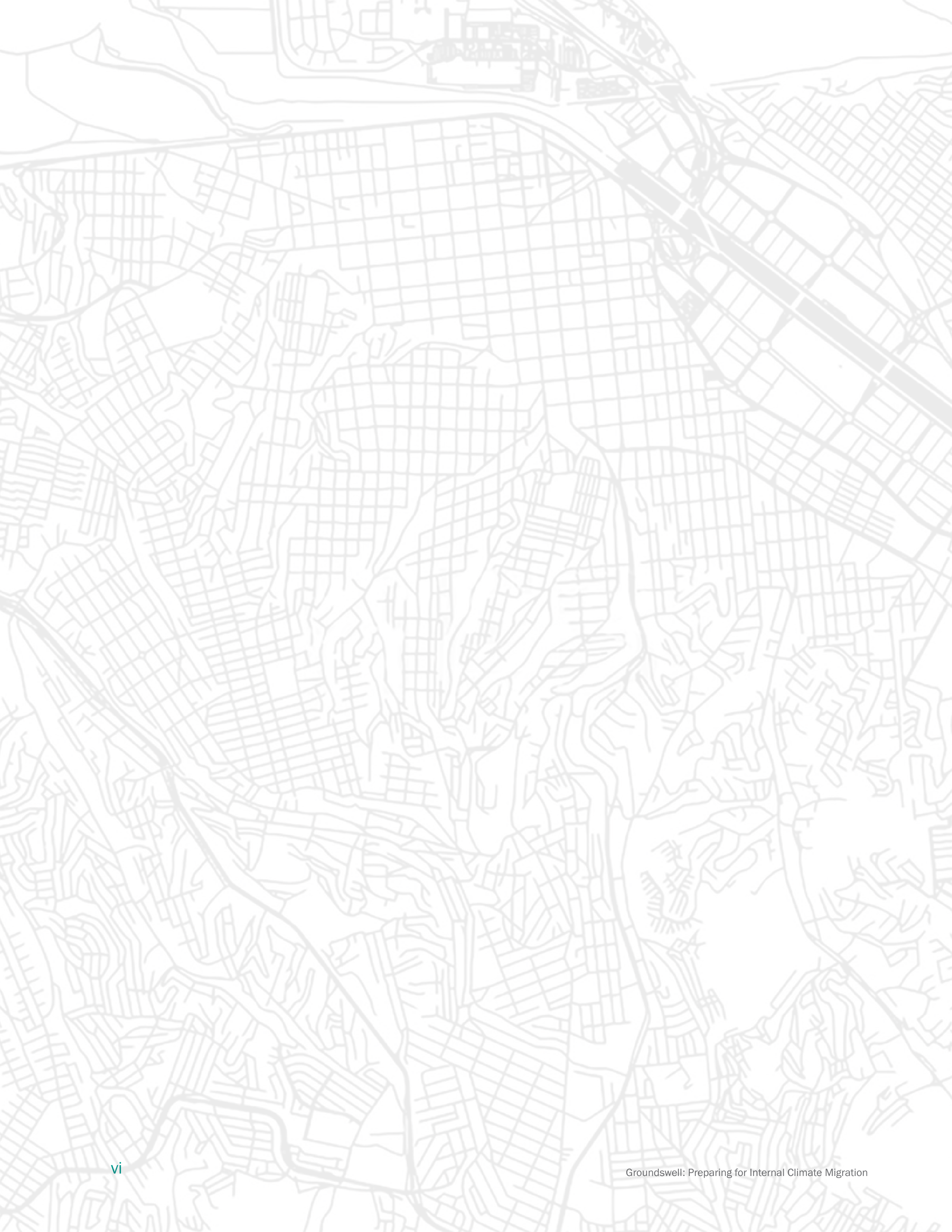

Glossary

Adaptation: Process of adjustment to actual or expected climate change and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate change and its effects.

Adaptive capacity: Ability of systems, institutions, humans, and other organisms to adjust to potential damage, take advantage of opportunities, and respond to consequences of climate impacts.

Agro-pastoralism: Combination of agriculture, crop-based livelihood systems, and pastoralism (see also pastoralism).

Anthropogenic biome: Anthropogenic biomes describe the terrestrial biosphere in its contemporary, human-altered form using global ecosystem units defined by patterns of sustained direct human interactions, for example, rainfed croplands.

Attractiveness: Desirability of a locale based on a number of factors including but not limited to economic opportunity, transportation infrastructure, proximity to family, the presence of social amenities, environment, and intangibles such as place attachment.

Biodiversity: Variety of plant and animal life in the world or in a particular habitat or ecosystem.

Biome: Large naturally occurring community of flora and fauna occupying a major habitat (for example, forest or tundra; see also anthropogenic biome).

Climate change: A change in the state of the climate that can be identified (for example, using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

Climate change–induced migration (shorthand internal climate migration): In this report, climate change-induced migration is migration that can be attributed largely to the slow-onset impacts of climate change on livelihoods owing to shifts in water availability and crop productivity, or to factors such as sea level rise or storm surge.

Climate in-migration hotspot: For the purposes of this study, climate in-migration hotspots are areas that will see increases in population in scenarios that take into account climate impacts relative to a population projection that does not take climate impacts into account. These increases can be attributed to in-migration, the "fast" demographic variable. Areas were considered to have increases in population when at least two of the three scenarios modelled had increases in population density in the highest 10th percentile of the distribution.

Climate migrant/migration: In this report, climate migrants are people who move - within countries - because of climate change-induced migration (see above). The modeling work captures people who move at spatial scales of over 14 kilometers - within a country - and at decadal temporal scales. Shorter distance or shorter term mobility (such as seasonal or cyclical migration) is not captured.

Climate out-migration hotspot: For the purposes of this study, climate out-migration hotspots are areas that will see decreases in population in scenarios that take into account climate impacts relative to a population projection that does not take climate impacts into account. These decreases can be attributed to out-migration, the "fast" demographic variable. Areas were considered to have decreases in population when at least two of the three scenarios modelled had decreases in population density in the highest 10th percentile of the distribution

Climate risk: Potential for consequences from climate variability and change where something of value is at stake and the outcome is uncertain. Often represented as the probability that a hazardous event or trend occurs multiplied by the expected impact. Risk results from the interaction of vulnerability, exposure, and hazard.

Coastal erosion: Erosion of coastal landforms that results from wave action, exacerbated by storm surge and sea level rise.

Coastal zone: In this report, the coastal zone is land area within 10 kilometers of the coastline.

Deforestation: Conversion of forest to non-forest.

Displacement: Forced removal of people or people obliged to flee from their places of habitual residence.

Distress migration: Movements from the usual place of residence, undertaken when an individual and/or their family perceive that there are no options open to them to survive with dignity, except to migrate. This may be a result of a rapid-onset climate event, other disasters, or conflict event, or a succession of such events, that result in the loss of assets and coping capacities.

Environmental mobility: Temporary or permanent mobility as a result of sudden or progressive changes in the environment that adversely affect living conditions, either within countries or across borders.

Extreme heat event: Three or more days of above-average temperatures, generally defined as passing a certain threshold (for example, above the 85th percentile for average daily temperature in a year).

Extreme weather event: Event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally fall in the 10th or 90th percentile of a probability density function estimated from observations. The characteristics of extreme weather vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (for example, drought or heavy rainfall over a season).

Forced migration: Migratory movement in which an element of coercion exists, including threats to life and livelihood, whether arising from natural or man-made causes (for example, movements of refugees and internally displaced persons as well as people displaced by natural or environmental disasters, chemical or nuclear disasters, famine, or development projects). Forced migration generally implies a lack of volition concerning the decision to move, though in reality motives may be mixed, and the decision to move may include some degree of personal agency or volition.

GEPIC: The GIS-based Environmental Policy Integrated Climate crop model (see Appendix A).

Gravity model: Model used to predict the degree of interaction between two places and the degree of influence a place has on the propensity of a population in other locations to move to it. It assumes that places that are larger or spatially proximate will exert more influence on the population of a location than places that are smaller and farther away.

HadGEM2-ES: Climate model developed by the Met Office Hadley Centre for Climate Change in the United Kingdom (see Appendix A).

Hazard: The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Immobility: Inability to move from a place of risk or not moving away from a place of risk due to choice.

Internal climate migrant (migration): See climate change-induced migration and climate migrant/migration.

Internal migration (migrant): Internal migration is migration that occurs within national borders.

International migration (migrant): Migration that occurs across national borders.

IPSL-CM5A-LR: Climate model developed by the Institut Pierre Simon Laplace Climate Modeling Center in France (see Appendix A).

Labor mobility: The geographical and occupational movement of workers.

LPJmL: A global water and crop model designed by Potsdam Institute for Climate Impact Research to simulate vegetation composition and distribution as well as stocks and land-atmosphere exchange flows of carbon and water, for both natural and agricultural ecosystems (see appendix A).

Migration: Movement that requires a change in the place of usual residence and that is longer term. In demographic research and official statistics, it involves crossing a recognized political/administrative border.

Mitigation (of climate change): Human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Mobility: Movement of people, including temporary or long-term, short- or long-distance, voluntary or forced, and seasonal or permanent movement as well as planned relocation (see also environmental mobility, labor mobility).

Other migrant: In this report, the term other migrant is used in reference to migrants who move largely for reasons other than climate impacts.

Planned relocation: People moved or assisted to move permanently away from areas of environmental risks.

Radiative forcing: Measurement of capacity of a gas or other forcing agent to affect the energy balance, thereby contributing to climate change.

Rainfed agriculture: Agricultural practice relying almost entirely on rainfall as its source of water.

Rapid-onset event: Event such as cyclones and floods which take place in days or weeks (in contrast to slow-onset climate changes that occur over long periods of time).

Representative Concentration Pathway (RCP): Trajectory of greenhouse gas concentration resulting from human activity corresponding to a specific level of radiative forcing in 2100. The low greenhouse gas concentration RCP2.6 and the high greenhouse gas concentration RCP8.5 employed in this report imply futures in which radiative forcing of 2.6 and 8.5 watts per square meter, respectively, are achieved by the end of the century.

Resilience: Capacity of social, economic, and environmental systems to cope with a hazardous event, trend, or disturbance by responding or reorganizing in ways that maintain their essential function, identity, and structure while maintaining the capacity for adaptation, learning, and transformation.

Sea level rise: Increases in the height of the sea with respect to a specific point on land. *Eustatic* sea level rise is an increase in global average sea level brought about by an increase in the volume of the ocean as a result of the melting of land-based glaciers and ice sheets. *Steric* sea level rise is an increase in the height of the sea induced by changes in water density as a result of the heating of the ocean. Density changes induced by temperature changes only are called *thermosteric*; density changes induced by salinity changes are called *halosteric*.

Shared Socioeconomic Pathway (SSP): Scenarios, or plausible future worlds, that underpin climate change research and permits the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. SSPs can be categorized by the degree to which they represent challenges to mitigation (greenhouse gas emissions reductions) and societal adaptation to climate change.

Slow-onset climate change: Changes in climate parameters—such as temperature, precipitation, and associated impacts, such as water availability and crop production declines—that occur over long periods of time (in contrast to rapid-onset climate hazards, such as cyclones and floods, which take place in days or weeks).

Stressor: Event or trend that has important effect on the system exposed and can increase vulnerability to climate-related risk.

Sustainable livelihood: Livelihood that endures over time and is resilient to the impacts of various types of shocks including climatic and economic.

System dynamics model: A model which decomposes a complex social or behavioral system into its constituent components and then integrates them into a whole that can be easily visualized and simulated.

Tipping element: Subsystems of the Earth system that are at least subcontinental in scale and can be switched—under certain circumstances—into a qualitatively different state by small perturbations. See tipping point.

Tipping point: Particular moment at which a component of the earth's system enters into a qualitatively different mode of operation, as a result of a small perturbation.

Vulnerability: Propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

WaterGAP2: The Water Global Assessment and Prognosis (WaterGAP) version 2 global water model developed by the University of Kassel in Germany (see Appendix A).

Abbreviations

AR5	Fifth Assessment Report by the Intergovernmental Panel on Climate Change
CIESIN	Center for International Earth Science Information Network of Columbia University
COP	Conference of Parties (of the UNFCCC)
ENSO	El Niño Southern Oscillation
GCM	global climate model
GCR	Global Compact on Refugees
GDP	gross domestic product
GHG	greenhouse gas
HDI	human development index
IDMC	Internal Displacement Monitoring Centre
IDP	internally displaced person
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
KNOMAD	Global Knowledge Partnership on Migration and Development
MDG	Millennium Development Goal
MECLEP	Migration, Environment and Climate Change: Evidence for Policy
NAP	National Adaptation Plan
NAPA	National Programmes of Action
NCAR	US National Center for Atmospheric Research
NCAR-CIDR	National Center for Atmospheric Research-CUNY Institute for Demographic Research
NDC	Nationally Determined Contribution
NELM	New Economics of Labor Migration
NGO	non-governmental organization
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
PIK	Potsdam Institute for Climate Impact Research
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
SIDS	Small Island Developing States
SRES	Special Report on Emissions Scenarios
SSP	Shared Socio-Economic Pathway
UN	United Nations
UN ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNCCD	United Nations Convention to Combat Desertification
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNHCR	Office of the United Nations High Commissioner for Refugees
UNISDR	United Nations Office for Disaster Risk Reduction

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Internal climate migrants are rapidly becoming the human face of climate change.

By 2050—in just three regions—climate change could force more than 143 million people to move within their countries.

Sub-Saharan Africa by 2050

86 million

internal climate migrants

> *In the planting season, it wouldn't rain, but when we didn't want it, it would rain. This created drought and because of this I didn't want to suffer anymore. I wanted to try my luck in the city, so I came to Hawassa."*
>
> —Wolde Danse (28) Ethiopia

South Asia by 2050

40 million

internal climate migrants

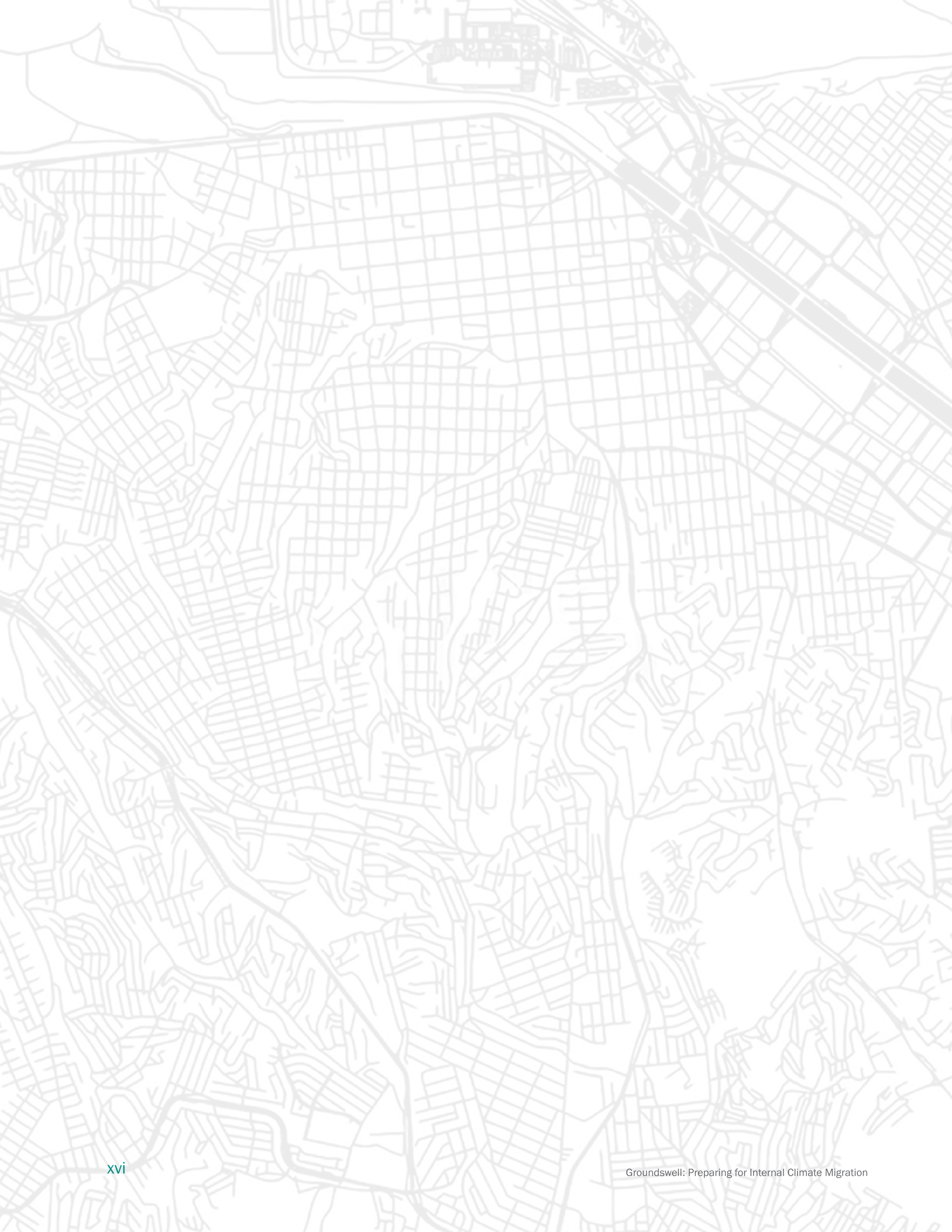
> *Floods come every year, but this year the situation is worse. Now all my family is living in one relative's house. I don't want to go back to my village, mainly because of the flood. In Dhaka, I can work and have a good secure life."*
>
> —Monoara Khatun (23) Bangladesh

Latin America by 2050

17 million

internal climate migrants

> *...we have jobs here so people migrate very little, there isn't a high need to go away...at the forest level there is employment; in businesses there is employment. The quality of the wood is one of our priorities. We have the famous green seal as a certified forest and not many communities have it."*
>
> —Javier Martinez (26) Mexico



Kristalina Georgieva
Chief Executive Officer (CEO), World Bank

Every day, climate change becomes a more urgent economic, social, and existential threat to countries and their people. We see this in cities facing unprecedented water crises, in coastal areas experiencing destructive storm surges, and in once vibrant agricultural areas no longer able to sustain essential food crops.

And, increasingly, we are seeing climate change become an engine of migration, forcing individuals, families and even whole communities to seek more viable and less vulnerable places to live.

This report brings a much-needed focus to the nexus between climate change, migration and development in three regions: Sub-Saharan Africa, South Asia and Latin America. Its startling conclusion is that they may have to cope with more than 143 million internal climate migrants by 2050 unless concerted action is taken at the national and global levels.

Internal, rather than cross-border, migration is the report's central focus for good reasons. There is growing recognition among researchers that more people will move within national borders to escape the effects of slow-onset climate change, such as droughts, crop failure, and rising seas.

The number of climate migrants could be reduced by tens of millions as a result of global action to reduce greenhouse gas emissions and with far-sighted development planning. There is an opportunity now to plan and act for emerging climate change threats.

At the World Bank Group, we support countries to tackle their climate challenges and to build robust social protection systems. This work ranges from investing in emissions-reducing solar and wind power projects to developing climate insurance mechanisms to protect the most climate-vulnerable countries from economic disaster. We also work with countries to identify the risks they face from growing threats like climate change and plan accordingly.

We also have a role to play in the global dialogue about how to better manage and prepare for climate change and its effects. At this moment, the world is working towards Global Compacts on migration and refugees as well as ways that the UN Framework Convention on Climate Change can address human displacement.

Internal climate migration is a development issue. Unless we act it will become the human face of climate change.

Overview

In recent times, cross-border migration and its implications for host countries have captured high-profile global attention. But there is increasing recognition that far more people are migrating within their own countries than across borders. They move for many reasons—economic, social, political, and environmental. Now, climate change has emerged as a potent driver of internal migration, propelling increasing numbers of people to move from vulnerable to more viable areas of their countries to build new lives.

KEY FINDINGS

This report, which focuses on three regions—Sub-Saharan Africa, South Asia, and Latin America that together represent 55 percent of the developing world's population—finds that climate change will push tens of millions of people to migrate within their countries by 2050. It projects that without concrete climate and development action, just over 143 million people—or around 2.8 percent of the population of these three regions—could be forced to move within their own countries to escape the slow-onset impacts of climate change. They will migrate from less viable areas with lower water availability and crop productivity and from areas affected by rising sea level and storm surges. The poorest and most climate-vulnerable areas will be hardest hit. These trends, alongside the emergence of "hotspots" of climate in- and out-migration, will have major implications for climate-sensitive sectors and for the adequacy of infrastructure and social support systems. The report finds that internal climate migration will likely rise through 2050 and then accelerate unless there are significant cuts in greenhouse gas emissions and robust development action.

APPROACH

Understanding the scale of internal climate migration and the patterns of people's movements is critical to countries so they can plan and prepare. But robust projections of internal climate migration over large areas are rare. This report—the first of its kind to introduce slow-onset climate impacts into a model of future population distribution—attempts to fill that gap. The focus on slow-onset climate impacts (water stress, crop failure, sea level rise) rather than rapid onset events such as floods and hurricanes, leads to a lower-bound estimate of the likely overall impact of climate change on migration across the three regions.

Beyond the three main regions of focus (Sub-Saharan Africa, South Asia and Latin America), deeper analysis was undertaken for three subregions: East Africa, South Asia (in its entirety), and Mexico and Central America which have contrasting climatic, livelihood, demographic, migration, and development patterns. Results were further contextualized through three country examples: Ethiopia, Bangladesh, and Mexico.

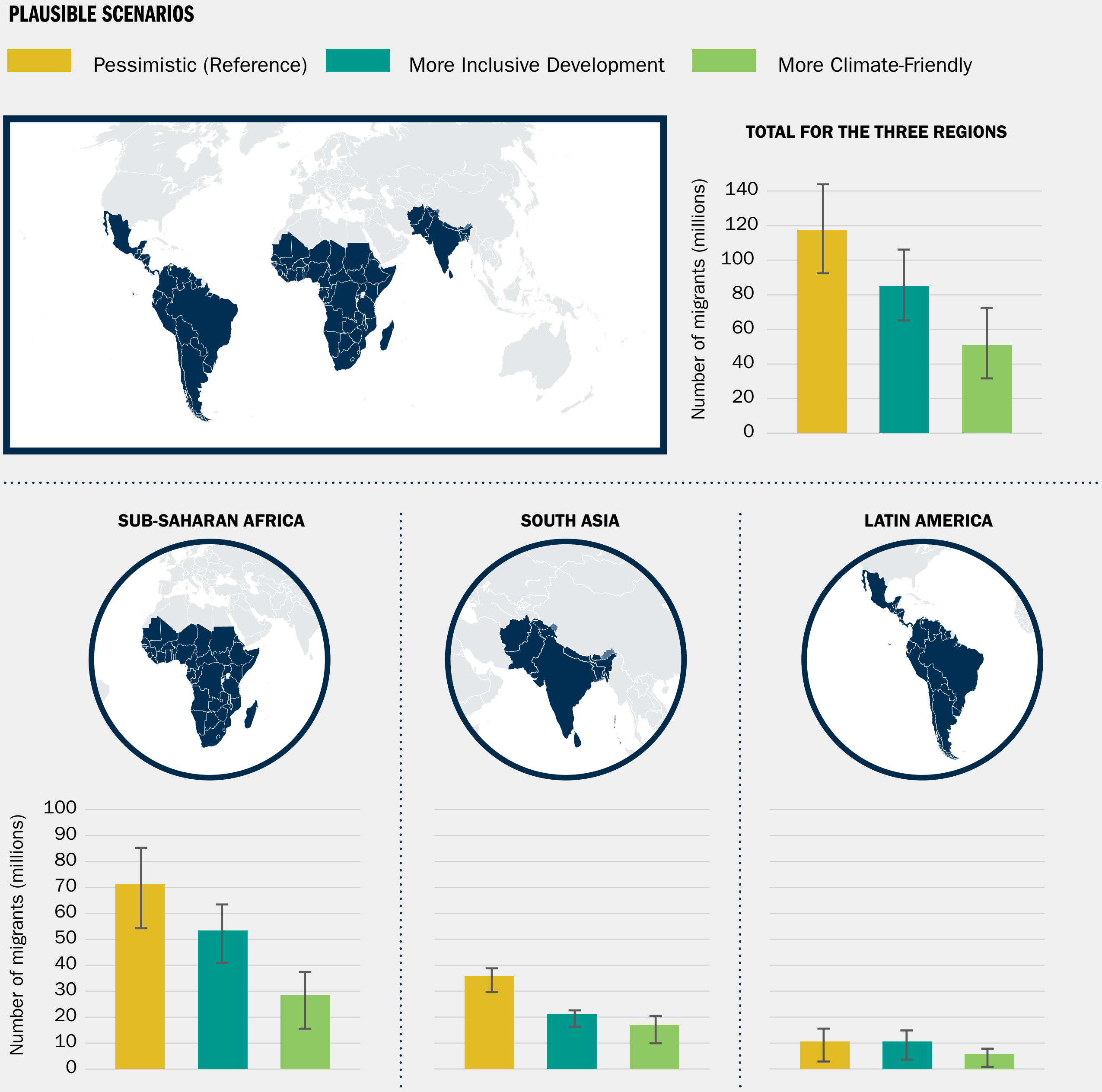
The model applies demographic, socioeconomic, and climate impact data at a 14-square kilometer grid cell level to model likely shifts in population within countries. To address the uncertainties of analyzing migration over the next 30 years, the report considers three potential climate and development scenarios. The model can be customized and expanded at different scales. Future work could modify and extend the models to more countries, more climate scenarios, and longer time periods, but also to more local levels. The scenario-based results should be seen as a plausible range of outcomes rather than precise forecasts.

The three scenarios are:

- "pessimistic" (high greenhouse gas emissions combined with unequal development pathways)—the "reference scenario" for the report;
- "more inclusive development" (similarly high emissions but with improved development pathways); and
- "more climate-friendly" (lower global emissions combined with unequal development).[i]

This scenario approach provides policymakers with a way to better understand and plan for the likely movement of people within their countries—over time and across different geographies—due to climate change impacts.

Figure 1: Projected number of climate migrants in Sub-Saharan Africa, South Asia, and Latin America under three scenarios, by 2050



Note: The whiskers on the bars in the charts represent the 95th percentile confidence intervals.

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[i] According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report under the lower emissions scenario, temperatures are likely to peak at 0.4°-1.6°C above baseline levels by 2050 and then stabilize. For the higher emissions scenarios, temperatures rise by 1.4°-2.6°C by 2050, and by 2.6°-4.8°C by 2100.

Key messages

MESSAGE 1:

The scale of internal climate migration will ramp up by 2050 and then accelerate unless concerted climate and development action is taken.

Under all three scenarios in this report, there is an upward trend of internal climate migration in Sub-Saharan Africa, South Asia, and Latin America by 2050. In the worst-case or "pessimistic" scenario, the number of internal climate migrants could reach more than 143 million (around 86 million in Sub-Saharan Africa, 40 million in South Asia, and 17 million in Latin America) by 2050 (Figure 1). The poorest people and the poorest countries are the hardest hit.

In the "more inclusive development" scenario, internal climate migration across the three regions could drop to between 65 and 105 million. The "more climate-friendly" scenario projects the fewest internal climate migrants, ranging from 31 million to 72 million across the three regions.

Across all scenarios, climate change is a growing driver of internal migration. Climate change impacts (crop failure, water stress, sea level rise) increase the probability of migration under distress, creating growing challenges for human development and planning. Vulnerable people have the fewest opportunities to adapt locally or to move away from risk and, when moving, often do so as a last resort. Others, even more vulnerable, will be unable to move, trapped in increasingly unviable areas.

Internal climate migration will intensify over the next several decades and could accelerate after 2050 under the pessimistic scenario due to stronger climate impacts combined with steep population growth in many regions.

Photo Credit: Maria de la Guardia/Connect4Climate/World Bank

MESSAGE 2:

Countries can expect to see "hotspots" of climate-induced in- and out- migration. This will have significant implications for countries and future development planning.

The report projects that climate-driven "out-migration" will occur in areas where livelihood systems are increasingly compromised by climate change impacts. These "hotspots" are increasingly marginal areas and can include low-lying cities, coastlines vulnerable to sea level rise, and areas of high water and agriculture stress (Figure 2 for East Africa). In the northern highlands of Ethiopia for example, deteriorating water availability and lower crop yields will drive climate migrants from rainfed cropland areas. Even Addis Ababa, Ethiopia's largest city, could see slower population growth due to its reliance on increasingly unpredictable rainfall. The major cities of Dhaka in Bangladesh and Dar es Salaam in Tanzania will also experience dampened population growth due to rising sea level and storm surges.

Climate "in-migration" hotspots across the three regions emerge in locations with better climatic conditions for agriculture as well as cities able to provide better livelihood opportunities. For example, the southern highlands between Bangalore and Chennai in India, the central plateau around Mexico City and Guatemala City, and Nairobi in Kenya are likely to become areas of increased climate in-migration.

Both types of hotspots emerge by 2030, and their number and spatial extent increase considerably by 2050. Planning and early action could help shape these hotspots: they are not pre-destined.

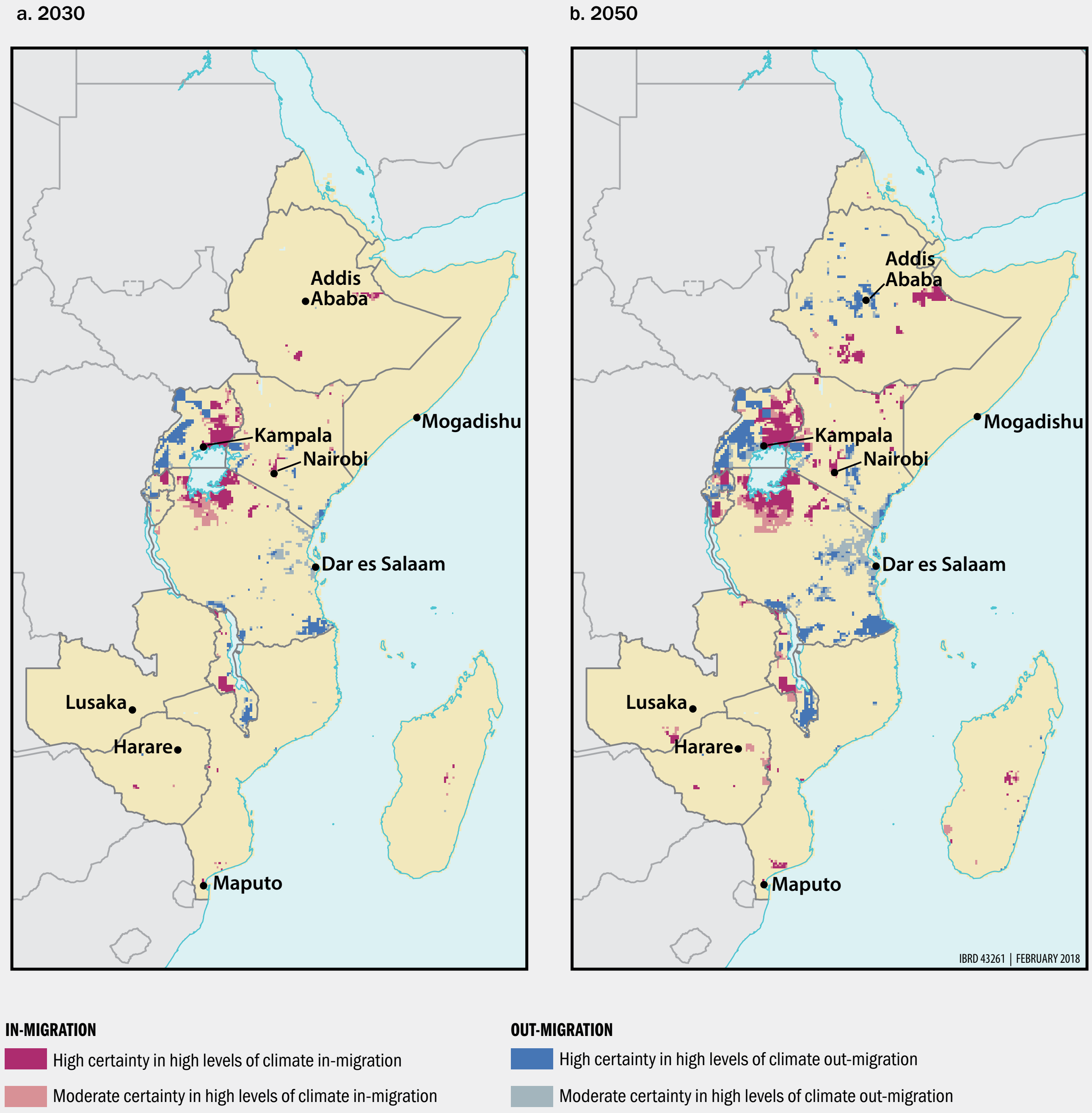
Many urban and peri-urban areas will need to prepare for an influx of people, including through improved housing and transportation infrastructure, social services, and employment opportunities. Policymakers can prepare by ensuring flexible social protection services and including migrants in planning and decision-making. If well managed, "in-migration" can create positive momentum, including in urban areas which can benefit from agglomeration and economies of scale.

Even with expected out-migration, many climate-vulnerable areas will still need to support significant numbers of people. This increases the need for development strategies to support people to adapt locally or "stay in place" in areas where it makes sense to do so. Components of successful local adaptation strategies include: investing in climate-smart infrastructure; diversifying income generating activities; building more responsive financial protection systems for vulnerable groups; and educating and empowering women. Poverty reduction and social protection programs targeted at rural areas can help to increase adaptive capacity to climate change, potentially reducing the need for people to move under distress.

Still, "adaptation in place" has its limits. Where there is no credible long-term pathway to viable livelihoods, there is a risk that people will be induced to remain in places where conditions are deteriorating. For example, about 20 million people in coastal Bangladesh are already having their health affected from saltwater intrusion into drinking water supplies related to sea level rise. Remittances from family members working elsewhere can induce people in these areas to stay, possibly against their best interests. Without appropriate policy interventions, perverse incentives to stay in place could greatly undermine community health and well-being.

Internal climate migrants do not necessarily stop at borders. While this report does not focus specifically on cross-border migration, the modeling identifies numerous migration hotspots in areas close to national borders. Climate change can be an inhibitor or a driver of cross-border migration, depending on a range of factors that propel individuals to decide to move.

Figure 2: Areas projected to have high climate in-migration and out-migration in East Africa, 2030 and 2050


a. 2030

b. 2050

Note: High certainty reflects agreement across all three scenarios modeled, and moderate certainty reflects agreement across two scenarios.

MESSAGE 3:

Migration can be a sensible climate change adaptation strategy if managed carefully and supported by good development policies and targeted investments.

Where the limits of local adaptation are anticipated, well-planned migration to more viable areas can be a successful strategy. A strong enabling environment for migration needs to be in place supported by direct incentives, such as skills training and job creation programs, for people to move to areas of low risk and greater opportunity. Strategies supporting internal migration need to safeguard not only the resilience of those moving, but also of those in sending and receiving communities.

Between 2030 and 2050, climate migration hotspots will intensify and possibly spread. Countries therefore will need to take a long-term, anticipatory approach to planning so that climate migrants are factored in to overall growth and development strategies.

Ethiopia, which could see a population increase of up to 85 percent by 2050 and experience lower agricultural productivity due to climate change, will need to plan for a more diversified economy, absorbing labor into non-agricultural and less climate-sensitive sectors.

Bangladesh, which is projected to have a third of the internal climate migrants in South Asia by 2050 under the pessimistic scenario, is developing a *Perspective Plan for 2041* that factors in climate change as a driver of future migration. The plan recognizes migration as a potential adaptation option for people living in the most vulnerable areas.

Mexico, as an upper middle-income country with a diversified and expanding economy that is relatively less climate sensitive, has some capacity to adapt to climate change but needs to pay close attention to its impacts on pockets of poverty.

Photo Credit: World Bank

MESSAGE 4:

Internal climate migration may be a reality but it doesn't have to be a crisis. Action across three major areas could help reduce the number of people being forced to move in distress.

Based on the report's projected range of internal migration, from a low of 31 million in the best-case to 143 million in the worst-case for the three regions, concerted action in three key areas could help reduce the number of internal climate migrants by as much as 80 percent by 2050.

1. Cut greenhouse gases now

Strong global climate action is needed to meet the Paris Agreement's[ii] goal of limiting the future temperature increase to less than 2°C by the end of this century. Even at this level of warming, countries will be locked into a certain level of internal climate migration. Still higher levels of greenhouse gas emissions could lead to the severe disruption of livelihoods and ecosystems, further creating the conditions for increased climate migration.

Without rapid greenhouse gas emissions reductions over the next two decades, the report's pessimistic scenario is likely to become reality. Under the more climate-friendly scenario (in which greenhouse gas emissions are significantly reduced), a far lower number of people are projected to migrate in all three regions.

The window of opportunity to cut greenhouse gases and reverse warming trends is closing quickly.

2. Embed climate migration in development planning

There is an urgent need for countries to integrate climate migration into national development plans. Most regions have poorly prepared laws, policies, and strategies to deal with people moving from areas of increasing climate risk into areas that may already be heavily populated.

National agencies need to integrate climate migration into all facets of policy. To secure resilience and development prospects for all those affected, action is needed at each phase of migration (before, during, and after moving). Governments will require guidance, technical assistance, and capacity building to develop national laws, policies, and strategies that are in line with international frameworks related to climate migration. The engagement of private actors, civil society, and international organizations is key to building policy frameworks and capacity.

3. Invest now to improve understanding of internal climate migration

More investment is needed to better contextualize and understand climate migration, particularly at scales ranging from regional to local, where climate impacts may deviate from the broader trends identified in a global-scale analysis. In many cases, a richer, more detailed set of climate, biophysical, socioeconomic, and political indicators is available at regional, national, and local levels.

There are inherent uncertainties in the way climate impacts will play out in a given locale and this will affect the magnitude and pattern of climate change-induced movements. Over time, as more data become available on climate change and its likely impacts on water availability, crop productivity, and sea level rise, the scenarios and models would need to be updated.

Increasing the modeling resolution and improving data inputs to produce more spatially-detailed projections are among the possible future applications of the approach used in this report. Building country-level capacity to collect and monitor relevant data can increase understanding of the interactions among climate impacts, ecosystems, livelihoods, and mobility and help countries tailor policy, planning,

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[ii] Countries adopted the Paris Agreement at the UN Conference of the Parties—COP21—in Paris on 12 December 2015. The Agreement entered into force less than a year later. In the agreement, all countries agreed to work to limit global temperature rise to well below 2°C, and given the grave risks, to strive for 1.5°C.

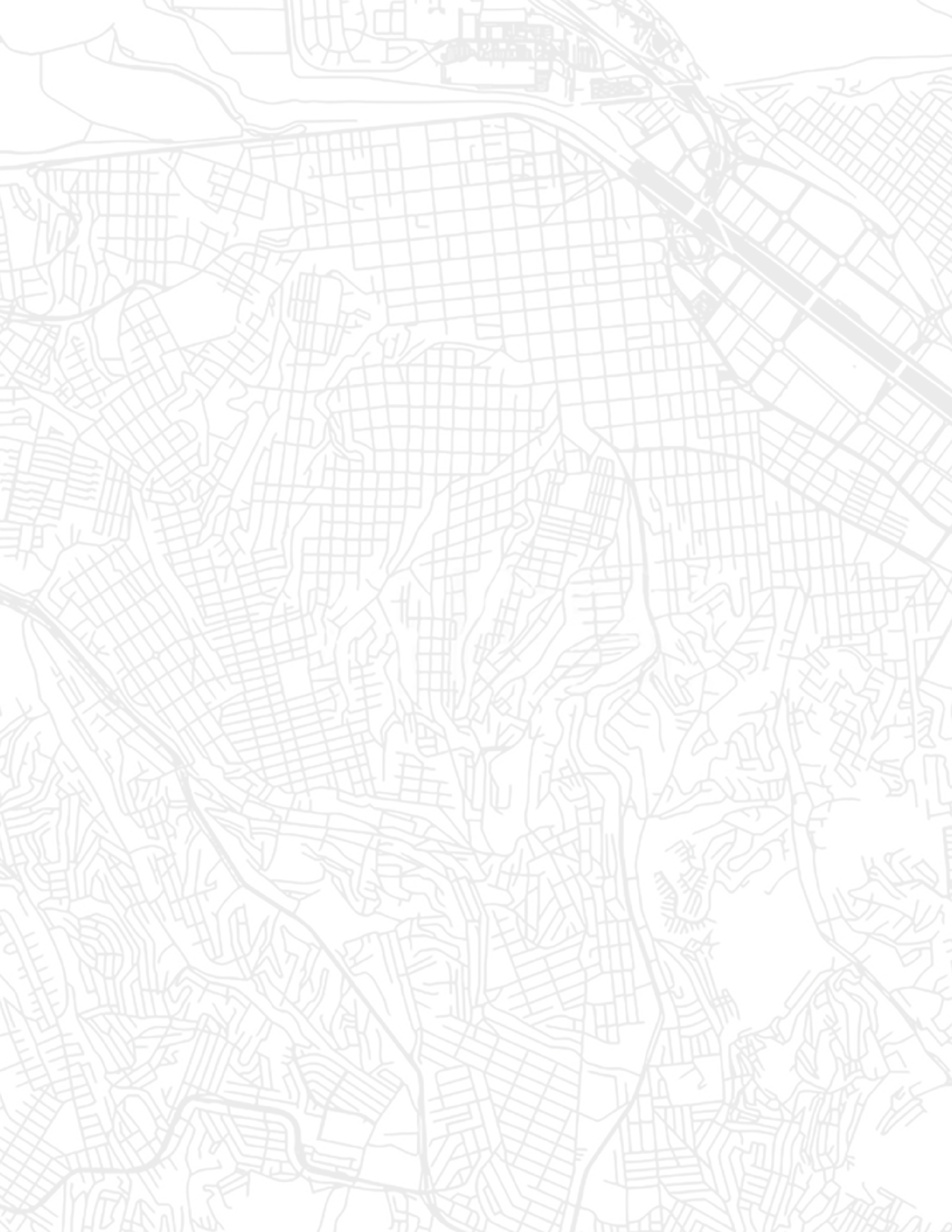
and investment decisions. Including climate-related and migration questions in national census and existing surveys is a cost-effective way to advance understanding. Decision-making techniques under deep uncertainty need to be further developed and applied for policy making and development planning.

Evidence-based research, complemented by country-level modeling is vital. In support of this, new data sources—including from satellite imagery and mobile phones—combined with advances in climate information can be beneficial to improving the quality of information about internal migration. In all of these efforts, the privacy of personal data needs to be protected.

CONCLUSION

Groundswell: Preparing for Internal Climate Migration helps to put a human face on the growing development issue of people being forced to move under distress to escape the long-term impacts of climate change. Its findings must be taken seriously if the world is to sustain recent development gains and provide sustainable livelihood options for all.

Photo Credit: Natalia Cieslik, World Bank



Chapter 1

Internal Climate Migration as a Key Development Issue

Mobility is emerging as the human face of climate change. There is also increasing recognition that far more people are migrating within their own countries than across borders. The impacts associated with climate change are already shifting patterns of mobility and will increasingly do so. Migration is a common strategy for survival, coping, income diversification, risk management, and adaptation for people facing economic stress and adverse climate conditions. Policy makers in countries need to anticipate the scale of internal climate migration over time, the places people will go to or stay in, and the development implications of their movements. This report uses a pioneering scenario-based approach that combines high-resolution demographic, socioeconomic, and climate data to isolate the portion of future changes in population distribution that can be attributed to internal climate migration.

Climate change impacts will pose one of the greatest threats to people, ecosystems, and development goals over the coming decades (IPCC 2014a). Current levels of carbon dioxide in the atmosphere are at a 650,000-year peak. The average global temperature has risen 1.1°C since 1880; 2016 was the warmest year on record; and 16 of 17 of the hottest years in NASA's 134-year record have been since 2000 (NASA 2017).

Warming close to 1.5°C above preindustrial levels by midcentury is probably already "locked in" to the earth's atmosphere by past and predicted greenhouse gas emissions. Only highly ambitious mitigation action seems likely to keep warming by end-of-century to less than 2°C above preindustrial levels (World Bank 2014; Mauritsen and Pincus 2017; Raftery and others 2017).

Climate change will intensify environmental degradation and natural hazards in many regions (UNEP 2016). In the next few decades, climate change impacts will work together with other stressors, such as pollution and overexploitation of resources (Olsson and others 2014), affecting a world population that is both urbanizing (UNDESA 2015) and growing rapidly (UNDESA 2017).

The impacts associated with climate change are already shifting patterns of mobility and will increasingly do so (Foresight 2011; Adger and others 2014). Because mobility is complex, driven by multiple, interacting processes that vary greatly over space and time, there is no straight line of causation from environmental stress to the movement of people (Black and others 2011a; Black, Kniveton, and Schmidt-Verkerk 2013; Foresight 2011). But climate change–driven pressure can directly and indirectly alter mobility patterns. In some cases, people migrate in an attempt to adapt to climate change (Black and others 2011b; McLeman 2016; Melde, Laczko, and Gemenne 2017). In others, the impacts of climate change will lead to movements under distress, induce displacement, or require planned relocation.

Favorable environments attract people who are moving (Hunter, Luna, and Norton 2015); people do not only move away from places of environmental stress, they are equally likely to move to them (Foresight 2011). Millions of people will be unable or unwilling to move from areas of environmental stress, rendering them immobile or "trapped" (Foresight 2011).

Such climate change–induced human movement has been increasingly acknowledged in discussions at all levels (Gemenne, Zickgraf, and Ionesco 2016). Climate change as a driver of mobility is recognized in the Sendai Framework for Disaster Risk Reduction, the Agenda for Humanity, the 2016 United Nations Summit for Refugees and Migrants, and the processes around the Global Compact for Migration and the Global Compact on Refugees. Mobility was not part of the Millennium Development Goals (MDGs), but the 2030 Sustainable Development Goals (SDGs) feature an explicit target (10.7) to "facilitate orderly, safe, and responsible migration and mobility of people, including through implementation of planned and well-managed migration policies." The United Nations Framework Convention on Climate Change (UNFCCC), the Cancun Adaptation Framework, and the Warsaw International Mechanism for Loss and Damage Associated with Climate Change recognize migration as an adaptation strategy to climate change and call for approaches to disaster displacement. A review of Nationally Determined Contributions (NDCs) submissions under the Paris Agreement indicates that at least 44 of 162 (about 27 percent of all submissions, mostly in Africa and in Asia Pacific and Oceania) refer to mobility in its various forms, including migration as an adaptation strategy.[1] Some National Adaptation Plans (NAPs) and National Programs of Action (NAPAs) under the UNFCCC also mention mobility. More recent developments include the Protection Agenda developed by the Nansen Initiative and its successor, the Platform on Disaster Displacement (Gemenne and Brücker 2015; Nansen Initiative 2015). Guidance and tools for planned relocation have also been developed (Brookings Institution, Georgetown University, and UNHCR 2015; Georgetown University, UNHCR, and IOM 2017). Yet, while attention is increasing, environmental mobility is still inadequately incorporated in policies and long-term development planning (Martin 2009; Martin 2012; Warner and others 2014; Warner and others 2015).

This report—intended as a catalyst for future work by the World Bank, development partners, and client countries—focuses on internal climate migration (Box 1.1), expected to be the most frequent form of mobility induced by climate change (Foresight 2011; Groschl and Steinwachs 2016; McLeman and others 2016). Such internal climate migration should be addressed within the development and climate change adaptation frameworks of affected countries for four reasons:

i. Internal migration (not just internal climate migration) is already happening at scale and is expected to increase even without climate change.
ii. Climate change will add large numbers of internal climate migrants.
iii. Climate change will hit poorer countries and communities disproportionately.
iv. Climate migration can have significant effects on the resilience of people affected that need to be managed carefully.

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[1] This figure comes from a background review conducted for this report in September 2016. It does not reflect submissions after this date.

Box 1.1: Climate change-induced migration—scope and terminology used in the report

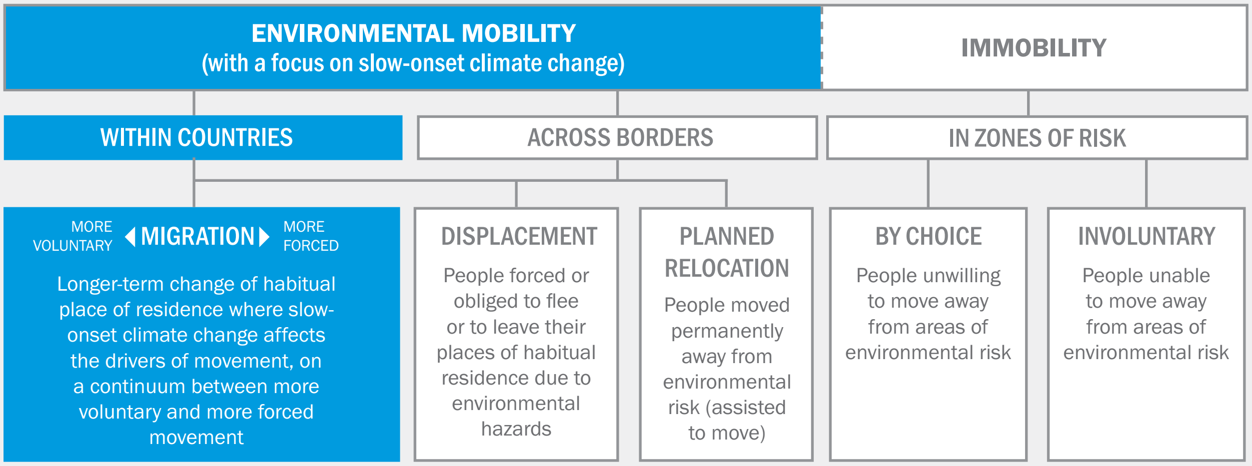
There is no universally agreed upon terminology for human movement in the context of environmental change (Dun and Gemenne 2008). This report uses the terms depicted in Figure 1.1, which are informed by the most common use and definitions established by the UN Office for the Coordination of Humanitarian Affairs (OCHA 1998); the United Nations Framework Convention on Climate Change (UNFCCC 2010); the International Organization for Migration (IOM 2014); the Intergovernmental Panel on Climate Change (IPCC 2014b); the Brookings Institution, Georgetown University, and the United Nations High Commissioner for Refugees (UNHCR) (2015); and the Internal Displacement Monitoring Centre (IDMC 2017a).

When environmental change affects the drivers of human movements, it is referred to as *environmental mobility* or *environmental movement* (Foresight 2011). As established in the Cancun Adaptation Framework (UNFCCC 2010), these terms encompass the categories of migration, displacement, and planned relocation. In practice, human movement seldom falls into simple boxes. Migration here is a longer-term change of habitual place of residence perceived as more voluntary. Yet, there is an important gray area between migration and displacement, and migration should be seen on a continuum from voluntary to forced instances, which can include an element of coercion such as threats to life and livelihood (Hugo 1996; Renaud and others 2007).

Environmental change can encompass many phenomena that affect mobility, some of which—such as volcanic eruptions—are not related to climate change. This report therefore uses *climate change–induced migration* (or the shorthand *climate migration*) only in discussions of migration largely linkable to climate change impacts, such as the results of the modeling of internal climate change migration presented in this report. As that modeling focuses on internal climate migration, the term *migration* in this report generally refers to movements within countries; discussions of international movements are also included in the report.

Although Figure 1.1 juxtaposes the umbrella terms *mobility* and *immobility*, they are not mutually exclusive. People may be trapped not only in their place of habitual residence but also in transit or at their final destination (Black, Kniveton, and Schmidt-Verkerk 2013; Zickgraf forthcoming).

Figure 1.1: Human mobility and immobility in the context of climate change
(areas in blue are the focus of the report)



Sources: Extended and adapted from Advisory Group on Climate Change and Human Mobility (2014), with inputs from OCHA (1998); UNFCCC (2010); IOM (2014); IPCC (2014b); Brookings Institution, Georgetown University, and UNHCR (2015); and IDMC (2017a).
Note: Mobility and immobility are not mutually exclusive.

All forms of environmental mobility, including international climate migration, have important development implications. Several studies highlight the likelihood of future international climate migration. The links are complex: climate change impacts can act as inhibitors or drivers of cross-border movements. For example, excessive precipitation has increased international migration from Senegal. But heat waves have decreased migration from Burkina Faso (Nawrotzki and Bakhtsiyarava 2017; Nawrotzki, Riosmena, and Hunter 2013). Small Island Developing States (SIDS) present a particularly stark illustration of this phenomenon: With some of the greatest vulnerability to climate change impacts, they will continue losing entire swaths of land and associated livelihoods. Cross-border movements induced by climate change are expected to be less frequent than internal movement (Foresight 2011; Groschl and Steinwachs 2016; McLeman and others 2016), but the political and development implications could well be considerable (see e.g. Watts and others 2017 on possible health consequences).

Disaster displacement, planned relocation, and immobility are also important policy concerns. There were 24.2 million new internal displacements brought on by sudden-onset extreme events such as floods and cyclones in 2016 (IDMC 2017b). Such rapid-onset extreme events have displaced an average of more than 26 million people a year from 2008-15 (IDMC 2015), a number expected to rise as such disasters become more frequent and severe because of climate change (Adger and others 2014).

Millions of people may be unwilling or unable to leave strained environments (Adger and others 2015; Foresight 2011). According to the Intergovernmental Panel on Climate Change (IPCC 2014a), vulnerable people often have the least opportunity to move or do so only under distress conditions. Mobility is often an adaptation of last resort (McLeman, 2009). Because of place attachment, negative incentives through policy, and other reasons, people may be unable to move away or choose to stay in areas that are at high risk (McKenzie and Yang 2014; Waldinger 2015; Koubi and others 2016). Relocating communities from increasingly uninhabitable spaces may be unavoidable for large numbers of people, yet such planned relocation could carry significant risks (de Sherbinin and others 2011).

This report emphasizes the importance of these other facets of human movement in the context of climate change and explores some of the discussions, trends, and numbers, to provide context for the study's focus on internal climate migration. Chapter 6, on managing climate migration for development, comes

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back to this point, arguing that it is paramount that development planning considers all forms of mobility together with internal climate migration in an anticipatory and holistic approach. Understanding where people facing intensifying slow-onset climate change might migrate within their own countries, when, and at what scale, is a key first step to discussing policy synergies.

INTERNAL CLIMATE MIGRATION FROM A DEVELOPMENT PERSPECTIVE

Internal climate migration needs to be addressed within countries' development and climate change adaptation frameworks for multiple reasons.

Internal migration is already happening at scale and is expected to increase even without climate change

The number of internal migrants worldwide has been conservatively estimated at 740–763 million (UNDESA 2013; UNDP 2009). These figures suggest that, at least three times more people migrated within countries than across borders in 2013, and about twice as many people were displaced internally than across borders in 2016 (IDMC 2017b; UNHCR 2017).

These numbers can be expected to rise, driven by factors such as population growth and urbanization. The global population is currently growing by 1.1 percent (83 million people) a year; it is expected to reach 9.8 billion in 2050. Within the 47 least developed countries, populations will double by then (UNDESA 2017).

Internal migration will also be driven by urbanization. By 2050, two-thirds of the global population is expected to be living in urban areas—2.5 billion people will live in cities by then, the majority in Asia and Africa. These trends will put pressure on urban structures but also provide opportunities in terms of agglomeration of population and economies of scale (Montgomery 2008; UNDESA 2015). Even without climate change impacts, rising internal migration means that effective management strategies are indispensable (UNDP 2009; UNDESA 2013).

Climate change will add large numbers of internal climate migrants

People have always fled natural disasters and sought better opportunities in new areas (Hugo 2008; IOM 2009). What is different today is the intensity and size of climate change–related environmental impacts on human communities and ecosystems (IPCC 2014a). They threaten to push many people into poverty (Hallegatte and others 2016). The cascading impacts linked to climate change are already shifting patterns of migration and will increasingly do so, especially for internal migration, although climate change always has to be considered as one driver among many (Foresight 2011; Adger and others 2014).

Climate change will hit poorer countries and communities disproportionately

Vulnerabilities to climate risks—a function of exposure, sensitivity, and adaptive capacity (Adger 2006; IPCC 2014a)—are often highest in poorer countries and communities (ND-GAIN 2017; WRI 2016). Natural disasters affect poor people more because their resources to confront hazards are scarce and many of their livelihoods depend on increasingly threatened ecosystem goods and services (Hallegatte and others 2017). As a result, the poorest often bear climate impacts disproportionately (World Bank 2012). These preexisting vulnerabilities shape the extent to which environmental change causes people to move and affects the type of movement.

The most vulnerable groups tend to have the fewest opportunities to adapt locally or move away from risk—and when moving they tend to do so in adverse circumstances. This can increase the probability of migration under distress, displacement, and planned relocation, all of which are challenging for human development and planning (Melde, Laczko, and Gemenne 2017). The past can give an indication of the probable locations of future challenges. Most migration relating to environmental change over the past two decades has been in countries outside the Organisation for Economic Co-operation and Development (OECD) (McLeman and others 2016), and about 97 percent of global disaster displacement from rapid-onset hazards (which are not modeled in this study) has been in low and middle income countries from 2008-13 (IDMC 2014).

Climate migration needs to be managed carefully in order to secure the resilience of all affected

Climate migration affects the well-being and resilience of people and surrounding systems in complex and evolving ways (UNDP 2009; Milan and others 2015; Melde, Laczko, and Gemenne 2017).

The challenges and potential benefits of development associated with climate migration often resemble those of labor migration, irregular migration, or forced displacement (Martin 2010). Migration is a common strategy for survival, coping, income diversification, risk management, and adaptation for people facing economic stress and adverse climatic conditions (Ellis 2000; Adger and others 2014; Melde, Laczko, and Gemenne 2017). The benefits and costs of climate migration go beyond the economic to include social, cultural, and psychological effects. Climate migration can have positive impacts on income, health, skills, education, equality, and resilience, depending on the characteristics of both receiving areas (including demand for labor, access to networks, credit, infrastructure, information, and security of land tenure) and of the migrants themselves (including their preexisting vulnerability and resilience) (Waldinger 2015).

Migration can also be a costly strategy. Some people may migrate to areas at risk (Foresight 2011). Discrimination, exclusion from social services, and higher levels of insecurity faced by migrants can also reduce their development and adaptation prospects (Melde, Laczko, and Gemenne 2017). Authorities and migrants, as well as sending and receiving areas, often have diverging perspectives on the cost–benefit calculus and adaptation potential of climate migration (Gemenne and Blocher 2017).

Migration under distress and displacement should be avoided as much as possible, but there is no consensus on the desirable conditions and forms of climate migration or how criteria are to be measured (McLeman and others 2016). By contrast, much can be done to improve the outcomes of migration (DRC 2009; UNDP 2009) and to mitigate or prepare for climate impacts that lead to migration under distress or displacement. To safeguard the resilience and well-being of affected people, development and climate change adaptation frameworks should urgently consider the multiple facets of climate migration (ADB 2012; ADB 2017; Gemenne and Blocher 2017; Martin and Bergmann 2017).

OBJECTIVE AND VALUE OF THIS REPORT

Policy makers in countries need to anticipate the scale of internal climate migration over time, the places people will go to or stay in, and the development implications of their movements. Mobility has emerged as the “human face of climate change” (Gemenne 2011a), and an appropriate management strategy will be vital to safeguard sustainable development prospects, uphold poverty reduction gains, and tackle inequalities. Strategies are needed to enable people affected by climate change to stay where they are if doing so is sensible and viable; to provide safe, dignified, and orderly mobility options, when staying would compromise resilience prospects; and to secure resilience for people who move, become displaced, host others, or stay behind.

Foresight and plausible projections for future climate migration are in short supply. Figures of 200 million (Myers 1993, 2002; Myers and Kent 1995) or 300 million people (Myers 2005) displaced by climate change worldwide by 2050 have been often cited. These estimates have helped shift the world’s focus to the issue, but they suffer from methodological constraints and are not sufficiently robust to anticipate the scale, timing, and spatial dimensions of the challenge (Gemenne 2011b).

Robust and transparent approaches are needed to model climate migration, within countries and regions. Population distributions are unlikely to evolve as they have in the past. Spatially and temporally explicit projections that take into account climate impacts are important for a range of users, including the humanitarian community and development actors grappling with potential limits to adaptation for rural livelihoods and how population may be redistributed internally as a result. For instance, unanticipated movements can represent risks to the people moving and to host communities and slow poverty-reduction efforts. Some movements under distress can be forestalled with the right investments made early enough, supported by the right projections. At the same time, in some cases migration represents an appropriate adaptation response to changing climatic and socioeconomic conditions (McLeman 2016; Melde, Laczko, and Gemenne 2017). Much can be done to tap the development potential of migration and prepare sending and receiving areas adequately. Beginning to understand potential directions, geographic and temporal variation, and the intensity of internal climate migration will help decision makers assess potential impacts and inform the policy and planning debate. Anticipatory diagnostics, such as the modeling in this report, can be one important piece of the puzzle.

This report presents a novel approach for scenario-based projections of internal climate migration up to 2050 for Sub-Saharan Africa, South Asia, and Latin America, in order to provide a baseline for climate-resilient development planning at scale. Its novelty lies in the transparent methods and the explicit illustration of scale, timing, and spatial distribution across regions. The three focus regions were selected because they provide contrasting climatic, livelihood, demographic, migration, and development patterns with differentiated vulnerability to climate risks. For the three scenarios detailed in the next section—pessimistic reference scenario, more inclusive development, and more climate-friendly—the report investigates plausible scales, temporal evolution, and spatial patterns of internal climate migration over and above internal migration from other sources. The report provides deeper analysis for the subregions of East Africa, South Asia (in its entirety), and Mexico and Central America. Spatially, the report provides estimates of where people could come from and go to within a country and identifies climate in-migration “hotspots” (areas of particularly high in-migration as a result of climate change) and climate out-migration “hotspots” (areas of particularly high out-migration as a result of climate change). It also shows how internal climate migration plays out over time. The results are contextualized through country examples from Ethiopia, Bangladesh, and Mexico.

OVERVIEW OF THE MODELING APPROACH

The report’s approach is based on a population model that combines socioeconomic and climate data. The model compares projections of national population distribution based on development pathways with projections that include the same development pathways but also incorporate specific, slow-onset climate impacts. Differences in population distributions among these sets of projections are assumed to be driven primarily by differences in internal climate migration. The modeling method was developed through a consortium of the Center for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University; the City University of New York (CUNY) Institute for Demographic Research (CIDR); and the Potsdam Institute for Climate Impact Research (PIK). It has been examined by global experts through consultations and several rounds of review, including a quality enhancement review and an external and internal peer review of the final report. Consultations were also conducted with representatives from government, academia, donors, and civil society organizations in Ethiopia, Bangladesh, and Mexico, to solicit feedback on the modeling results.

The model can be customized and expanded at different scales. Future work could modify and extend the models to more countries, more climate impacts, and longer time periods, but also to more granular levels. The scenario-based results should be seen as a plausible range of outcomes rather than precise forecasts. Chapter 3 and Box 3.1 describe the range of uncertainty associated with the projections.

The model has several features:

- *It focuses on incremental, decadal internal migration induced by slow-onset climate change over and above that expected to occur even in the absence of climate change*. Internal migration caused by factors such as population growth and urbanization has already been investigated (Jones and O’Neill 2016); it serves as the “no climate impacts” comparison baseline. The literature shows that water scarcity, declining crop yields, and sea level rise are among the major potential climate impacts facing low-income countries. These slow-onset impacts will also be important drivers of migration. They affect the relative appeal of different locations. The model does not include short-term climate variations or extremes such as cyclones, except where successive shocks accumulate over multiple years. Although disaster displacement from rapid-onset events cannot be modeled here, it is a substantial development concern. Policy responses need to look at it alongside climate migration.

- *It focuses on internal migration in three developing regions, by aggregating country-level modeling results.* Planned relocation, immobility, or movements across borders are also very important policy concerns; they are not modeled.[2] Development planning should consider all of these forms of mobility together, in a holistic and anticipatory manner.

- *It focuses on movements in decadal increments up to 2050, not shorter-term or cyclical migration*. The report examines internal climate migration over a timeframe that policy makers can relate to. The aim is to inform near- and midterm action as well as long-term planning that needs to begin now. The trend of slow-onset impacts for the second half of the century, discussed in Chapter 4, indicates that

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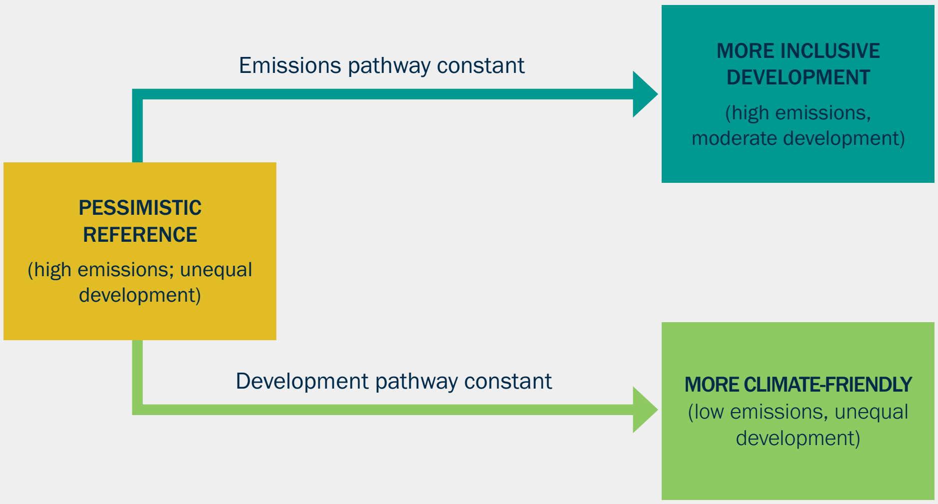
[2] Although international climate migration is not modeled, the different Shared Socioeconomic Pathways (SSPs) used in the model do include projections of non-climate-related international migration.

they will be much more pronounced and nonlinear after 2050. They will likely translate into increasing pressure on livelihoods and escalate the scale of climate migration if the global community does not make use of the window of opportunity for cutting emissions and act on climate migration now.

- *The applied geographical modeling scale limits the spatial scope of results.* The model does not capture migration over distances of less than about 14 kilometers. Small territories such as Small Island Developing States (SIDS) cannot be included at this resolution. Climate migration from such territories is an important policy concern.

Internal climate migration is projected under three scenarios (Figure 1.2).[3] In the pessimistic reference scenario, little to no climate policy leads to high greenhouse gas emissions, and inequality remains high, leaving developing regions highly vulnerable to climate change and with limited adaptive capacity. Urbanization rates are also high across low and middle income countries. In the more climate-friendly scenario, development challenges remain the same but emissions are lower and close to the goals of the Paris Agreement. In the more inclusive development scenario, emissions remain high but inequality, urbanization rates, and population growth are more moderate. Population distributions in the three scenarios are compared with three projections that include the same development pathways but no climate impacts.[4] Chapter 3 and Appendix A explain the scenarios and the modeling approach in more detail.

Figure 1.2: Projecting internal climate migration under three plausible scenarios



Note:
1. The scenarios are based on combinations of two Shared Socioeconomic Pathways—SSP2 (moderate development) and SSP4 (unequal development)—and two Representative Concentration Pathways—RCP 2.6 (low emissions) and RCP 8.5 (high emissions).
2. Estimates of climate migrants are derived by comparing these plausible climate migration (RCP-SSP) scenarios with development only (SSP) or the "no-climate impact" scenarios.

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[3] Chapter 3 explains the assumptions behind the scenarios.

[4] The assumed differences in emissions between the lower and higher emissions futures are less pronounced in the first half of this century than after 2050. Because of different demographic growth rates in the scenarios, the projected number of people living in the world also differs considerably in the pessimistic reference and more climate-friendly scenarios on the one hand and the more inclusive development scenario on the other.

STRUCTURE OF THE REPORT

Chapter 2 sets the stage for the discussion of the modeling approach and results by reviewing the evidence and theories on climate migration. It examines current migration patterns, theories about why people migrate, and the role of climate change as a driver. It then reviews climatic changes likely to have large impacts on livelihoods and migration patterns and the literature on impacts of climate migration. It provides context by looking at international movements, disaster displacement, and the current discussion around the relationship among climate change, conflict, and mobility.

Chapter 3 explains the data, methods, and justifications for the report's modeling approach, which can be customized and expanded at different scales. It sets the report in the context of previous efforts and other approaches to model climate migration and explains why the gravity model used to simulate behavior is well suited for modeling at broader scale with geographic specificity.

Chapter 4 provides projections of how climate change will likely shift population distribution under the three scenarios in Sub-Saharan Africa, South Asia, and Latin America. It also discusses results from the modeling exercise for the three subregions: East Africa, South Asia (in its entirety), and Mexico and Central America.

Chapter 5 illustrates and contextualizes the patterns described in Chapter 4 for three country illustrative examples: Ethiopia, Bangladesh, and Mexico. It relates the findings to each country's context and discusses the implications of the research. It includes a comparison of the examples that highlights both common and distinct issues . It also presents the highlights of consultations in the country examples.

Chapter 6 discusses takeaway messages from the report that can guide a more holistic and anticipatory approach to internal climate migration and other forms of movement associated with climate change.

Appendix A provides technical details on the methodology. Appendix B describes the results of the water and crop model for the three regions studied.

Photo Credit: Dominic Chavez/World Bank

REFERENCES

Adger, W. N. 2006. “Vulnerability.” *Global Environmental Change* 16 (3): 268–81. doi:10.1016/j.gloenvcha.2006.02.006.

Adger, W. N., N. W. Arnell, R. Black, S. Dercon, A. Geddes, and D. Thomas. 2015. “Focus on Environmental Risks and Migration: Causes and Consequences.” *Environmental Research Letters* 10 (6): 60201.

Adger, W. N., J. M. Pulhin, J. Barnett, G. D. Dabelko, G. K. Hovelsrud, M. Levy, Ú. Oswald Spring, and C. H. Vogel. 2014. “Human Security.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, 755–791. Cambridge, UK and New York, NY: Cambridge University Press.

Advisory Group On Climate Change And Human Mobility. 2014. “Human Mobility In The Context Of Climate Change: Recommendations for Cop 20 Lima, Peru.” https://www.iom.int/files/live/sites/iom/files/pbn/docs/Human-Mobility-in-the-context-of-Climate-Change.pdf.

ADB (Asian Development Bank). 2012. *Addressing Climate Change and Migration in Asia and the Pacific.* Manila, Philippines: Asian Development Bank. http://www.worldcat.org/oclc/780416971.

———. 2017. *A Region at Risk: The Human Dimensions of Climate Change in Asia and the Pacific.* Manila: Asian Development Bank. http://www.worldcat.org/oclc/993853371.

Black, R., D. Kniveton, and K. Schmidt-Verkerk. 2013. “Migration and Climate Change: Toward an Integrated Assessment of Sensitivity.” In *Disentangling Migration and Climate Change*, 29–53. Springer.

Black, R., W. N. Adger, N. W. Arnell, S. Dercon, A. Geddes, and D. Thomas. 2011a. “The Effect of Environmental Change on Human Migration.” *Global Environmental Change* 21 (S1): S3–11

Black, R., S. R. G. Bennett, S. M. Thomas, and J. R. Beddington. 2011b. “Climate Change: Migration as Adaptation.” *Nature* 478 (7370): 447–49. doi:10.1038/478477a.

Brookings Institution, Georgetown University, and UNHCR. 2015. “Guidance On Protecting People From Disasters And Environmental Change Through Planned Relocation.” http://www.unhcr.org/protection/environment/562f798d9/planned-relocation-guidance-october-2015.html.

de Sherbinin, A., M. Castro, F. Gemenne, M. M. Cernea, S. Adamo, P. M. Fearnside, G. Krieger, S. Lahmani, A. Oliver-Smith, A. Pankhurst, and T. Scudder. 2011. “Preparing for Resettlement Associated with Climate Change.” *Science* 334 (6055): 456–457. doi:10.1126/science.1208821

DRC (Development Research Center). 2009. “Making Migration Work for Development.” Brighton, UK. http://www.migrationdrc.org/publications/misc/Making_Migration_Work_for_Development.pdf.

Dun, O. V., and F. Gemenne. 2008. “Defining ‘Environmental Migration.’” *Forced Migration Review* 31: 10–11.

Ellis, F. 2000. *Rural Livelihoods and Diversity in Developing Countries*. Oxford, UK: Oxford University Press.

Foresight. 2011. *Migration and Global Environmental Change: Final Project Report*. The Government Office for Science, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/287717/11-1116-migration-and-global-environmental-change.pdf.

Gemenne, F. 2011a. “How They Became the Human Face of Climate Change. The Emergence of ‘climate Refugees’ in the Public Debate, and the Policy Responses It Triggered.” In Migration and Climate Change, 225–60. Cambridge University Press.

———. 2011b. Why the numbers don’t add up. A review of estimates and predictions of people displaced by environmental changes. Global Environmental Change, 21, pp.S41-S49

Gemenne, F. and J. Blocher. 2017. “How Can Migration Serve Adaptation to Climate Change? Challenges to Fleshing out a Policy Ideal.” *The Geographical Journal*. Wiley Online Library.

Gemenne, F., and P. Brücker. 2015. “From the Guiding Principles on Internal Displacement to the Nansen Initiative: What the Governance of Environmental Migration Can Learn from the Governance of Internal Displacement.” *International Journal of Refugee Law* 27 (2): 245–63.

Gemenne, F., C. Zickgraf, and D. Ionesco. 2016. “The State of Environmental Migration 2016: A Review of 2015.” Liège, Belgium: Presses Universitaires de Liège.

Georgetown University, UNHCR, and IOM. 2017. “A Toolbox: Planning Relocations to Protect People from Disasters and Environmental Change.” http://www.unhcr.org/protection/environment/596f1bb47/planned-relocation-toolbox.html.

Groschl, J. and T. Steinwachs. 2016. “Do Natural Hazards Cause International Migration?” No. 6145 (October 2016). CESifo Economic Studies, Munich, Germany.

Hallegatte, S., M. Fay, M. Bangalore, T. Kane, J. Rozenberg, A. Vogt-Schilb, and U. Narloch. 2016. “Shock Waves: Managing the Impacts of Climate Change on Poverty.” Climate Change and Development. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/22787.

Hallegatte, S., A. Vogt-Schilb, M. Bangalore, and J. Rozenberg. 2017. “Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters.” Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/25335.

Hugo, G. 1996. “Environmental Concerns and International Migration.” *International Migration Review* 30 (1): 105–31.

Hunter, L.M., J.K. Luna, and R.M. Norton. 2015. “Environmental Dimensions of Migration.” *Annual Review of Sociology* 41: 377–97.

IDMC (Internal Displacement Monitoring Centre). 2014. “IDMC Global Estimates 2014: People Displaced by Disasters.” Geneva.

———. 2015. “Global Estimates 2015: People Displaced by Disasters.” Geneva. http://www.internal-displacement.org/assets/library/Media/201507-globalEstimates-2015/20150713-global-estimates-2015-en-v1.pdf.

———. 2017a. “Global Disaster Displacement Risk: A Baseline for Future Work.” Geneva.

———. 2017b. “Global Report on Internal Displacement-GRID 2017.” Geneva: IDMC and NRC (Norwegian Refugee Council). http://www.internal-displacement.org/global-report/grid2017/pdfs/2017-GRID.pdf.

IOM (International Organization for Migration). 2009. *Migration, Environment and Climate Change: Assessing the Evidence,* ed. F. Laczko and C. Aghazarm. Geneva.

———. 2014. Migration, Environment and Climate Change: Evidence for Policy (MECLEP): Glossary. Geneva. https://publications.iom.int/system/files/pdf/meclep_glossary_en.pdf.

IPCC (Intergovernmental Panel on Climate Change). 2014a. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, et al. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. https://www.ipcc.ch/report/ar5/.

———. 2014b. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Annex II: Glossary. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. https://www.ipcc.ch/report/ar5/

Jones, B., and B. C. O’Neill. 2013. “Historically Grounded Spatial Population Projections for the Continental United States.” Environmental Research Letters 8 (4): 44021. doi:10.1088/1748-9326/8/4/044021

Koubi, V., G. Spilker, L. Schaffer, and T. Bernauer. 2016. “Environmental Stressors and Migration: Evidence from Vietnam.” *World Development* 79: 197–210.

Martin, S. F. 2009. “Managing Environmentally Induced Migration.” In *Migration, Environment and Climate Change: Assessing the Evidence*, edited by Frank Laczko and Christine Aghazarm, 353–85. Geneva: International Organization for Migration.

———. 2010. “Climate Change, Migration and Governance.” *Global Governance* 16: 397–414.

———. 2012. “Environmental Change and Migration: Legal and Political Frameworks.” *Environment and Planning C: Government and Policy* 30 (6): 1045–60.

Martin, S. F., and J. Bergmann. 2017. “Environmental Change and Human Mobility: Reducing Vulnerability & Increasing Resilience.” KNOMAD Policy Brief, World Bank, Washington, DC. http://www.knomad.org/docs/environmental_change/Policy Brief 6_Environmental Change and Human Mobility_final.pdf.

Mauritsen, T., and R. Pincus. 2017. “Committed Warming Inferred from Observations.” *Nature Climate Change* 7 (9): 652–55. http://dx.doi.org/10.1038/nclimate3357.

McKenzie, D., and D. Yang. 2014. “Evidence on Policies to Increase the Development Impacts of International Migration.” KNOMAD Working Paper, World Bank, Washington, DC. http://www.knomad.org/docs/working_papers/KNOMAD Working Paper 2_McKenzie-Yang_12-19-2014.pdf.

McLeman, R. 2009. Climate change and adaptive human migration: lessons from rural North America. In *Adapting to Climate Change: Thresholds, Values, Governance*, ed. Adger, W.N., I. Lorenzoni, and K. O’Brien, 296–310. Cambridge, UK and New York, NY: Cambridge University Press.

———. 2016. “Migration as Adaptation: Conceptual Origins, Recent Developments, and Future Directions.” *In Migration, Risk Management and Climate Change: Evidence and Policy Responses* ed. A. Milan, B. Schraven, K. Warner, and N. Cascone. Dordrecht

McLeman, R., M`. Opatowski, B. Borova, and M. Walton-Roberts. 2016. “Environmental Migration and Displacement: What We Know and Don’t Know.” http://www.laurierenvironmentalmigration.com/wp-content/uploads/2015/11/WLU-Environmental-Migration-Background-Report.pdf.

Melde, S., F. Laczko, and F. Gemenne. 2017. “Making Mobility Work for Adaptation to Environmental Changes: Results from the MECLEP Global Research.” Geneva. https://publications.iom.int/system/files/pdf/meclep_comparative_report.pdf.

Milan, A., S. Melde, N. Cascone, M. Schindler, and K. Warner. 2015. “When Do Households Benefit from Migration?” Volume 1, Issue 8. Migration, Environment and Climate Change: Policy Brief Series. https://publications.iom.int/system/files/policy_brief_series_issue8_16june2016.pdf.

Montgomery, M. R. 2008. “The Urban Transformation of the Developing World.” *Science* 319 (5864): 761–64.

Myers, N. 1993. “Environmental Refugees in a Globally Warmed World.” *BioScience* 43 (11): 752–761.

———. 2002. Environmental Refugees: A Growing Phenomenon of the 21st Century. *Philosophical Transactions of the Royal Society B* 357 (1420), 609–613.

———. 2005. “Environmental Refugees: An Emergent Security Issue.” Presented at the 13th Economic Forum, Prague, 23–27 May.

Myers, N., and Kent, J. 1995. “Environmental Exodus: An Emergent Crisis in the Global Arena.” Climate Institute, Washington, DC.

Nansen Initiative. 2015. “Agenda for the Protection of Cross-Border Displaced Persons in the Context of Climate Change: Volume I.” Geneva. https://nanseninitiative.org/wp-content/uploads/2015/02/PROTECTION-AGENDA-VOLUME-1.pdf.

NASA (National Aeronautics and Space Administration). 2017. “Global Climate Change: Evidence.” https://climate.nasa.gov/evidence/.

Nawrotzki, R.J., F. Riosmena, and L.M. Hunter. 2013. “Do Rainfall Deficits Predict U.S.-Bound Migration from Rural Mexico? Evidence from the Mexican Census.” *Population Research and Policy Review* 32 (1): 129–58. doi:10.1007/s11113-012-9251-8.

Nawrotzki, R.J., and M. Bakhtsiyarava. 2017. “International Climate Migration: Evidence for the Climate Inhibitor Mechanism and the Agricultural Pathway.” *Population, Space and Place* 23 (4).

ND-GAIN. 2017. “Notre Dame Global Adaptation Index, Section Vulnerability, Data from 2015.” South Bend, IN. http://index.gain.org/ranking/vulnerability.

OCHA (United Nations Office for the Coordination of Humanitarian Affairs). 1998. *Guiding Principles on Internal Displacement.* New York and Geneva. http://www.internal-displacement.org/assets/publications/Tools-and-Frameworks/199808-training-OCHA-guiding-principles-Eng2.pdf.

Olsson, L., M. Opondo, P. Tschakert, A. Agrawal, S.H. Eriksen, S. Ma, L.N. Perch, and S.A. Zakieldeen, 2014. “Livelihoods and Poverty.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, 793–832. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Platform on Disaster Displacement. 2017. http://disasterdisplacement.org/

Raftery, Adrian E., Alec Zimmer, Dargan M. W. Frierson, Richard Startz, and Peiran Liu. 2017. “Less than 2°C Warming by 2100 Unlikely.” *Nature Climate Change* 7 (9). Nature Publishing Group: 637–41. http://dx.doi.org/10.1038/nclimate3352.

Renaud, F. G., J. J. Bogardi, O. Dun, and K. Warner. 2007. “Control, Adapt or Flee: How to Face Environmental Migration?” Interdisciplinary Security Connections’ Publication Series of UNU-EHS. Vol. 5. UNU-EHS, Bonn, Germany.

UNDESA (United Nations Department of Economic and Social Affairs). 2013. “Cross-National Comparisons of Internal Migration: An Update on Global Patterns and Trends.” Population Division Technical Paper No. 2013/1. New York. http://www.un.org/en/development/desa/population/publications/pdf/technical/TP2013-1.pdf.

———. 2015. *World Urbanization Prospects Final Report 2014 Revision.* New York. https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Report.pdf.

———. 2017. “World Population Prospects - Key Findings & Advance Tables - 2017 Revision.” New York. https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf.

UNDP (United Nations Development Programme). 2009. *Human Development Report 2009.* New York. http://hdr.undp.org/sites/default/files/reports/269/hdr_2009_en_complete.pdf.

UNEP (United Nations Environment Programme). 2016. “Loss and Damage: The Role of Ecosystem Services.” Nairobi, Kenya. http://collections.unu.edu/view/UNU:5614.

UNFCCC (United Nations Framework Convention on Climate Change). 2010. “Cancun Agreements: Cancun Adaptation Framework, Paragraphs 11-35, Decision 1.CP/16.” http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=4.

United Nations High Commissioner for Refugees (UNHCR), Office of the, Georgetown University and Brookings Institute. 2014. “Planned Relocations, Disasters and Climate Change: Consolidating Good Practices and Preparing for the Future.” Background Document: Sanremo Consultation, 12–14 March 2014. UNHCR. http://www.unhcr.org/53c4d6f99.pdf.

UNHCR (United Nations High Commissioner for Refugees). 2017. *Global Trends: Forced Displacement In 2016.* Geneva.

Waldinger, M. 2015. “The Effects of Climate Change on Internal and International Migration: Implications for Developing Countries.” Working Paper No. 217, Centre for Climate Change Economics and Policy, London.

Warner, K., W. Kälin, S. F. Martin, Y. Nassef, S. Lee, S. Melde, H. E. Chapuisa, M. Franck, and T. Afifi. 2014. “Integrating Human Mobility Issues within National Adaptation Plans” United Nat (2).

Warner, K., W. Kälin, S. F. Martin, and Y. Nassef. 2015. “National Adaptation Plans and Human Mobility.” *Forced Migration Review* 49: 8–9. http://www.fmreview.org/en/climatechange-disasters/warner-kaelin-martin-nassef.pdf.

Watts, N., W.N. Adger, S. Ayeb-Karlsson, Y. Bai, P. Byass, D. Campbell-Lendrum, T. Colbourn, P. Cox, M. Davies, M. Depledge, A. Depoux, P. Dominguez-Salas, P. Drummond, P. Ekins, A. Flahault, D. Grace, H. Graham, A. Haines, I. Hamilton, A. Johnson, I. Kelman, S. Kovats, L. Liang, M. Lott, R. Lowe, Y. Luo, G. Mace, M. Maslin, K. Morrissey, K. Murray, T. Neville, M. Nilsson, T. Oreszczyn, C. Parthemore, D. Pencheon, E. Robinson, S. Schuette, J. Schumake-Guillemot, P. Vineis, P. Wilkinson, N. Wheeler, B. Xu, J. Yang, Y. Yin, C. Yu, P. Gong, H. Montgomery, and A. Costello. 2017. “The Lancet Countdown: Tracking Progress on Health and Climate Change.” *The Lancet* 389 (10074). Elsevier: 1151–64. doi:10.1016/S0140-6736(16)32124-9.

World Bank. 2012. *Turn down the Heat: Why a 4°C Warmer World Must Be Avoided*. Washington, DC. http://documents.worldbank.org/curated/en/865571468149107611/Turn-down-the-heat-why-a-4-C-warmer-world-must-be-avoided.

———. 2014. “Turn Down the Heat: Confronting the New Climate Normal.” Washington, DC. https://openknowledge.worldbank.org/handle/10986/20595.

WRI (World Resources Institute). 2016. *World Risk Report 2016*. UNU-EHS and Bündnis Entwicklung Hilft.

Zickgraf, C. n.d. “Immobility.” In *Routledge Handbook on Environmental Displacement*, ed. F. Gemenne and R. McLeman. Routledge. http://hdl.handle.net/2268/194480.

Chapter 2

Understanding the Climate Change–Migration Nexus

There is growing realization among researchers, policy makers, and the wider public that the impacts of climate change will have a large effect on global migration patterns in the coming decades. Although there is no consensus on the current number of climate migrants, most research recognizes that the rate of climate migration is increasing and that growing climate risks in the coming decades will accelerate this trend. This chapter presents the state of play of migration trends, with a focus on the impacts of climate change on these patterns, and provides context for the modeling approach and the analysis done in this report.

Migration has important impacts on people, places, and development. It can enhance adaptive capacity under certain conditions, but it can also destroy livelihoods if not adequately planned for and managed (McLeman 2016). A rich body of literature describes the conditions and complexities underlying migration (including climate change-induced) and the impacts of climate migration (albeit to a lesser degree). Research on climate migration first emerged in the 1980s. Output rose to about 10 peer-reviewed publications a year in the 1990s and to more than 100 a year since 2008, including at least 447 empirical case studies, mostly on Africa, the Asia-Pacific region, and the American continent (Ionesco, Mokhnacheva, and Gemenne 2016).[5] The work carried out for this report builds on previous work.

This chapter overviews the scale of current internal migration, underlying causes, and its impacts.[6] Overlaying this information with expected climate trends, the chapter aims to draw attention to the change in the pace of climate migration and its future impacts. This context informs the modeling approach in Chapter 3, and the interpretation and narrative of the results in the subsequent chapters.

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[5] Ionesco, Mokhnacheva, and Gemenne (2016) draw on studies recorded in the Climig Database by the Institute of Geography University of Neuchâtel, Switzerland (https://www.unine.ch/geographie/climig_database), which includes research in several languages.

[6] The chapter also draws on background papers commissioned for this report, including McLeman (2016) and Hunter (2016).

TRENDS AND PATTERNS OF INTERNAL MIGRATION

Migration within countries generally entails people moving between administrative units within their country. The United Nations Development Programme (UNDP 2009) estimates that there were 740 million internal migrants globally at the turn of the millennium—three times the number of international migrants.[7] Bell and Charles-Edwards (2013) estimate that in 2005, 763 million people were internal migrants. It is likely that the estimates were conservative and the number is higher today. In China alone, some 150 million migrants from rural areas were living in urban areas in 2009 (Chan 2013). Data gaps and methodological issues make it hard to estimate the current level of internal migration worldwide.

Internal migration shows significant heterogeneity across and within countries (Bell and Charles-Edwards 2013). For example, internal migration intensities—the total number of internal migrants as a share of the overall population—have fallen in Latin America but increased in China and some African countries. Part of this heterogeneity may be definitional: The smaller the administrative unit considered, the higher the rates of internal migration, because smaller units capture more of the overall movement of people. In 1995–2000, for example, internal migration intensities were as low as 0.8 percent in Indonesia (in eight provinces) and as high as 20 percent in New Zealand (in 75 territorial authorities) (Bell and Charles-Edwards 2013).

A significant proportion of internal migrants will end up in major cities. Internal migration is a large contributor to urbanization (Tacoli and others 2014). The share of the population living in urban areas has risen in almost all countries. It averages 32 percent, 49 percent, and 78 percent, respectively, in least developed, less developed, and developed countries (PRB 2016; UNDESA 2014). About 40 percent of the urban growth rate in low and middle income countries is related to migration (Montgomery 2008), although the pattern is not uniform across countries: Migration represents less than one-third of urban population growth in Sub-Saharan Africa but far more in Asia (Tacoli and others 2014).

This report focuses on internal climate migration but underlines that all forms of movements induced by climate change need to be considered and addressed holistically. For context, Box 2.1 on the next page briefly outlines patterns of international movements of people and linkages with climate change.

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[7] This estimate is conservative, based on census data and counting only movements across the largest administrative units in a country (usually states or provinces). Calculation of the number of internal migrants used census data from a sample of 24 countries covering 57 percent of the world's population. It applied the regional patterns found in these data to estimate the number of about 740 million internal migrants in the world.

Box 2.1: Cross-border migration and its linkages with climate change

About nine million people a year migrate between countries (Abel and Sander 2014), and about 244–250 million people live outside their country of birth (UNDESA 2015; World Bank 2017a). Although absolute numbers are higher today than in the past, international migration has not changed greatly in percentage terms since 1990 (Abel and Sander 2014).

South–South migration accounts for more than 90 million migrants between countries in the global South, closely followed by South–North routes with about 85 million migrants (IOM 2015). A majority of international migration is to areas of economic opportunities: More than 60 percent of international migrants (150 million people) are classified as migrant workers (ILO 2015). Family relations, social networks, and many other factors also influence the motivations and direction of international migration.

Similar to internal climate migration, there is no single straight line from climate change impacts to international migration, and the economic, political, and social obstacles to such movement are often considerable (e.g., Czaika and de Haas 2013; Foresight 2011). Results from a systematic review of the small but growing body of peer-reviewed literature on the subject show that climate change may increase international migration, especially as it plays out through impacts on natural resource-based livelihoods. Yet it can also inhibit cross-border movements (Obokata, Veronis, and McLeman 2014). Nawrotzki and Bakhtsiyarava (2017), for example, find that excessive rain increases international migration from Senegal but that heat waves decrease it from Burkina Faso.

While current numbers of international climate migration are probably not large (Obokata, Veronis, and McLeman 2014), it is unclear what the future of international climate migration will look like. Cross-border movements provide opportunities for people affected by climate impacts but can also entail challenges (such as for health systems, see Watts and others 2017), especially when movements are large or rapid, or border spaces are sensitive (Foresight 2011). For example, competition over scarce resources in receiving areas can create tensions (Schleussner and others 2016; United Nations and World Bank 2017). Reuveny's (2007) meta-review of 38 cases of migration induced by environmental change finds that factors influencing conflict included competition over resources, with ethnic tensions and distrust acting as exacerbating factors. Environmental changes can intensify tensions in regions where population growth and pressure on natural resources will increase competition between migrants and existing populations over access to arable land, water, and pasture (Marc and others 2015).

This highlights the need to take a holistic policy and planning approach that considers all forms of mobility in the context of climate change. Cross-border approaches integrated in anticipatory planning mechanisms can help. This includes preparing cross-border areas through tailored strategies to minimize risks (Warnecke, Tänzler, and Vollmer 2010). Participatory and inclusive resource management mechanisms can also reduce the potential for additional environmental stress (Martin 2005).

THEORIES AND DRIVERS OF MIGRATION

Theories of migration provide complementary insights into a complex decision-making process. This section focuses on three schools of thought—classical economic approaches, push-pull theories, and the New Economics of Labor Migration—to illustrate the factors involved when people decide to migrate (see Massey and others 1993 for a good overview of other theories).

Most of the migration literature since the 1950s has been based on classical macroeconomic and microeconomic theories. Migrants are assumed to be opportunity-seekers who weigh the financial costs and benefits of potential destinations and make rational decisions based on the information available to them (see, for example, Todaro 1969, 1980). Classical economic approaches assume that migration typically flows from low-wage to high-wage labor markets and from low-opportunity to high-opportunity locales.

Other factors also affect decisions to migrate and the capability to carry them out. People seldom have perfect information. They are rational actors only to a degree, and decisions are not necessarily made just by the individual. The poorest people often have insufficient capabilities to access high-wage or high-opportunity markets.

Going beyond the idea of individual cost-benefit analysis, the influential push-pull theory suggests that four factors shape migration: factors in the sending area, factors in the destination areas, “intervening” facilitators and obstacles, and personal factors (Lee 1966). Push factors (such as poverty, lack of opportunities, and migration networks) are associated with source areas. Pull factors (such as jobs, social services, family members, and social networks) are related to destination areas. The push-and-pull framework suggests that individual characteristics of affected populations have an important influence on migration decisions. Personal factors include age, gender, and ethnicity (Lee 1966; Geddes and others 2012; De Jong and Gardner 2013; Zickgraf and others 2016). Migration studies suggest, for instance, that younger people are more mobile (Hatton and Williamson 2005). Ethnicity, wealth, and gender all affect migration outcomes within populations similarly affected by climate change (Adger and others 2014).

Push-pull theories also show that people are rarely able to migrate wherever they wish. Movements can be restricted by natural geographic features (such as rivers and mountains) but also by entry requirements, travel costs, and sometimes physical obstacles (such as fences), particularly for international destinations or movement over long distances (Czaika and de Haas 2013). Barriers to internal migration also exist. For instance, concerns over loss of property rights in destination areas and other bureaucratic constraints prevent many individuals who would benefit from moving from doing so (Waldinger 2015). Tight financial resources and the paucity of information also limit potential migration, as does access to social networks to draw on for support (Palloni and others 2001).

Push-pull theories help explain why large urban areas, with their greater range of economic opportunities and better services, are often preferred destinations for migrants from rural areas and smaller towns and villages. They also show that alongside factors in sending and receiving areas, intervening and personal factors are important.

The New Economics of Labor Migration (NELM) suggests that not all migration decisions can be explained by individuals who weigh economic opportunities or are pushed from origin and pulled toward destination areas. Through surveys, it has demonstrated that migration decisions are often part of a household’s collective strategy to diversify its income sources and reduce its exposure to hardships and risks (e.g. Stark and Bloom 1985). In some dryland regions of West Africa, for example, households send young adults to cities to seek wages in the dry season to reduce the number of mouths to feed and benefit from remittances (Rain 1999). Household members may also migrate indefinitely, on the understanding that the migrants will repay the costs and absence from the household workforce by remitting money home (Mazzucato 2011). NELM emphasizes the importance of larger households in migration decision making and shows that migration may be related to risk reduction and livelihood diversification as much as economic opportunity-seeking. All these factors are important in understanding migration in the context of climate change, which is often understood to be a livelihood, coping, risk management, or adaptation strategy by households (Adger and others 2014).

These theories of migration mostly focus on more voluntary instances of movements, but mobility occurs on a continuum, from voluntary to forced migration and displacement (Hugo 1996). While not within the modeling scope of this report, Box 2.2 provides context on the dynamics of disaster displacement.

Box 2.2: Spotlight on disaster displacement

For people displaced by extreme events or conflict, both staying and leaving carry high risks; either choice may threaten survival (World Bank 2017a). Displacement can be said to be a function of the likelihood, severity, and nature of the hazard; the exposure of people; and preexisting vulnerabilities (IDMC 2015). It tends to emphasize “push” more than “pull” factors: People make decisions, often quickly and under duress, based on what they perceive to be the optimal coping strategy at a particular time. Violence is the strongest correlate of decisions to flee (World Bank 2017a).

Different types of climate-related hazards tend to generate different types of mobility. Key factors are the speed of onset of a climate hazard and the ability of the people affected to perceive the risk and adapt in anticipatory fashion (Renaud and others 2011). Rapid-onset events, such as extreme storms and floods, usually result in short-term displacement (followed by return to affected areas) (Kälin 2010; Brzoska and Fröhlich 2015; Black and others 2011). Such events also tend to generate migration “churn”—a mix of shorter- and longer-term displacement and out-migration and, potentially, sudden influxes of migrants from unaffected areas, such as reconstruction workers (De Waard, Curtis, and Fussell 2016). By contrast, slow-onset events, such as droughts, tend not to generate immediate changes in migration patterns, at least not initially (McLeman 2014). Drought-related changes in migration patterns, for instance, are more likely to emerge in areas where land degradation is severe (Neumann and Hilderink 2015) or drought is less common, such as Bangladesh (Gray and Mueller 2012a). Longer-term trends in crop yields or water availability are likely to contribute to out-migration (Nawrotzki and others 2017; Bohra-Mishra, Oppenheimer and Hsiang 2014). That said, the impact of successive climate shocks may erode household assets and therefore adaptive capacity in ways that can eventually influence decisions to migrate (IDMC 2016; Warner and others 2012), or even trap people in place (Black, Kniveton, and Schmidt-Verkerk 2013).

Displacement as a result of extreme and rapid-onset events, such as floods and storms, fluctuates from year to year but continues to be high. Between 2008 and 2015, the Internal Displacement Monitoring Center (IDMC) recorded an annual average of 26.2 million displacements caused by natural disasters. In 2015, about 19.2 million people in 113 countries were displaced by disasters caused by rapid-onset extreme events such as floods (8.3 million) and storms (6.3 million)—twice the number caused by conflict and violence. In 2016, that number was 24.2 million, with South and East Asia most affected (IDMC 2017).

According to the IDMC, disaster displacement has consistently affected poorer countries the most; low and middle income countries account for 95 percent of the global total. Smaller territories, such as Small Island Developing States (SIDS), suffer disproportionately. SIDS as diverse as Fiji and Tonga in the Pacific and Belize, Cuba, and Haiti in the Caribbean were among the 10 countries with the largest disaster displacements relative to population (IDMC 2014, 2016, 2017).

Many poor people have limited resources to confront disasters, and their livelihoods depend directly on increasingly threatened ecosystem goods and services (Hallegatte and others 2017). As a result, the poorest often bear climate impacts disproportionately (World Bank 2012a), with their well-being losses (equivalent to consumption) more than twice as large as the world’s average (Hallegatte and others 2017). The needs of displaced people are often far more pressing than those of other migrants, stemming from their lack of land, jobs, and homes; marginalization; food insecurity; and higher morbidity and mortality.

Disasters through rapid-onset events already displace large numbers of people, and the numbers are expected to rise as such events become more frequent and severe because of climate change (Adger and others 2014; IDMC 2015, 2017). The impacts of disaster displacement will be added to those of climate migration. Although people often wish to return to their homes after a time, some remain in protracted situations for years or become displaced several times (IDMC 2017), underscoring the fact that all forms of mobility in the context of climate change require concerted and comprehensive planning and action.

Photo Credit: Shutterstock

CLIMATE CHANGE AS A DRIVER OF MIGRATION

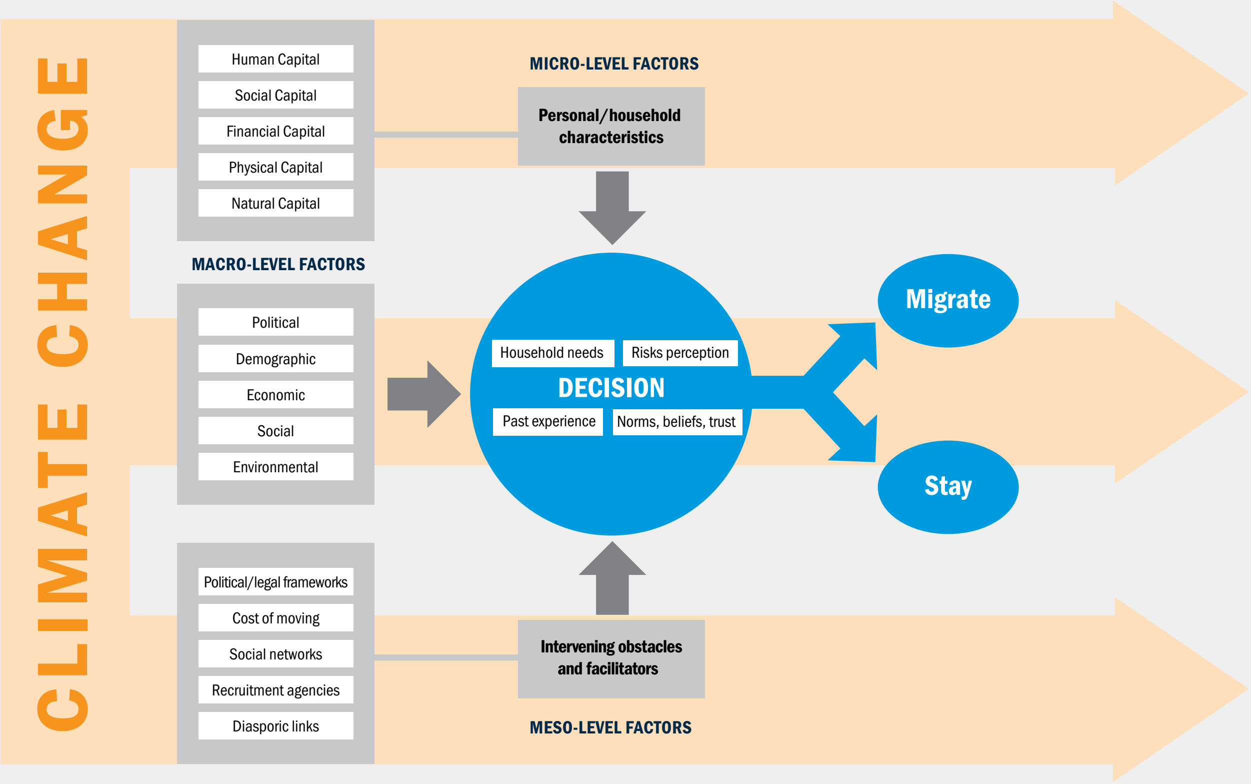
The decision to migrate is complex. The influencing factors change over time and vary across individuals and their larger households. Climate change adds complexity to the already difficult decision to stay in or leave one's home. Understanding of four elements—the impacts of climate change on resource quality and availability; the implications for livelihood strategies in particular ecological regions; the role migration plays in supporting livelihoods; and how migration patterns may shift as people attempt to adapt to the changes they experience—is necessary. This section explores the ways in which climate change shapes livelihood activities, including migration decisions.

The Foresight Report (2011) developed a framework of climate migration that builds on theories and empirical studies on migration. It emphasizes that climate change influences migration decisions through existing migration drivers, especially economic, environmental, and to some extent political drivers—by, for instance, depressing rural wages, raising agricultural prices, shaping exposure to hazards, and stressing ecosystems. The framework conceptualizes environmental change as affecting macro, meso (intermediate) and micro levels of migration choices and capabilities. Macro-level influences are beyond the control of individuals, households, or communities but have ongoing direct effects on livelihoods, incomes, and well-being; they shape migration possibilities and opportunities. Macro-level factors include demographic (for example, the size of the population and the rate of growth); economic (for example, labor markets and commodity prices); political (for example, laws and conflict); social (for example, gender relations); and environmental variables. At the meso level, intervening facilitators and obstacles include employment agencies or migrant-smuggling networks. Micro-level factors include characteristics of individuals and households (for example, health, skills, and perceptions of risks). The migration decision is not a simple binary choice, but is also based on behavioral elements (Martin and others 2014). Such elements include the household's perceptions of its vulnerability to climate change–related risks, its assessment of its future needs, household members' beliefs and norms, and their experience (if any) of migration.

People can decide to migrate as a livelihood strategy when climate change affects overarching variables such as the economy, environment, and political system they live in. Climate change has the most direct impact on macro-level factors, especially through economic channels, but affects variables at all three levels. It can act as a push or pull factor by altering the relative attractiveness of locations. It can also affect inhibitors or facilitators of migration and the accessibility of places, or influence the livelihood capital of individuals and households.

Livelihoods depend on access to capital of various types, the quantities and qualities of which vary by geographic region and livelihood system. Scoones (1998) identifies the following forms of livelihood capital: natural (ecological goods and services); economic or financial; human (skills, knowledge, physical health and abilities); and social (benefits and opportunities that arise through social relationships). Climate change can affect livelihoods directly and indirectly, sometimes concurrently. Although the direct physical impacts of climate change may be the most visible, the less visible indirect effects can be just as pernicious (Gemenne, 2011). In Figure 2.1 the impacts of climate change represented by the orange arrows are not uniform across space or over time.

Figure 2.1: Foresight model adapted to illustrate climate change, livelihoods, and household migration behaviour



Source: Extended and adapted from Foresight (2011) and McLeman (2016)

CLIMATE CHANGE IMPACTS ON LIVELIHOODS AND MIGRATION PATTERNS THROUGH 2050

Building on the framework in Figure 2.1, this section highlights climate changes that are likely to have large impacts on livelihoods and migration patterns through 2050. The data draw on the IPCC Working Group I and II contribution to the Fifth Assessment Report and on peer-reviewed literature.

Climate change will influence migration through warming and drought, which will affect agricultural production and access to water; rising sea level, which makes coastal areas and island states uninhabitable; the increasing intensity and frequency of natural disasters; and competition over natural resources, which may contribute to drivers of conflict. The first three points are discussed in Box 2.3 below, and Box 2.4 reviews the climate change-conflict-migration nexus.

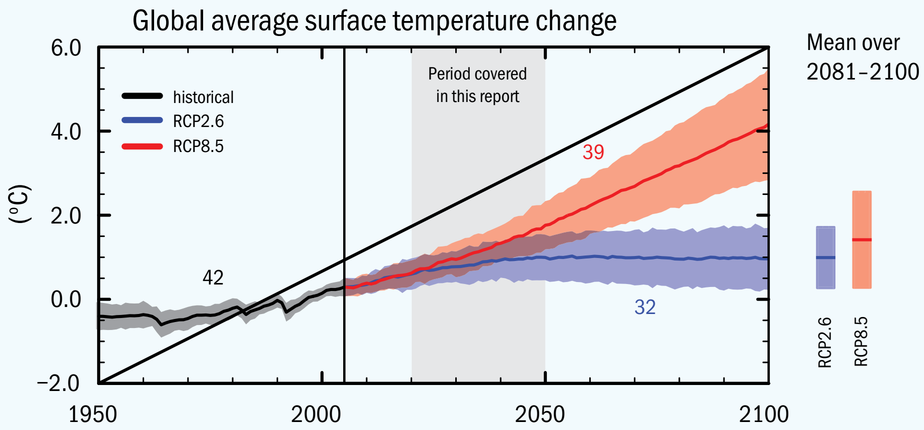
Box 2.3: How does climate change affect people and their livelihoods?

Four aspects of climate change affecting people and their livelihoods are reviewed here: temperature, water availability, sea level rise, and extreme events.

Temperature

By 2050, average global temperatures are expected to increase by between 0.3°C (the lower boundary [RCP2.6]) and 2.5°C (the upper boundary [RCP8.5]). Additional increases for the remainder of the century are projected to range from 0.3°C to 4.8°C, depending on future emissions (Box Figure B2.3.1).

Figure B2.3.1 Past and projected global average surface temperature change above the 1986–2005 baseline



Source: Adapted from IPCC (2013a).
Note: See Chapter 3 for explanation of the Representative Concentration Pathways (RCPs), which are trajectories of greenhouse gas concentrations resulting from human activity, and modeling input of RCPs used in this report from 2020-50. The numbers of CMIP5 models used to calculate the multi-model mean is indicated.

Extreme heat events are occurring more frequently. Unusual and unprecedented heat extremes affect livelihoods primarily through their effect on agricultural yields and food security. Significant crop yield impacts are already being felt; if temperatures rise toward 4°C higher than the 1986–2005 baseline, climate change will add further pressure on agricultural systems. Crop yield decreases associated with a 2°C increase in temperatures relative to that baseline are expected to be as large as 50 percent in Central America and the Caribbean. Ecosystem shifts are projected with increasing temperatures. When coupled with changes in precipitation patterns, they greatly diminish ecosystem services. Substantial adverse effects on marine ecosystems and their productivity are also expected with rising temperatures, increases in ocean acidity, and likely reductions in available oxygen as a result of their combined effects. With increased warming by 2050, and without taking into account changes in ocean acidity, fishery catches in several locations are projected to decrease markedly as fish populations migrate toward cooler waters.

Water availability

Freshwater resources are at risk from climate change in several regions. The impact of climate change on freshwater resources is felt through changes in rainfall patterns, increasing temperatures, and increased evapotranspiration (Abtew and Melesse 2013). In Central America, some central parts of South America, and southern central Asia, overall surface water availability is, with relatively high confidence, projected to decline substantially (Schewe and others 2014). A risk of decreasing water availability also exists, albeit with somewhat lower confidence, for Central and Southern Africa. Models also project increased water availability for India and the Horn of Africa, but with lower confidence. In many of these regions, population growth and rising incomes will have a greater impact on water resource availability than climate change; the two factors may yield declining per capita supplies of water even in areas projected to have higher rainfall (World Bank 2016).

Box 2.3: How does climate change affect people and their livelihoods? *continued*

Regions that are already dry can expect to become dryer and experience greater frequency or intensity of extreme heat events (Trenberth and others 2014). This pattern is likely to affect Ethiopia and Mexico, which have extensive drylands (see Chapter 5). Climate change is likely to undermine food security through decreased crop yields and increasing risk of crop failure caused by drought.

Climate change is also diminishing winter snowpack and leading to the retreat of glaciers. Snowpack and glaciers act as buffers between precipitation and runoff. Their retreat will affect the magnitude and shift the seasonality of river discharge in some of the most populous river basins on earth (Arnell and Gosling 2013; Bozkurt and Sen 2013). Major rivers such as the Ganges, Indus, and Brahmaputra are highly susceptible to glacier melt and reductions in snowfall, but are also densely populated (World Bank 2013). These three river basins provide water to about 750 million people, indicating immense climate vulnerability in these areas (Immerzeel, Van Beek, and Bierkens 2010). Already a substantial loss of glacier volume and extent has been observed in the Andes and Central Asia. Since the 1960s, the surface area of Central Asian glaciers has fallen by 3–14 percent, depending on location; losses of about 50 percent and up to 80 percent are projected, respectively, for a world 2°C and 4°C warmer than the 1986–2005 baseline (World Bank 2014). Increasing glacial melt poses a high risk of flooding, severely reduces freshwater resources during crop-growing seasons, and can have a negative impact on hydropower supply.

Sea level rise

Changes in sea level—currently averaging three millimeters a year and increasing (IPCC 2013b; Hay and others 2015; Dieng and others 2017)—will be the most problematic for settlements on very low-lying land (within one meter of sea level), especially areas that experience subsidence, erosion, or tropical cyclones and extreme storm events. Sea level rise can salinize groundwater and surface freshwater bodies. It can also increase salt-water intrusion into freshwater aquifers (particularly in the Middle East and North Africa), a process made worse by other climate impacts (such as reduced water availability). Together, these impacts present substantial problems to agriculture and human consumption.

Sea level rise poses a particular threat to large urban settlements and major infrastructure along the coast, particularly in Small Island Developing States (SIDS), where the ability to retreat to higher ground is limited. Rising sea level will greatly increase risks from storm surges and tropical cyclones, in particular for highly exposed SIDS and low-lying coastal zones. In the country examples in Chapter 5, large areas of Bangladesh are vulnerable.

Extreme events

All populations should expect increasing variability in climatic norms and conditions and be prepared for abrupt, nonlinear changes (Streets and Glantz 2000; Schneider 2004). Areas that already experience extreme storm events, especially in mid-latitudes and the wet tropics, should expect to experience as great or greater frequencies of such events, with the potential for more high-intensity events through 2050 (IPCC 2013b). The intensity of extreme storms is likely to increase, creating greater risks of flooding and damage to homes and coastal infrastructure (Chan and others 2012). The greater prevalence of extreme events will affect rural and urban communities, particularly on sloping lands and in coastal regions. Bangladesh falls into this category. SIDS face some of the highest levels of exposure and vulnerability to extreme storm events (World Bank 2013).

This report models climate impacts on internal migration through water availability and crop productivity, as well as sea level and storm surge. The literature shows that water scarcity and declining yields, along with sea level rise, are among the major impacts facing low income countries, and that these impacts will be important drivers of migration (see Henry, Schoumaker, and Beauchemin 2004; Feng, Krueger, and Oppenheimer 2010; Nawrotzki, Riosmena, and Hunter 2013; and Chapter 3). Water deficits can also have wider impacts on the economy, as households curtail spending and agricultural-processing industries and other businesses retrench. There is less evidence of what may happen to regions that experience increases in rainfall over time. Households may send one or more members to cities or other rural areas in search of an alternative livelihood, or they may abandon farming or other rural livelihoods altogether, as has happened in rapidly urbanizing countries such as China. The literature suggests that extremes are more likely to result in short-term displacement than sustained migration (Kälin 2010; Black and others 2011; Brzoska and Fröhlich 2015).

Box 2.4: The climate–conflict–migration nexus

The review of the empirical evidence in the latest IPCC report concludes that climate change can affect known drivers of conflict, such as unstable institutions, but finds little agreement on direct causal pathways or a strong relationship with armed conflict (Adger and others 2014). There is some agreement that existing patterns of conflict could be reinforced under climate change—in, for example, already fragile regions or areas with ethnical divides (Schleussner and others 2016; Buhaug 2016). Major security actors such as the U.S. Department of Defense (2015) have tended to frame climate change as a “threat multiplier,” which can exacerbate existing risks. Nonetheless, the world’s development and sustainability trajectory significantly influences how climate will influence conflict drivers and risks (Hegre and others 2016).

Conflict is both a process and an inherent feature of human interaction, with a raft of expressions, stages, locations, arenas, and impacts (Galtung 2008). However, its emergence and evolution are always “the result of an individual context-specific mixture of interconnected factors,” (Schleussner and others 2016, 9216). Climate change is hypothesized to drive or exacerbate conflicts through, for example, pressure on resources, natural disasters, and sea level rise. These factors can threaten livelihoods, increase competition, intensify cleavages, reduce state capability and legitimacy, trigger poorly designed climate action with unintended consequences, and lead to large movements of people that may have negative impacts in receiving areas (Buhaug, Gleditsch, and Thiesen 2010).

Some qualitative studies examine the influence of environmental stress on specific conflicts, such as insurgencies in Assam in India (Burrows and Kinney 2016; Homer-Dixon 2010). Cross-case quantitative studies find significant statistical correlations between climate change and violence or conflict (Burke, Hsiang, and Miguel 2015; Carleton, Hsiang, and Burke 2016; Mares and Moffett 2016). They posit that if human responses to climate change remain unchanged, climate change has the potential to increase violence and conflict.

This large-scale quantitative work has received criticism with respect to the definition of conflict, sample selection, statistical methods, and lack of explanation of causal mechanisms at work (Buhaug and others 2014; Buhaug 2010, 2014; Selby 2014). Other empirical work and quantitative analyses challenge their findings (Buhaug 2010; O’Loughlin and others 2012; Bergholt and Lujala 2012; Slettebak 2012; Klomp and Bulte 2013; Bernauer, Böhmelt, and Koubi 2012). These analyses argue that adaptation capacity, institutions, and existing vulnerabilities mediate the effects of climate change on factors that may drive conflict, and that other factors than environmental ones are often more important in igniting conflict.

For climate impacts and their influence on migration, understanding uncertainty, variability, thresholds and “tipping points” is key. Most regions will become hotter and drier. There is uncertainty as to the specific manifestations of climate change, however, partly because natural variability will remain the dominant factor in observed climate trends in the near term and partly because the period through 2050 represents a transition during which anthropogenic changes to the atmosphere become a more dominant influence on climate systems (IPCC 2013b). The spatial and temporal variability of the impacts of climate change make it difficult to have precise predictions of the frequency or extent to which specific areas, countries, or regions will experience particular climate risks or hazards. Chapter 3 explains how this uncertainty affects the modeling effort.

A tipping point is a particular moment at which a component of the earth's system enters into a qualitatively different mode of operation, as a result of a small perturbation (Levermann and others. 2012; Schellnhuber 2009). Abrupt climate change occurs when the system crosses this tipping point, triggering a transition to a new state at a faster rate (Michaelowa 2002). Tipping points exist because of nonlinearity—the fact that there is no simple proportional relationship between cause and effect (IPCC 2013b). Systems such as the Arctic summer sea ice, the Greenland ice sheet, the El Niño-Southern Oscillation, and the Amazon rainforest may reach their tipping points at different times (Lenton and others 2008; World Bank 2013). For instance, in about 50 years, the tipping point for the Amazon rainforest may be triggered by changing precipitation and dry seasonal length that would make it difficult for the rainforest to reestablish itself, resulting in substantial biodiversity loss and further decreases in rainfall (Lenton and others 2008). This report's modeling cannot capture such relationships. Their existence may rapidly affect the scale of climate migration after a system reaches a tipping point. An indication of the approach of a tipping point, or rapid movement toward an observed change in climate, livelihood, or climate migration trend, underscores the urgency to scale up climate change mitigation and adaptation efforts now.

Independently of uncertainties associated with climate change projections, and potential future tipping points, evidence shows that climate migration is already taking place (Ionesco, Gemenne, and Zickgraf 2015). There is also consensus that the future may see the emergence of areas where combinations of exposure, sensitivity, and adaptive capacity put whole communities at risk (de Sherbinin 2014). People have moved and will continue to move toward zones of environmental risk, such as coastal cities (de Sherbinin and others 2012; Geddes and others 2012). Changed climate patterns will expand patterns of cyclical, seasonal, and rural-to-urban migration (Ammer and others 2016). The largest form of movement will be internal; when people cross borders, most will move to neighboring countries, often from one low-income country to another (Foresight 2011; McLeman and others 2016; Groschl and Steinwachs 2016). Table 2.1 presents the findings of a systematic review of 160 peer-reviewed publications on climate migration.

Table 2.1: Summary of research findings on the interconnectivity between climate change, livelihoods and migration

Finding	Characteristics/implications	Strength* of evidence
Migration is a key component of sustainable livelihoods and household adaptive capacity in low and middle income countries	Migration is one of many possible ways in which households adapt to and cope with climatic and nonclimatic risks/ uncertainty. In countries with weak institutions, migration may be the only form of adaptation available. Households that lack migration options are inherently more vulnerable and less adaptable to the impacts of climatic variability and change.	Broad base of evidence from wide range of empirical studies in multiple regions
Reliance on migration to meet rural livelihood needs is growing	Growing reliance on migration is a common trend across less developed countries. Seasonal migration is common in regions with highly seasonal climates. Migration for longer durations is becoming increasingly common. Most migrants are young adults.	Broad base of evidence from wide range of empirical studies in multiple regions
Most climate-related migration takes place across short distances within countries or across contiguous borders	Local migration has relatively low costs. The destination may be urban or rural, depending on wage-earning opportunities.	Broad base of evidence from wide range of empirical studies in multiple regions

Finding	Characteristics/implications	Strength* of evidence
Households that receive remittances from migrants have greater long-term social and economic prospects	Remittances from international migrants are typically of greater value than remittances received from internal migrants. Within communities, remittances increase socioeconomic inequality. Remittances can help improve prospects for disaster recovery and to some extent for preparedness and adaptation, but the overall contribution to building climate resiliency is uncertain.	🟩 Broad base of evidence from wide range of empirical studies in multiple regions
Rural to urban migration rates are high and growing	Rural to urban migration rates are growing especially rapidly in Sub-Saharan Africa, although that region is less urbanized than others.	🟩 Conclusive statistical evidence
Households that participate in rural to urban resource-sharing networks have greater food security	Such networks are likely to grow in importance as impacts of climate change on food production systems strengthen. Households lacking access to such networks are more vulnerable.	🟩 Strong empirical evidence from Sub-Saharan Africa and South America
Migration is a key means of recovering from extreme weather events, including floods and droughts	After an extreme event, households send young adults to seek wage labor opportunities to rebuild lost/damaged housing and livelihood assets. The duration and destination of migration vary by context.	🟩 Strong empirical evidence from Central America, East Africa, and South and Southeast Asia
People in remote areas have worse migration opportunities and adaptation prospects	Remoteness and isolation are important factors in the vulnerability of mountain populations and some dryland areas. People living in areas with good access to roads, markets, and social infrastructure have a greater range of adaptation options and potential migration destinations.	🟨 Strong empirical evidence from dryland areas of Africa, the Andes, and Nepal
Gender dimensions can change over time, but have important implications for climate migration	Where only men migrate, women, children, people with disabilities, and the elderly left behind are at greater risk of food insecurity and personal safety. Land degradation and climatic variability can force higher levels of gendered migration or longer-duration migration. Gender dimensions can change over time.	🟨 Case study evidence from Bangladesh, Nepal, and Pakistan; more research needed in other countries and regions
Empirical research shows persuasively that climate resilience must be built urgently given the known risks, but there remains uncertainty about which strategies hold the greatest promise and how to implement them	The impacts of extreme heat, dryness, and variability in precipitation on regional migration patterns will grow through 2050 but can be moderated by sound development strategies. Climate impacts on food systems, water resources, and livelihoods accelerate in nonlinear fashion after 2050, as will the risks of large-scale displacements and distress migration. Business as usual will fall far short of meeting future adaptation needs.	🟨 Climate model evidence increasingly strong Models of future crop yields vary but decline for several crops Systems understandings of general climate–migration dynamics are increasingly strong, with strong agreement across the research literature Further empirical research on resilience-building needed across most regions

Source: McLeman (2016).

* Green = strong evidence few uncertainties. Yellow = reasonably strong evidence, uncertainties in some regions or areas.

POSSIBLE INFLUENCES OF CLIMATE IMPACTS ON MIGRATION IN SPECIFIC ECOSYSTEMS

This section explores what the literature says about possible future climate migration for key ecosystems. The findings are based on a systematic review of the literature conducted in a background paper for this report (McLeman 2016).

Migration patterns will change across ecosystems when facing climate change impacts alongside other stressors such as deforestation, land degradation, and biodiversity loss. In drylands, labor migration and rural to urban migration can be expected to increase, and extreme events will probably lead to more migration under distress. In tropical and temperate forest regions, churning migration patterns in forest frontier areas are likely, as are growing rates of young adult labor migration out of more established farming areas. In coastal zones, by midcentury there may be increased rates of rural to urban migration, temporary and indefinite, as well as displacement from smaller atolls and the seaward edge of deltas as a result of erosion and salinization. For montane regions, though case-dependent, further increases in already high rates of rural to urban migration and to international destinations are projected. Smallholder cropping regions can expect increased rates of rural to urban migration across all regions, both temporary and indefinite (Table 2.2).

Table 2.2: Overview of climate change and macro trends on livelihoods in key ecosystems, and possible migration trends by 2050

Main climatic influences on migration by ecosystem type	Other macro trends	Impact on livelihoods	Possible migration trends	Strength* of evidence
Drylands				
Extreme heat events, droughts, dryness, and precipitation variability	Growing intensification and market-orientation of agriculture Land degradation, water scarcity, and depletion of soil nutrients Increasing enclosures and land grabs	Pastoralism declines Specialized livestock pasturing increases Average farm size shrinks Small-scale farms lack capital to intensify Outside interests acquire farms on best, most accessible land	Labor migration increases Rural to urban migration increases Extreme events increase distress migration	Very strong case-based evidence from range of Sub-Saharan African countries Smaller range of studies for dryland migration in other regions
Tropical and temperate forest regions				
Increased extreme heat events and precipitation variability, which may increase fires and adversely affect forest health	High rates of deforestation in the Americas, Central Africa, and Southeast Asia Loss of biodiversity Land degradation Smallholder farmers are key drivers of forest change in Africa Commercial enterprises are key drivers of forest change in Americas and Asia	Indigenous and customary forest users squeezed out Small farms created, bought, and sold in dynamic process Larger, intensive farm operators acquire best lands	Churning migration patterns appear in forest frontier areas Rates of young adult labor migration out of more established farming areas increase	Strong case-based evidence of migration processes in Americas and Southeast Asia More evidence from Africa desirable Considerable variability in expected impacts of climate change across regions

Main climatic influences on migration by ecosystem type	Other macro trends	Impact on livelihoods	Possible migration trends	Strength* of evidence
Coastal zones				
Sea level rise and increased intensity of storms, causing floods, erosion, soil salinization, aquifer salinization; warming ocean temperatures, affecting reef health; possible increased variability of precipitation	Rapid urbanization and industrial development in deltaic regions of Asia Loss of protective features (mangroves, marshes) Expanding aquaculture across coastal Asia Declining offshore fish stocks	Economic opportunity increasingly urban based Small-scale fishing declines in many regions Coastal farms under increasingly intensive cultivation Some farms in Southeast Asia converted to shrimp aquaculture	Rates of rural to urban migration, temporary and indefinite, increase Displacement from smaller atolls and seaward edge of deltas occurs, as a result of erosion and salinization	Strong statistical and case-based evidence for coastal states in Asia and Oceania; fewer data and cases for Africa
Montane regions				
Increased precipitation variability and warming temperatures, leading to growing seasonal and interannual water scarcity; flash floods and landslides of increasing magnitudes; effects vary widely across regions because of inherent heterogeneity of mountain environments	Reinforced endemic poverty through remoteness, lack of physical and social infrastructure Deforestation problematic around many mountain settlements	Pastoralism declines, but larger numbers of livestock are kept by less mobile farmers Subsistence farmers lack food security Livelihoods become highly diversified Seasonal and longer-term migration becomes essential to livelihoods	Further increases in already high rates of rural to urban migration occur within mountain countries and to international destinations	Strong case-based evidence from Ecuador, India, Nepal, Pakistan, and Peru Statistical evidence on migration weak for Nepal Strong confidence in region-wide predictions, but local experience will vary considerably
Smallholder cropping regions				
Increased frequency of extreme heat events, dryness, droughts in most regions; more intense extreme precipitation events in some regions; greater variability of precipitation in some regions; water scarcity in some regions	Global and regional population growth drives growing food demand Greater pressure for intensification of production in all regions, especially Africa and South Asia, where yield gaps are greatest	Small-scale farmers, pastoralists increasingly squeezed off best land Need to intensify production increases need for cash incomes, capital to invest in new technologies, crop varieties, irrigation Some areas in Asia under irrigation may need to revert to rainfed agriculture, reducing household incomes Productivity in some regions and of some crops may decline, rates to vary by region and crop type	Rural to urban migration temporary and indefinite, increase across all regions	Strong statistical evidence on current crop production Models of future crop productivity display variability but are consistent across regions Quantitative studies from several countries in Latin America, Asia, and Sub-Saharan Africa provide strong evidence of climate–rural income–migration linkages Large array of case-based evidence from all continents

Source: McLeman (2016).
* Green = strong evidence few uncertainties. Yellow = reasonably strong evidence, uncertainties in some regions or areas.

Small Island Developing States are particularly vulnerable to climate impacts, making them an important location of future climate migration. These states are likely to experience more frequent and more severe storms, coastal erosion, and sea level rise (IPCC 2013b). Because of their small size, they could not be included at the resolution of the model applied in this report.

IMPACTS OF MIGRATION ON PEOPLE AND AREAS

Migration affects the well-being of people and surrounding systems in complex ways that evolve over time (UNDP 2009; Milan and others 2015; Melde, Laczko, and Gemenne 2017). Migration is a common coping, income diversification, risk management, and adaptation strategy for people facing economic stress and adverse climatic conditions (Ellis 2000; Adger and others 2014; Melde, Laczko, and Gemenne 2017). Climate migration is not good or bad in itself; the cost-benefit calculus is heavily dependent on perspective (Gemenne and Blocher 2017). Understanding the conditions under which positive or negative outcomes can result is necessary for managing the possible future trends outlined in this report in Chapters 4 and 5. As studies on the impacts of climate migration are still limited, this section also reviews evidence drawn from the general migration literature on systemic issues that arise from migration.

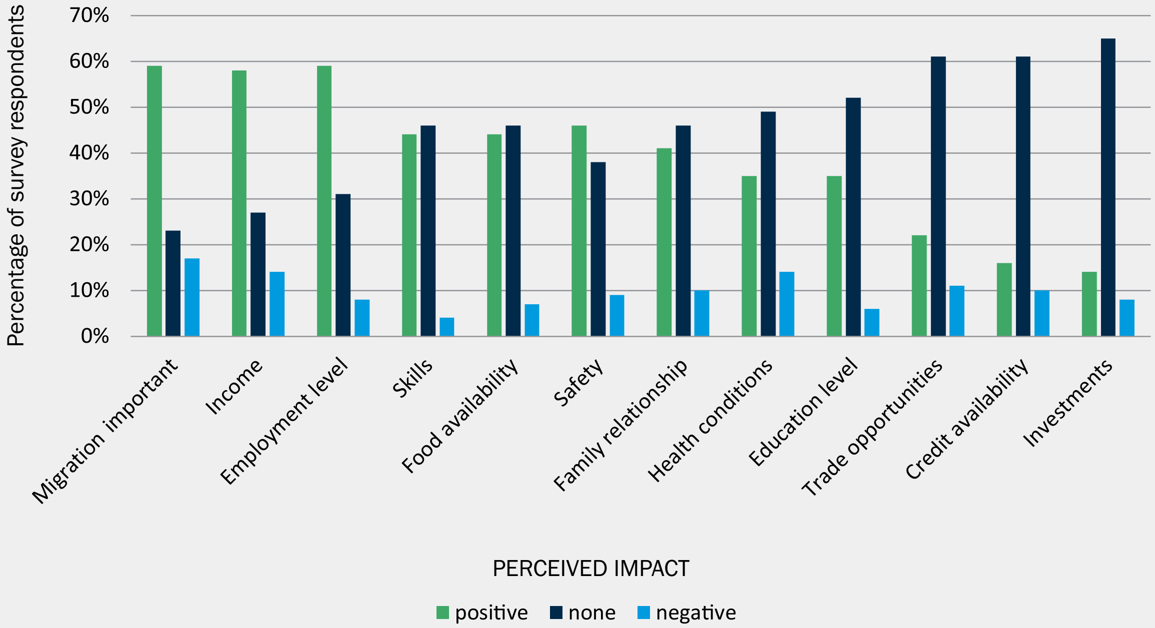
Impacts on migrants and their households

Outcomes of movements depend on the conditions under which people move (UNDP 2009). Climate extremes erode household livelihoods and assets (Zomers and others 2016; Warner and Van der Geest 2013), diminishing the capabilities needed for successful establishment in destination areas. Hugo (2009) argues that displaced people are more likely to find it difficult to adjust to their new destination for multiple reasons, connected with the unexpectedness of the move, their emotional state, and the unfamiliarity of their new surroundings.

People with greater capabilities—and therefore greater freedom to choose migration timing and destinations—often improve their economic situation after migrating. Harttgen and Klasen (2009) find that in 14 of 16 developing countries they studied, the Human Development Index was higher for internal migrants than for nonmigrants. For cross-border migrants moving from low- to high-income countries, a World Bank study (2017b, 15) finds on average “a 15-fold increase in income, a doubling of school enrollment rates, and a 16-fold reduction in child mortality.” Access to better health services, water quality, and sanitation at the destination, combined with a longer duration of stay, can have profound positive health impacts on migrants (UNDP 2009; Yabiku and others 2009). People who migrate to urban centers with better access to health services improve their chances of survival relative to rural residents, although their health outcomes are worse than those of urban nonmigrants (UNDP 2009).

Migration generally has positive impacts on households in sending areas, although those benefits are unevenly distributed. Respondents in surveys conducted through the Migration, Environment and Climate Change: Evidence for Policy (MECLEP) project, implemented by the International Organization for Migration (IOM) through a consortium of six universities, find migration to have generally positive, or neutral, impacts on the household economy. Only a very small proportion of respondents indicate that migration had negative impacts on income, employment, safety, and education (Figure 2.2).

Figure 2.2: Perceived impact of migration on households according to a 2016 survey conducted by the International Organization for Migration



Source: IOM (2016).

Migration can be a positive adaptation strategy for people who migrate, but displacements challenge adaptation, and planned relocation shows mixed results. In Haiti seasonal migration helped reduce vulnerability. In all six countries studied by Melde, Laczko, and Gemenne (2017), migrant households reported mainly positive impacts of migration on income growth and diversification. Many also reported having learned, applied, and taught new skills through migration. Most migrant households also stated that they improved their health conditions and education thanks to migration. However, migrant households also experience more discrimination, exclusion from employment and access to important social services and systems than nonmigrants and are more likely to face insecurity; some also live in less robust houses than locals. Although these factors can undermine human development and adaptation prospects, the report finds that migration can increase adaptive capacities, especially if policy enables better access to social services, action against discrimination and exclusion, and protection of migrants.

Migration often generates remittances that can buffer environmental and economic shocks faced by household members who remain behind. Such transfers can increase and diversify assets and resources available to the sending household, allowing for more flexibility in livelihood strategies and less reliance on the local environment (World Bank 2006; Acosta 2007; Adams 2011; Acharya Leon-Gonzalez 2012; Le De, Gaillard, and Friesen 2013; Guadagno 2017). Remittances are often spent primarily on food, but better-off households also spend sizable shares on education, health care, and housing (UNDP 2009). Remittances are part of livelihood and insurance strategies in the event of sudden shocks and slow-onset disasters. In response to rainfall shocks in the Philippines, remittances decrease when the recipients' income increases and rise when local income falls. About 60 percent of exogenous declines in income are replaced by remittance inflows from migrants overseas (Yang and Choi 2007). Remittances can help improve prospects for disaster recovery and to some extent preparedness and adaptation; the contribution to resilience is less clear (for example, Mohapatra, Joseph, and Ratha 2009; Joseph, Wodon, and Blankespoor 2014; Manandhar 2016; Banerjee and others 2017).

Out-migration and remittances are not altogether beneficial for sending areas, however. Remittances may increase inequality, as the poorest households may be unable to send migrants—and even if they do, they may not be able to send remittances (Zickgraf and others 2016). Migration can also lead to remittance dependence and loss of intellectual capital (de Haas 2007), although the literature has cast doubt on the universal validity of the brain drain (de Haas 2010). In terms of environmental impacts, out-migration sometimes leads to a reduction in environmental pressure, through agricultural deintensification and land abandonment, because of the decline in the available labor force and the increase in cash income through remittances (Reichert 1981; Zimmerer 1993; Rudel and others 2005; Qin 2010). In Albania, Bolivia, and Mexico, out-migration is associated with an increase in vegetation cover (Preston, Macklin, and Warburton 1997; Lopez and others 2006; Muller and Sikor 2006). But out-migration can also weaken traditional forms of community-based natural resource management, as a result of declines in the human capital necessary to maintain it (Robson and Nayak 2010), and remittances can finance the use of environmentally destructive methods of natural resource extraction.

Impacts on migrant receiving areas

Migration has positive and negative impacts on receiving or destination areas. International in-migration replenishes the labor supply and skills, spurs entrepreneurship and innovation, eases strains on pension systems, and helps care for the elderly (KNOMAD 2017). However, it is frequently associated with localized population growth and attendant environmental impacts through, for example, changes in land use, deforestation, and land degradation (Starrs and Wright 1995; Hugo 1996; Bilsborrow 1992). Migration-related shifts in land use may alter the local environment, with negative impacts on health and forests. In the Brazilian Amazon, it can increase malaria risk (de Castro and others 2006). Environmental degradation is also associated with conflict, although the linkages are complex (see Box 2.4).

Photo Credit: Shutterstock

The effect of in-migration on the wages and employment of existing employees depends largely on whether migrants are substitutes for or complements of the existing labor force (Borjas, Freeman, and Katz 1997; Card 2001; Borjas 2003; Borjas 2006; Federman, Harrington, and Krynski 2006; Boustan, Fishback, and Kantor 2010). In many receiving areas, migrants may take “dirty, difficult, and dangerous” jobs, seasonal work, and informal sector work (IOM 2005). Some studies find no local wage effects on in-migration. Others find evidence of downward pressure (Kleemans and Magruder 2012; Maystadt, Mueller, and Sebastian 2016; McIntosh 2008). Generally, however, the impact of migration on destination areas is context dependent, based on the characteristics of the migrants, the receiving areas, and the larger overall structures, creating scope for policy entry points.

Urbanization is among the most important impacts of migration in destination areas. By 2050, it is expected that 70 percent of the world’s population will be urbanized (PRB 2016). Many rapidly growing cities have struggled with negative externalities, such as high unemployment, strained infrastructure, and environmental degradation (Bencivenga and Smith 1997; Beauchemin and Schoumaker 2005; Yin and others 2011; Kavzoglu 2008). By 2030, some two billion people—40 percent of urban residents—are expected to be living in slums (UNDP 2009). Most slum areas have inadequate access to safe water and sanitation; insecure land tenure; and inadequate waste management, transport, and electricity (de Sherbinin and others 2009; Connell and Lea 2002). Yet cities are often unfairly stigmatized; they may offer the best hope for improved conditions for migrants, as well as environmental conservation in rural areas (Marcotullio, Baptista, and de Sherbinin 2011).

Gendered impacts of migration patterns and impacts on vulnerable groups

This section draws from a review of the literature conducted in a background paper for this report (Hunter, 2016).

The impacts of shocks to ecosystems and livelihoods from climate change are not distributed evenly across population subgroups (Soares and others 2012). In many places, social groups in vulnerable situations—the poor and underprivileged, women, the elderly, children—are also the most severely affected by climate change impacts (for example, Reckien and others 2017). These subgroups are generally less able to cope with and respond to hazards or shocks because of their disadvantaged position: socially because of marginalized status; economically because they are poorer; and politically because of lack of independence, decision-making power, and underrepresentation (Gaillard 2010; Alston 2015). Beyond embodied vulnerabilities, the Office of the United Nations High Commissioner for Human Rights reports that vulnerabilities can arise from the circumstances that people on the move encounter in transit, at borders, and at reception or destination, particularly in lengthy and fragmented journeys.

Migration shows wide regional variation by gender. African countries and Mexico have seen increased migration by men in recent decades (Donato and Gabbacia 2015); other parts of the world have seen increases in migration by women. Asian countries have recorded increases in the proportion of female emigrants since 1960; emigrants from the Philippines include more women than men (IOM 2014). These streams are shaped by globalization, which has shifted labor demands and resulted in new migration “pulls” for women. The increase in dual-income households and aging populations in destination countries, for example, has fueled a rise in demand for care-giving services, for which women are most often sought.

Internal rural to urban migration patterns have led to shifts in traditional gender roles and some empowerment of women in their communities and households. In Vietnam, for example, women’s migration to urban areas has increased since the mid-1990s, influenced in part by the economic reforms of the late 1980s (Thao and Agergaard 2012). Rural women, particularly single women, are now heavily employed in light manufacturing, social work, and health care sectors in urban areas. Married female migrants are more likely to be employed in the informal sector. In their wives’ absence, husbands have taken on greater responsibilities for child care, housework, and agriculture. These changes in the division of labor have seen women gain influence in household purchasing and investment decisions, especially concerning remittances (World Bank 2012b). Where male household heads migrate for work, women may increasingly manage household finances. In agriculture, for example, male migration leaves many women as the de facto head of household, with more responsibility for overseeing and maintaining subsistence production for the family (Griener and Sakdapolrak 2013; Deere 2005; Radel and Schmook 2008).

A handful of studies offer insights on the effect of climate-related migration on gender issues. Gender norms often shape the ways in which men and women engage in agricultural and natural resource tasks; changes in these aspects of the local environment have gendered impacts, including on migration. In rural Nepal, for instance, men are responsible for gathering fuelwood and women for gathering fodder (Bohra-Mishra and Massey 2011). In these areas, environmental changes that make wood collection more time consuming are associated with local migration by men but not women; increases in the collection time for fodder are associated with increases in local migration by women but not men (Massey, Axinn, and Ghimire 2010).

Land tenure, tenure security, and productivity play roles in the gender–migration–climate change association. In the Loja province of the southern Ecuadorian Andes, for example, land-poor households are less likely than others to migrate abroad, although both women and men migrate internally, to diversify livelihoods. Land-rich households, in contrast, are more likely to send male but not female migrants abroad (Gray 2010).

Women and girls experience greater disadvantage than men from pervasive discrimination and structural inequalities in access to, and control of, resources. For instance, women with low socioeconomic status are more likely to get injured or die in natural disasters (Cannon 2002; Frankenberg and others 2011; Ikeda 1995; Hunter and others 2016; Paul 2010); greater socioeconomic gender equality mitigates this dynamic (Neumayer and Plümper 2007). Such inequalities also shape postdisaster experience. Women sometimes have less access to relief resources (Bradshaw 2004) and may be subject to additional workloads (Enarson, Fothergill, and Peek 2002). Women displaced by disasters are often at increased risk of sexual violence (Felten-Biermann 2006; Anastario, Shehab, and Lawry 2009) and mental health problems (Dell'Osso and others 2013; Viswanath and others 2013), in part because of exposure to violence (Anastario, Shehab, and Lawry 2009) and heavy caregiving burdens, which can increase anxiety and posttraumatic stress (Mills, Edmondson, and Park 2007).

But men and boys can also be in vulnerable situations (Demetriades and Esplen 2008). Gender norms for migration influence who is more likely to migrate when climate pressures intensify. Cultural norms that encourage male migration can put them in risky situations. Masculine gender norms such as those related to risk perceptions and risk-taking behavior can increase the vulnerability for men during natural disasters, as seen during Hurricane Mitch in Central America in 1998 (Bradshaw 2004; West and Orr 2007).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FIVE MAIN POINTS EMERGE FROM THIS CHAPTER

- Internal migration is already happening at scale and is expected to increase.
- Migration decisions are the product of complex human decision making.
- Climate change will affect multiple aspects of human livelihoods that feed into migration decisions.
- The impacts of internal migration can be substantial in both sending and receiving areas.
- Migration is an adaptation strategy and must be managed for both its opportunities and challenges.

Climate change affects livelihoods both directly and indirectly. People can decide to migrate as a livelihood strategy when climate change affects overarching variables such as the economy, environment, and political system they live in. Climate change can also affect inhibitors or facilitators of migration, and people's natural, financial, human, and social capital. Ecosystems and associated livelihoods can shape current and future outcomes. The impacts of migration are often substantial; they need to be carefully investigated and managed within development and adaptation frameworks. Migration can be an important strategy for livelihood diversification and poverty reduction, and it is a major part of adaptation. At the same time, migration presents multiple challenges. For example, migrants and their families can face high risks and costs, such as discrimination and violence. Many migrants are also moving to areas that will be increasingly vulnerable. Remittances have the potential to create or increase inequalities in some cases. Furthermore, under certain conditions, in-migration can have adverse impacts on destination areas, including on social cohesion, infrastructure, and the environment.

Policy makers need to bear in mind the opportunities and challenges of internal climate migration when designing responses and long-term plans. Much can be done to improve the outcomes of migration (DRC 2009; UNDP 2009); bolster its adaptation potential (Melde, Laczko, and Gemenne 2017); and mitigate or prepare for climate impacts that lead to migration under distress, displacement, entrap people or require planned relocation. For example, integrated spatial planning that considers climate migration in terms of areas of destination or origin, as well as targeted interventions such as social protection measures and diversification of livelihoods, can help communities adapt in place or move in safety and dignity (see Chapter 6). People in vulnerable situations should be prioritized in responses and planning, as they will bear the brunt of climate change impacts. The gendered dimensions of climate migration also require special attention.

REFERENCES

Abel, G. J., and N. Sander. 2014. “Quantifying Global International Migration Flows.” *Science* 343 (6178): 1520–22. doi:10.1126/science.1248676.

Abtew, W., and A. Melesse. 2013. “Climate Change and Evapotranspiration.” In *Evaporation and Evapotranspiration,* 197–202. Dordrecht, Netherlands: Springer.

Acharya, C. P., and R. Leon-Gonzalez. 2012. “The Impact of Remittance on Poverty and Inequality: A Micro-Simulation Study for Nepal.” *Asian Journal of Empirical Research* 3 (9):1061–1080.

Acosta, P. 2007. “Entrepreneurship, Labor Markets, and International Remittances: Evidence from El Salvador.” In *International Migration, Economic Development and Policy,* ed. Ç. Özden and M. Schiff. Washington, DC: World Bank.

Adams, G. F. 2011. *Globalization, Today and Tomorrow*. Abingdon, Oxon; New York: Routledge.

Adger, W. N., J. M. Pulhin, J. Barnett, G. D. Dabelko, G. K. Hovelsrud, M. Levy, Ú. Oswald Spring, and C. H. Vogel. 2014. “Human Security.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, 755–791. Cambridge, UK and New York, NY: Cambridge University Press.

Alston, M. 2015. *Women and Climate Change in Bangladesh*. London : Routledge.

Ammer, M., M. Mayrhofer, A. Randall, and J. Salsbury. 2016. “Time to Act: How the EU Can Lead on Climate Change and Migration Time to Act.” Accessed February 8. https://eu.boell.org/sites/default/files/hbs_time_to_act.pdf.

Anastario, M., N. Shehab, and L. Lawry, 2009. “Increased Gender-based Violence Among Women Internally Displaced in Mississippi 2 Years Post–Hurricane Katrina.” *Disaster Medicine and Public Health Preparedness* 3 (01): 18–26.

Arnell, N. W., and S. N. Gosling. 2013. “The Impacts of Climate Change on River Flow Regimes at the Global Scale.” *Journal of Hydrology* 486 (2013/04): 351–64.

Banerjee, S., D. Kniveton., R. Black, S. Bisht, P.J. Das, B. Mahapatra, and S. Tuladhar. 2017. “Do Financial Remittancces Build Household-Level Adaptive Capacity? A Case Study of Flood-Affected Households in India.” KNOMAD Working Paper 18, World Bank, Washington, DC.

Beauchemin, C., and B. Schoumaker. 2005. “Migration to Cities in Burkina Faso: Does the Level of Development in Sending Areas Matter?” *World Development* 33 (7): 1129–52.

Bell, M., and E. Charles-Edwards. 2013. “Cross-National Comparisons of Internal Migration: An Update on Global Patterns and Trends.” New York: UNDESA.

Bencivenga, V. R., and B. D. Smith. 1997. “Unemployment, Migration, and Growth.” *Journal of Political Economy* 105 (3): 582–608.

Bergholt, D., and P. Lujala. 2012. “Climate-Related Natural Disasters, Economic Growth, and Armed Civil Conflict.” *Journal of Peace Research* 49 (1): 147–162.

Bernauer, T., T. Böhmelt, and V. Koubi. 2012. “Environmental Changes and Violent Conflict.” *Environmental Research Letters* 7 (1): 15601.

Bilsborrow, R. E. 1992. “Population-Growth, Internal Migration, and Environmental Degradation in Rural-Areas of Developing-Countries.” *European Journal of Population–Revue Europeenne De Demographie* 8 (2): 125–48.

Black, R., D. Kniveton, and K. Schmidt-Verkerk. 2013. “Migration and Climate Change: Toward an Integrated Assessment of Sensitivity.” In *Disentangling Migration and Climate Change*, 29–53. Springer.

Black, R., W. N. Adger, N. W. Arnell, S. Dercon, A. Geddes, and D. Thomas. 2011. “The Effect of Environmental Change on Human Migration.” *Global Environmental Change* 21 (S1): S3–11.

Bohra-Mishra, P., and D.S. Massey, 2011. “Environmental Degradation and Out-Migration: New Evidence from Nepal.” In *Migration and Climate Change*, 74–101. Cambridge University Press.

Bohra-Mishra, P., M. Oppenheimer, and S.M. Hsiang. 2014. “Nonlinear Permanent Migration Response to Climatic Variations but Minimal Response to Disasters.” *Proceedings of the National Academy of Sciences* 111 (27): 9780–9785.

Borjas, G. J. 2003. “The Labor Demand Curve Is Downward Sloping: Reexamining the Impact of Immigration on the Labor Market.” *Quarterly Journal of Economics* 118 (4): 1335–74.

———. 2006. “Native Internal Migration and the Labor Market Impact of Immigration.” *Journal of Human Resources* 41 (2): 221–58.

Borjas, G. J., R. B. Freeman, and L. F. Katz. 1997. “How Much Do Immigration and Trade Affect Labor Market Outcomes?” *Brookings Papers on Economic Activity* 1 (1997): 1–90.

Boustan, L. P., P. V. Fishback, and S. Kantor. 2010. “The Effect of Internal Migration on Local Labor Markets: American Cities During the Great Depression.” *Journal of Labor Economics* 28 (4): 719–46.

Bozkurt, D., and O. L. Sen. 2013. “Climate Change Impacts in the Euphrates–Tigris Basin Based on Different Model and Scenario Simulations.” *Journal of Hydrology* 480 (2013/02 2013): 149–61.

Bradshaw, S. 2004 “Socio-Economic Impacts of Natural Disasters: A Gender Analysis.” UN Economic Commission for Latin America and the Caribbean (ECLAC) Series Manuales 3. Santiago, Chile: United Nations Publications. https://www.cepal.org/mujer/reuniones/conferencia_regional/manual.pdf

Brzoska, M., and C. Fröhlich. 2015. “Climate Change, Migration and Violent Conflict: Vulnerabilities, Pathways and Adaptation Strategies.” *Migration and Development* 5 (2): 190–210.

Buhaug, H. 2010. “Climate Not to Blame for African Civil Wars.” *Proceedings of the National Academy of Sciences* 107 (38): 16477–16482.

———. 2016. “Climate Change and Conflict: Taking Stock.” *Peace Economics, Peace Science and Public Policy* 22 (4). doi:10.1515/peps-2016-0034 T4.

Buhaug, H., N. P. Gleditsch, and O. M. Theisen. 2010. “Implications of Climate Change for Armed Conflict.” In *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*. Washington, DC: World Bank.

Buhaug, H., J. Nordkvelle, T. Bernauer, T. Böhmelt, M. Brzoska, J. W. Busby, A. Ciccone, H. Fjelde, E. Gartzke, N. P. Gleditsch, J. A. Goldstone, H. Hegre, H. Holtermann, V. Koubi, Link, J. S. A., P. M. Link, P. Lujala, J. O′Loughlin, C. Raleigh, J. Scheffran, J. Schilling, T. G. Smith, O. M. Theisen, Tol, R. S. J., H. Urdal, and N. von Uexkull. 2014. “One Effect to Rule Them All? A Comment on Climate and Conflict.” *Climatic Change* 127 (3): 391–397. http://dx.doi.org/10.1007/s10584-014-1266-1.

Burke, Marshall, Solomon M. Hsiang, and Edward Miguel. 2015. “Climate and Conflict.” *Annual Review of Economics* 7 (1): 577–617.

Burrows, K., and P. L. Kinney. 2016. “Exploring the Climate Change, Migration and Conflict Nexus.” *International Journal of Environmental Research and Public Health* 13 (4): 443.

Card, D. “Immigrant Inflows, Native Outflows, and the Local Labor Market Impacts of Higher Immigration.” *Journal of Labor Economics* 19 (1): 22–64.

Carleton, T., S.M. Hsiang, and M. Burke. 2016. “Conflict in a Changing Climate.” *The European Physical Journal Special Topics* 225 (3): 489–511.

Cannon, T. 2002. “Gender and Climate Hazards in Bangladesh.” *Gender & Development* 10 (2): 45–50.

Chan, F.K.S., G. Mitchell, O. Adekola, and A. McDonald. 2012. “Flood Risk in Asia’s Urban Mega-Deltas: Drivers, Impacts and Response.” *Environment and Urbanization Asia* 3 (1): 41–61.

Chan, K.W. 2013. “China: Internal Migration.” In *The Encyclopedia of Global Human Migration*, ed. I. Ness: Blackwell Publishing Ltd.

Connell, J., and J. Lea. 2002. “Urbanisation in the Island Pacific: Towards Sustainable Development.” *Routledge Pacific Rim Geographies (Book 3)*. London : Routledge.

Czaika, M., and H. de Haas. 2013. “The Effectiveness of Immigration Policies.” *Population and Development Review* 39 (3): 487–508.

DRC (Development Research Center). 2009. “Making Migration Work for Development.” Brighton, UK. http://www.migrationdrc.org/publications/misc/Making_Migration_Work_for_Development.pdf.

de Castro, M. C., R. L. Monte-Mor, D. O. Sawyer, and B. H. Singer. 2006. “Malaria Risk on the Amazon Frontier.” *Proceedings of the National Academy of Sciences of the United States of America* 103 (7): 2452–57.

de Haas, H. 2007. “Remittances, Migration and Development: Policy Options and Policy Illusions.” In South–South Migration: Implications for Social Policy and Development, ed. K. Hujo and N. Piper. London: Palgrave Macmillan.

———. 2010. “Migration and Development: A Theoretical Perspective.” *The International Migration Review* 44 (1): 227–264. doi:10.1111/j.1747-7379.2009.00804.x.

De Jong, G.F., and R. W. Gardner. 2013. “Migration Decision Making: Multidisciplinary Approaches to Microlevel Studies in Developed and Developing Countries.” Elsevier.

de Sherbinin, A. 2014. “Climate Change Hotspots Mapping: What Have We Learned?” *Climatic Change* 123 (1): 23–37.

de Sherbinin, A., A. Rahman, A. Barbieri, J.C. Fotso, and Y. Zhu (eds.). 2009. “Urban Population-Environment Dynamics in the Developing World: Case Studies and Lessons Learned.” Paris: Committee for International Cooperation in National Research in Demography (CICRED).

de Sherbinin, A., M. Levy, S. Adamo, K. MacManus, G. Yetman, V. Mara, L. Razafindrazay, B. Goodrich, T. Srebotnjak, C. Aichele, and L. Pistolesi. 2012. “Migration and Risk: Net Migration in Marginal Ecosystems and Hazardous Areas.” *Environmental Research Letters* 7 (4).

De Waard, J., K. J. Curtis, and E. Fussell. 2016. “Population Recovery in New Orleans after Hurricane Katrina: Exploring the Potential Role of Stage Migration in Migration Systems.” *Population and Environment* 37 (4): 449–63.

Deere, C.D. 2005. “The Feminization of Agriculture? Economic Restructuring in Rural Latin America.” Geneva: United Nations Research Institute for Social Development.

Dell’Osso, L., C. Carmassi, G. Massimetti, P. Stratta, I. Riccardi, C. Capanna, K.K. Akiskal, H.S. Akiskal, and A. Rossi. 2013. “Age, Gender and Epicenter Proximity Effects on Post-Traumatic Stress Symptoms in L’Aquila 2009 Earthquake Survivors.” *Journal of Affective Disorders* 146 (2): 174–180.

Demetriades, J., and E. Esplen. 2008. “The Gender Dimensions of Poverty and Climate Change Adaptation.” *IDS Bulletin* 39 (4): 24–31.

Dieng, H. B., A. Cazenave, B. Meyssignac, and M. Ablain. 2017. “New Estimate of the Current Rate of Sea Level Rise from a Sea Level Budget Approach.” *Geophysical Research Letters* 44 (8): 3744–51.

Donato, Katharine M., and Donna Gabaccia. 2015. “Gender and International Migration.” New York: Russell Sage Foundation.

Ellis, F. 2000. *Rural Livelihoods and Diversity in Developing Countries*. Oxford: Oxford University Press.

Enarson, E, A. Fothergill, and L. Peek. 2007. “Gender and Disaster: Foundations and Directions.” *Handbook of Disaster Research*: 130–146. New York: Springer.

Federman, M. N., D. E. Harrington, and K. J. Krynski. 2006. “The Impact of State Licensing Regulations on Low-Skilled Immigrants: The Case of Vietnamese Manicurists.” *American Economic Review* 96 (2): 237–41.

Felten-Biermann, C. 2006. “Gender and Natural Disaster: Sexualized Violence and the Tsunami.” *Development* 49 (3): 82–86.

Feng, S., A.B. Krueger, and M. Oppenheimer. 2010. “Linkages among Climate Change, Crop Yields and Mexico–US Cross-Border Migration.” *Proceedings of the National Academy of Sciences* 107 (32): 14257–14262.

Foresight. 2011. *Migration and Global Environmental Change: Final Project Report*. London: The Government Office for Science. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/287717/11-1116-migration-and-global-environmental-change.pdf.

Frankenberg, E., T. Gillespie, S. Preston, B. Sikoki, and D. Thomas. 2011. "Mortality, the Family and the Indian Ocean Tsunami." *The Economic Journal* 121 (554): F162–F182.

Gaillard, J.C. 2010. "Vulnerability, Capacity and Resilience: Perspectives for Climate and Development Policy." *Journal of International Development* 22 (2): 218–32. doi:10.1002/jid.1675.

Galtung, Johan. 2008. "Conflict Theory." In *Encyclopedia of Violence, Peace, & Conflict*, ed. Lester R. Kurtz. Amsterdam and London: Elsevier.

Geddes, A., W.N. Adger, N.W. Arnell, R. Black, and D.S. Thomas. 2012. "Migration, environmental change, and the 'challenges of governance'." *Environment and Planning C: Government and Policy* 30 (6): 951–967.

Gemenne, F. 2011. "How They Became the Human Face of Climate Change. The Emergence of 'Climate Refugees' in the Public Debate, and the Policy Responses It Triggered." In *Migration and Climate Change*. Cambridge, UK: Cambridge University Press.

Gemenne, F., and J. Blocher. 2017. "How Can Migration Serve Adaptation to Climate Change? Challenges to Fleshing out a Policy Ideal." *The Geographical Journal* 183 (4).

Gray, C.L., 2010. "Gender, natural capital, and migration in the southern Ecuadorian Andes." *Environment and Planning A* 42 (3): 678–696.

Gray, C.L., and V. Mueller 2012. "Natural disasters and population mobility in Bangladesh." *Proceedings of the National Academy of Sciences* 109 (16): 6000–6005.

Greiner, C., and P. Sakdapolrak. 2013. "Rural–Urban Migration, Agrarian Change, and the Environment in Kenya: A Critical Review of the Literature." *Population and Environment* 34 (4): 524–553.

Groschl, J., and T. Steinwachs. 2016. "Do Natural Hazards Cause International Migration?" CESifo Economic Studies No. 6145 (October 2016), CESifo, Munich, Germany.

Guadagno, L. 2017. "Human Mobility in a Socio-Environmental Context: Complex Effects on Environmental Risk." In *Identifying Emerging Issues in Disaster Risk Reduction, Migration, Climate Change and Sustainable Development*. Springer International Publishing.

Hallegatte, S., A. Vogt-Schilb, M. Bangalore, and J. Rozenberg. 2017. "Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters." Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/25335.

Harttgen, K., and S. Klasen. 2009. "A Human Development Index by Internal Migration Status." Human Development Research Paper No. 54, United Nations Development Programme, New York.

Hatton, T. J., and J. G. Williamson. 2005. "What Fundamentals Drive World Migration?" In *Poverty, International Migration and Asylum* 5-38. Palgrave Macmillan UK.

Hay, C. C., E. Morrow, R. E. Kopp, and J. X. Mitrovica. 2015. "Probabilistic Reanalysis of Twentieth-Century Sea-Level Rise." *Nature* 517 (7535): 481–84.

Hegre, H., H. Buhaug, K. V. Calvin, J. Nordkvelle, S. T. Waldhoff, and E. Gilmore. 2016. "Forecasting Civil Conflict along the Shared Socioeconomic Pathways." *Environmental Research Letters* 11 (5): 54002.

Henry, S., B. Schoumaker, and C. Beauchemin. 2004. "The Impact of Rainfall on the First out-Migration: A Multi-Level Event-History Analysis in Burkina Faso." *Population and Environment* 25 (5): 423–60.

Homer-Dixon, T.F. 2010. *Environment, Scarcity, and Violence.* Princeton, NJ: Princeton University Press.

Hugo, G. 1996. "Environmental Concerns and International Migration." *International Migration Review* 30 (1): 105–31.

———. 2009. "Best Practice in Temporary Labour Migration for Development: A Perspective from Asia and the Pacific." *International Migration* 47 (5): 23–74.

Hunter, L.M. 2016. “Gender, Climate Change and Mobility: Exploring Migration, Displacement, and Planned Relocation In the Context of Environmental Change in Ecosystems.” Background paper for this report.

Hunter, L.M., Castro, J., Kleiber, D. and Hutchens, K., 2016. “Swimming and Gendered Vulnerabilities: Evidence from the Northern and Central Philippines.” *Society & Natural Resources* 29 (3): 380–385.

IDMC (Internal Displacement Monitoring Centre). 2014. *IDMC Global Estimates 2014: People Displaced by Disasters.* Geneva.

———. 2015. *Global Estimates 2015: People Displaced by Disasters.* Geneva. http://www.internal-displacement.org/assets/library/Media/201507-globalEstimates-2015/20150713-global-estimates-2015-en-v1.pdf.

———. 2016. *Global Estimates 2015: People Displaced by Disasters.* Geneva.

———. 2017. “Global Report on Internal Displacement-GRID 2017.” Geneva: IDMC and NRC (Norwegian Refugee Council). http://www.internal-displacement.org/global-report/grid2017/pdfs/2017-GRID.pdf.

ILO (International Labour Organization). 2015. “Global Estimates of Migrant Workers and Migrant Domestic Workers : Results and Methodology: Special Focus on Migrant Domestic Workers.” Geneva. http://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_436343.pdf.

IOM (International Organization for Migration). 2005. *World Migration Report 2005: Costs and Benefits of International Migration.* Geneva.

———. 2014. *Migration, Environment and Climate Change: Evidence for Policy (MECLEP): Glossary.* Geneva. https://publications.iom.int/system/files/pdf/meclep_glossary_en.pdf.

———. 2015. “2015 Global Migration Trends Factsheet.” Geneva. http://gmdac.iom.int/global-migration-trends-factsheet

———. 2016. “Adapting to Climate Change through Migration: A Case Study of the Vietnamese Mekong River Delta.” ed. Han Entzinger and Peter Scholten. Geneva.

IPCC (Intergovernmental Panel on Climate Change). 2013a. “Summary for Policymakers.” In *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge, UK and New York, NY: Cambridge University Press.

———. 2013b. *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. T.F. Stocker, D. Qin T.F., G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge, UK and New York, NY: Cambridge University Press.

Ikeda, K., 1995. “Gender Differences in Human Loss and Vulnerability in Natural Disasters: A Case Study from Bangladesh.” *Indian Journal of Gender Studies* 2 (2): 171–193.

Immerzeel, W.W., L.P. Van Beek, and M.F. Bierkens. 2010. “Climate Change Will Affect the Asian Water Towers.” *Science* 328 (5984): 1382–85.

Ionesco, D., F. Gemenne, and C. Zickgraf. 2015. “Introduction.” In *The State of Environmental Migration 2015*, ed. Dina Ionesco, François Gemenne and Caroline Zickgraf, 7-10. Paris: Sciences Po.

Ionesco, D., D, Mokhnacheva, and F. Gemenne. 2016. *The Atlas of Environmental Migration*. Routledge.

Joseph, G., Q. Wodon, and B. Blankespoor. 2014. “Do Remittances Reach Households Living in Unfavorable Climate Areas? Evidence from the Republic of Yemen.” MPRA Paper 56939, University Library of Munich, Munich, Germany.

Kälin, W. 2010. *Conceptualising Climate-Induced Displacement: Climate Change and Displacement: Multidisciplinary Perspectives.* Oxford, UK: Hart Publishing.

Kavzoglu, T. 2008. “Determination of Environmental Degradation Due to Urbanization and Industrialization in Gebze, Turkey.” *Environmental Engineering Science* 25 (3): 429–38.

Kleemans, M., and J. Magruder. 2012. “Labor Market Changes in Response to Immigration: Evidence from Internal Migration Driven by Weather Shocks.” *Manuscript, University of California, Berkeley*.

Klomp, Jeroen, and Erwin Bulte. 2013. “Climate Change, Weather Shocks, and Violent Conflict: A Critical Look at the Evidence.” *Agricultural Economics* 44 (s1): 63–78.

KNOMAD. 2017. “Migration and Remittances, Recent Developments and Outlook Special Topic: Global Compact on Migration.” Washington, DC: World Bank.

Le De, L., J.C. Gaillard, and W. Friesen. 2013. “Remittances and Disaster: A Review.” *International Journal of Disaster Risk Reduction* 4: 34–43.

Lee, E. 1966. “A Theory of Migration.” *Demography* 3 (1): 47–57.

Lenton, Timothy M., Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans Joachim Schellnhuber. 2008. “Tipping Elements in the Earth’s Climate System.” *Proceedings of the National Academy of Sciences* 105 (6): 1786–93.

Levermann, A., J.L. Bamber, S. Drijfhout, A. Ganopolski, W. Haeberli, N.R.P. Harris, M. Huss, K. Krüger, T.M. Lenton, R.W. Lindsay, D. Notz, P. Wadhams, and S. Weber. 2012. “Potential Climatic Transitions with Profound Impact on Europe.” *Climatic Change* 110 (3): 845–878

Lopez, E., G. Bocco, M. Mendoza, A. Velazquez, and J. R. Aguirre-Rivera. 2006. “Peasant Emigration and Land-Use Change at the Watershed Level: A Gis-Based Approach in Central Mexico.” *Agricultural Systems* 90 (1–3): 62–78.

Manandhar, B. 2016. “Remittance and Earthquake Preparedness.” *International Journal of Disaster Risk Reduction* 15: 52–60.

Marc, Alexandre; Verjee, Neelam; Mogaka, Stephen. 2015. The Challenge of Stability and Security in West Africa. Africa Development Forum;. Washington, DC: World Bank; and Agence Française de Développement © World Bank. https://openknowledge.worldbank.org/handle/10986/22033 License: CC BY 3.0 IGO.

Marcotullio, P., S. Baptista, and A. de Sherbinin. 2011. “Urbanization, Poverty Reduction and Ecosystem Integrity.” In Integrating Ecology and Poverty Reduction: The Application of Ecology in Development Solutions, ed. F. De Clerk, J. Ingram, and C. Rumbaitis Del Rio. New York: Springer.

Mares, D.M. and K.W. Moffett. 2016. “Climate Change and Interpersonal Violence: A “Global” Estimate and Regional Inequities. *Climatic Change* 135 (2): 297–310.

Martin, Adrian. 2005. “Environmental Conflict between Refugee and Host Communities.” *Journal of Peace Research* 42 (3): 329–346

Martin, S. F. 2012. “Environmental Change and Migration: Legal and Political Frameworks.” *Environment and Planning C: Government and Policy* 30 (6): 1045–60.

Martin, M., M. Billah, T. Siddiqui, C. Abrar, R. Black, and D. Kniveton. 2014. “Climate-Related Migration in Rural Bangladesh: A Behavioural Model.” *Population and Environment* 36 (1): 85–110.

Massey, D. S., J. Arango, G. Hugo, A. Kouaouci, A. Pellegrino, and J. E. Taylor. 1993. “Theories of International Migration: A Review and Appraisal.” *Population and Development Review* 19 (3): 431–66.

Massey D.S., W.G. Axinn, and D.J. Ghimire. 2010. “Environmental Change and out-Migration: Evidence from Nepal.” *Population and Environment* 32 (2): 109–36.

Maystadt, J. F., V. Mueller, and A. Sebastian. 2016. “Environmental Migration and Labor Markets in Nepal.” *Journal of the Association of Environmental and Resource Economists* 3 (2): 417–52.

Mazzucato, V. 2011. “Reverse Remittances in the Migration-Development Nexus: Two-Way Flows between Ghana and the Netherlands.” *Population, Space and Place* 17 (5): 454–68.

McIntosh, M.F. 2008. “Measuring the Labor Market Impacts of Hurricane Katrina Migration: Evidence from Houston, Texas.” *The American Economic Review* 98 (2).

McLeman, R.A. 2014. *Climate and Human Migration: Past Experiences, Future Challenges.* New York, NY : Cambridge University Press.

———. 2016. “Interconnectivity of Climate Change, Ecosystems, Livelihoods, and Migration: Implications for Long Term, Climate-Resilient Development Planning.” World Bank. Background Paper for this report.

McLeman, R., M. Opatowski, B. Borova, and M. Walton-Roberts. 2016. “Environmental Migration and Displacement: What We Know and Don’t Know.” Waterloo, ON: Wilfrid Laurier University. http://www.laurierenvironmentalmigration.com/wp-content/uploads/2015/11/WLU-Environmental-Migration-Background-Report.pdf.

Melde, S., F. Laczko, and F. Gemenne. 2017. “Making Mobility Work for Adaptation to Environmental Changes: Results from the MECLEP Global Research.” Geneva: International Organization for Migration. https://publications.iom.int/system/files/pdf/meclep_comparative_report.pdf.

Michaelowa, A. 2004. “National Research Council, Abrupt Climate Change: Inevitable Surprises.” *Climatic Change* 64 (3): 377–380.

Milan, A., S. Melde, N. Cascone, M. Schindler, and K. Warner. 2015. “When Do Households Benefit from Migration?” *Migration, Environment and Climate Change: Policy Brief Series* 1 (8). Geneva: International Organization for Migration. https://publications.iom.int/system/files/policy_brief_series_issue8_16june2016.pdf.

Mills, M.A., D. Edmondson, and C.L. Park. 2007. “Trauma and Stress Response among Hurricane Katrina Evacuees.” *American Journal of Public Health* 97 (Supplement 1): S116–S123.

Mohapatra, S., G. Joseph, and D. Ratha. 2009. “Remittances and Natural Disasters. Ex-post Response and Contribution to Ex-Ante Preparedness.” World Bank Policy Research Working Paper 4972, World Bank, Washington, DC.

Montgomery, M. R. 2008. “The Urban Transformation of the Developing World.” *Science* 319 (5864): 761–64.

Muller, D., and T. Sikor. 2006. “Effects of Postsocialist Reforms on Land Cover and Land Use in South-Eastern Albania.” *Applied Geography* 26 (3–4): 175–91.

Nawrotzki, R.J., and M. Bakhtsiyarava. 2017. “International Climate Migration: Evidence for the Climate Inhibitor Mechanism and the Agricultural Pathway.” *Population, Space and Place* 23 (4).

Nawrotzki, R. J., F. Riosmena, and L.M. Hunter. 2013. “Do Rainfall Deficits Predict U.S.-Bound Migration from Rural Mexico? Evidence from the Mexican Census.” *Population Research and Policy Review* 32 (1): 129–58. doi:10.1007/s11113-012-9251-8.

Nawrotzki, R.J., D.M. Runfola, L.M. Hunter, and F. Riosmena. 2016. “Domestic and International Climate Migration from Rural Mexico.” *Human Ecology* 44 (6): 687–99. doi:10.1007/s10745-016-9859-0.

Nawrotzki, R.J., J. DeWaard, M. Bakhtsiyarava, and J. Trang Ha. 2017. “Climate Shocks and Rural-Urban Migration in Mexico: Exploring Nonlinearities and Thresholds.” *Climatic Change* 140 (2): 243–58. doi:10.1007/s10584-016-1849-0.

Neumann, K., and Hilderink, H., 2015. “Opportunities and Challenges for Investigating the Environment–Migration Nexus.” *Human Ecology* 43 (2): 309–322.

Neumayer, E., and T. Plümper. 2007. “The Gendered Nature of Natural Disasters: The Impact of Catastrophic Events on the Gender Gap in Life Expectancy, 1981–2002.” *Annals of the Association of American Geographers* 97 (3): 551–566.

O’Loughlin, John, Frank D. W. Witmer, Andrew M. Linke, Arlene Laing, Andrew Gettelman, and Jimy Dudhia. 2012. “Climate Variability and Conflict Risk in East Africa, 1990–2009.” *Proceedings of the National Academy of Sciences* 109 (45): 18344–18349.

Obokata, R., L. Veronis, and R. McLeman. 2014. “Empirical Research on International Environmental Migration: A Systematic Review.” *Population and Environment* 36 (1): 111–35. doi:10.1007/s11111-014-0210-7.

Palloni, A., D. S. Massey, M. Ceballos, K. Espinosa, and M. Spittel. 2001. “Social Capital and International Migration: A Test Using Information on Family Networks.” *American Journal of Sociology* 106 (5): 1262–98.

Paul, B.K. 2010. “Human Injuries Caused by Bangladesh’s Cyclone Sidr: An Empirical Study.” *Natural Hazards* 54 (2): 483–495.

PRB (Population Reference Bureau). 2016. “2016 World Population Data Sheet.” Washington, DC.

Preston, D., M. Macklin, and J. Warburton. 1997. “Fewer People, Less Erosion: The Twentieth Century in Southern Bolivia.” *Geographical Journal* 163 (Jul 1997): 198–205.

Qin, H. 2010. “Rural-to-Urban Labor Migration, Household Livelihoods, and the Rural Environment in Chongqing Municipality, Southwest China.” *Human Ecology* 38 (5): 675–90.

Radel, C. and B. Schmook. 2008. “Male Transnational Migration and its Linkages to Land-Use Change in a Southern Campeche Ejido.” *Journal of Latin American Geography* 7 (2): 59-84.

Rain, D. R. 1999. *Eaters of the Dry Season: A Circular Migration System in the West African Sahel.* Boulder, CO: Westview Press.

Reckien, D., S. Lwasa, D. Satterthwaite, D. McEvoy, F. Creutzig, M. Montgomery, D. Schensul, D. Balk, I. Khan, B. Fernandez, D. Brown, J. Osorio, M. Tovar Restrepo, A. de Sherbinin, A. Sverdlik, E. Porio, A. Nair, S. McCormick, E. Bautista, and S. Lwasa. 2017. “Climate Change Interactions with Equity and Environmental Justice.” In *Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network.* Cambridge, UK: Cambridge University Press.

Reichert, J. S. 1981. “The Migrant Syndrome: Seasonal United-States Wage Labor and Rural-Development in Central Mexico.” *Human Organization* 40 (1): 56–66.

Renaud, F. G., O. Dun, K. Warner, and J. Bogardi. 2011. “A Decision Framework for Environmentally Induced Migration.” *International Migration* 49 (Jun 2011): e5–e29.

Reuveny, R. 2007. “Climate Change-Induced Migration and Violent Conflict.” Political Geography 26 (6): 656–673.

Robson, J. P., and P. K. Nayak. 2010 “Rural out-Migration and Resource-Dependent Communities in Mexico and India.” *Population and Environment* 32 (2–3): 263–84.

Rudel, T. K., O. T. Coomes, E. Moran, F. Achard, A. Angelsen, J. C. Xu, and E. Lambin. 2005. “Forest Transitions: Towards a Global Understanding of Land Use Change.” *Global Environmental Change-Human and Policy Dimensions* 15 (1): 23–31.

Schewe, J., J. Heinke, D. Gerten, I. Haddeland, N. Arnell, D. Clark, R. Dankers, S. Eisner, B. Fekete, F. Colon-Gonzalez, S. Gosling, H. Kim, X. Liu, Y. Masaki, F. Portmann, Y. Satoh, T. Stacke, Q. Tang, Y. Wada, D. Wisser, T. Albrecht, K. Frieler, F. Piontek, L. Warszawski, and P. Kabat. 2014. “Multimodel Assessment of Water Scarcity under Climate Change.” *Proceedings of the National Academy of Sciences* 111 (9): 3245–50. doi:10.1073/pnas.1222460110.

Schleussner, Carl-Friedrich, Jonathan F. Donges, Reik V. Donner, and Hans Joachim Schellnhuber. 2016. “Armed-Conflict Risks Enhanced by Climate-Related Disasters in Ethnically Fractionalized Countries.” *Proceedings of the National Academy of Sciences* 113 (33): 9216–9221.

Schneider, S. H. 2004. “Abrupt Non-Linear Climate Change, Irreversibility and Surprise.” *Global Environmental Change: Human and Policy Dimensions* 14 (3): 245–58.

Schellnhuber, H.J. (ed.). 2009. “Tipping Elements in Earth Systems.” Special Feature. *Proceedings of the National Academy of Sciences* 106: 20561–20621

Scoones, I. 1998. “Sustainable Rural Livelihoods: A Framework for Analysis.” IDS Working Paper 72, Institute for Development Studies, Brighton, UK.

Selby, J. 2014. “Positivist Climate Conflict Research: A Critique.” *Geopolitics* 19 (4): 829–856.

Slettebak, R.T. 2012 “Don’t Blame the Weather! Climate-Related Natural Disasters and Civil Conflict.” *Journal of Peace Research* 49 (1): 163–176.

Soares, M. B., A. S. Gagnon, and R. M. Doherty. 2012. “Conceptual Elements of Climate Change Vulnerability Assessments: A Review.” *International Journal of Climate Change Strategies and Management* 4 (1): 6–35.

Stark, O., and D. E. Bloom. 1985. “The New Economics of Labor Migration.” *American Economic Review* 75 (2): 173–78.

Starrs, P.F., and J.B. Wright. 1995. “Great Basin Growth and the Withering of Californa’s Pacific Idyll.” *Geographical Review* 85: 417–35.

Streets, D. G., and M. H. Glantz. 2000. "Exploring the Concept of Climate Surprise." *Global Environmental Change: Human and Policy Dimensions* 10 (2): 97–107.

Tacoli, C., G. McGranahan, D. Balk, B. Anderson, and D. Satterthwaite. 2015. "Urbanisation, Rural–Urban Migration and Urban Poverty." IIED Working Paper, International Institute for Environment and Development, London.

Thao, V.T. and J. Agergaard. 2012. "'Doing Family' Female Migrants and Family Transition in Rural Vietnam." *Asian Population Studies* 8 (1): 103–19.

Todaro, M.P. 1969. "Model of Labor Migration and Urban Unemployment in Less Developed Countries." *American Economic Review* 59 (1): 138–48.

———. 1980. "Internal Migration in Developing Countries: A Survey." In Population and Economic Change in Developing Countries, edited by R.A Easterlin, 361-402. Chicago: University of Chicago Press, 1980.

Trenberth, K. E., A. G. Dai, G. van der Schrier, P. D. Jones, J. Barichivich, K. R. Briffa, and J. Sheffield. 2014. "Global Warming and Changes in Drought." *Nature Climate Change* 4 (1): 17–22.

UNDESA (United Nations Department of Economic and Social Affairs). 2014. *World Urbanization Prospects*. New York. https://esa.un.org/unpd/wup/DataQuery/.

———. 2015. "World Population Prospects: The 2015 Revision, Key Findings and Advance Tables." New York.

UNDP (United Nations Development Programme). 2009. "Human Development Report 2009." New York. http://hdr.undp.org/sites/default/files/reports/269/hdr_2009_en_complete.pdf.

United Nations and World Bank. 2017. Pathways for Peace: Inclusive Approaches to Preventing Violent Conflict. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/28337 License: CC BY 3.0 IGO."

United States Department of Defense. 2015. "2014 Climate Change Adaptation Roadmap." Washington, DC.

Viswanath, B., A.S. Maroky, S.B. Math, J.P. John, A.V. Cherian, S.C. Girimaji, V. Benegal, A. Hamza, and S.K. Chaturvedi. 2013. "Gender Differences in the Psychological Impact of Tsunami." *International Journal of Social Psychiatry* 59 (2): 130–136.

Waldinger, M. 2015. "The Effects of Climate Change on Internal and International Migration: Implications for Developing Countries." Working Paper No. 217, Centre for Climate Change Economics and Policy, London.

Warnecke, A., D. Tänzler, and R. Vollmer. 2010. "Climate Change, Migration and Conflict: Receiving Communities under Pressure?" Washington, DC: German Marshall Fund of the United States.

Warner, K., and K. Van der Geest. 2013. "Loss and Damage from Climate Change: Local-Level Evidence from Nine Vulnerable Countries." *International Journal of Global Warming* 5 (4): 367.

Warner, K., K. van der Geest, S. Kreft, S. Huq, S. Harmeling, K. Koesters, and A. de Sherbinin. 2012. "Evidence from the Frontlines of Climate Change: Loss and Damage to Communities Despite Coping and Adaptation." Bonn, Germany: United Nations University.

Watts, N., W.N. Adger, S. Ayeb-Karlsson, Y. Bai, P. Byass, D. Campbell-Lendrum, T. Colbourn, P. Cox, M. Davies, M. Depledge, A. Depoux, P. Dominguez-Salas, P. Drummond, P. Ekins, A. Flahault, D. Grace, H. Graham, A. Haines, I. Hamilton, A. Johnson, I. Kelman, S. Kovats, L. Liang, M. Lott, R. Lowe, Y. Luo, G. Mace, M. Maslin, K. Morrissey, K. Murray, T. Neville, M. Nilsson, T. Oreszczyn, C. Parthemore, D. Pencheon, E. Robinson, S. Schuette, J. Schumake-Guillemot, P. Vineis, P. Wilkinson, N. Wheeler, B. Xu, J. Yang, Y. Yin, C. Yu, P. Gong, H. Montgomery, and A. Costello. 2017. "The Lancet Countdown: Tracking Progress on Health and Climate Change." *The Lancet* 389 (10074). Elsevier: 1151–64. doi:10.1016/S0140-6736(16)32124-9.

West, D.M., and M. Orr. 2007. "Race, Gender, and Communications in Natural Disasters." *Policy Studies Journal* 35 (4): 569–586.

World Bank. 2006. "Economic Implications of Remittances and Migration." In Economic Global Prospectus. Washington, DC: World Bank.

———. 2012a. Turn down the Heat : Why a 4°C Warmer World Must Be Avoided. Washington, D.C. World Bank. http://documents.worldbank.org/curated/en/865571468149107611/Turn-down-the-heat-why-a-4-C-warmer-world-must-be-avoided.

———. 2012b. World Development Report 2012: Gender Equality and Development. Washington, DC. https://openknowledge.worldbank.org/handle/10986/4391.

———. 2013. Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience. Washington, DC.

———. 2014. Turn Down the Heat: Confronting the New Climate Normal. Washington, D.C. https://openknowledge.worldbank.org/handle/10986/20595.

———. 2016. High and Dry: Climate Change, Water, and the Economy. World Bank, Washington, DC.

———. 2017a. Forcibly Displaced: Toward a Development Approach Supporting Refugees, the Internally Displaced, and Their Hosts. Washington, DC: World Bank. doi:10.1596/978–1-4648–0938–5. License: Creative Commons Attribution CC BY 3.0 IGO.

———. 2017b. Pacific Possible : Long-term Economic Opportunities and Challenges for Pacific Island Countries. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/28135 License: CC BY 3.0 IGO.

Yabiku, S.T., Glick, J.E., Wentz, E.A., Haas, S.A. and Zhu, L., 2009. "Migration, Health, and Environment in the Desert Southwest." *Population and Environment* 30 (4–5): 131–158.

Yang, D., H. Choi. 2007. "Are Remittances Insurance? Evidence from Rainfall Shocks in the Philippines." *The World Bank Economic Review* 27 (2): 219–48.

Yin, J., Z. Yin, H. Zhong, S. Xu, X. Hu, J. Wang, and J. Wu. 2011. "Monitoring Urban Expansion and Land Use/Land Cover Changes of Shanghai Metropolitan Area during the Transitional Economy (1979–2009) in China." *Environmental Monitoring and Assessment* 177 (1): 609–621.

Zickgraf, C., S. Vigil, F. de Longueville, P. Ozer, F. Gemenne. 2016. "The Impact of Vulnerability and Resilience to Environmental Changes on Mobility Patterns in West Africa." KNOMAD Working Paper 14, World Bank, Washington, DC.

Zimmerer, K. S. 1993. "Soil-Erosion and Social (Dis)Courses in Cochabamba, Bolivia: Perceiving the Nature of Environmental Degradation." *Economic Geography* 69 (3): 312–27.

Zomers, Z., K. van der Geest, A. de Sherbinin, S. Kienberger, E. Roberts, G. Harootunian, A. Sitati, and R. James. 2016. "Loss and Damage: The Role of Ecosystem Services." Nairobi, Kenya: United Nations Environment Programme.

Chapter 3

Modeling Climate Migration Within Countries

Internal climate migration is already taking place. As climate impacts increase over the course of this century, the scale of such migration is expected to increase. But by how much, over what time frame, and where? This chapter presents the modeling methods used in the scenario-based approach to estimate climate change-induced migration within countries. This first-ever attempt to introduce climate impacts into a model of future population distribution over large areas starts with the most important sectoral impacts on migration—on water and crop models—and through sea level rise. This focus on slow-onset climate change, excluding cross-border movements and displacement from climate variability and extremes and cross-border movement, presents a lower-bound estimate of the likely impact of climate change on migration. The modeling provides transparent, spatially explicit estimates of change in population distribution (and indirectly climate migration) as a function of climate and development trends. Sources of uncertainty and the possibilities of expanding the scope of the work are laid out.

Governments and development partners can no longer assume that the evolution of population distribution and development activities targeting rural livelihoods will remain unchanged. They need to anticipate shifts in population distribution as a response to climate change. The modeling is intended to assist governments and development partners in understanding possible future outcomes based on combinations of two development pathways and two climate trajectories, using multiple model combinations.

The selected development pathways, based on Shared Socioeconomic Pathways (SSPs), include a "moderate development" and an "unequal development" scenario. Under the moderate development pathway, low and middle income countries are characterized by moderate population growth, urbanization, income growth, and education. Under the unequal development pathway, low and middle income countries follow different pathways. Low income countries have high population growth rates and urbanization and low gross domestic product (GDP) and education levels. Middle income countries have low population growth rates, high urbanization, moderate GDP, and low education levels. Inequality remains high, and economies are relatively isolated, leaving developing regions highly vulnerable to climate change with limited adaptive capacity.

The forecasts are based on two greenhouse gas concentration trajectories (based on Representative Concentration Pathways [RCPs]). According to the IPCC Fifth Assessment Report under the lower emissions scenario, temperatures are likely to peak at 0.4°–1.6°C above baseline levels by 2050 and then stabilize.

Figure 3.1: Modeling approach to estimating climate change-induced internal migration

MODELING INPUTS

Development pathways
Shared Socioeconomic Pathways (SSPs)—SSP2 (moderate development) and SSP4 (unequal development).

GHG emission pathways drive climate impacts using ISIMIP water and crop model results, and sea-level rise augmented by storm surge. Two Representative Concentration Pathways (RCPs) used: RCP 2.6 (low emissions) and RCP 8.5 (high emissions).

PLAUSIBLE INTERNAL CLIMATE MIGRATION SCENARIOS UP TO 2050

Pessimistic/ Reference
(RCP8.5/SSP4)
🟨

More inclusive development
(RCP8.5/SSP2)
🟩

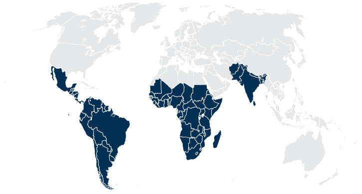
More climate-friendly
(RCP2.6/SSP4)
🟩

GRAVITY MODEL

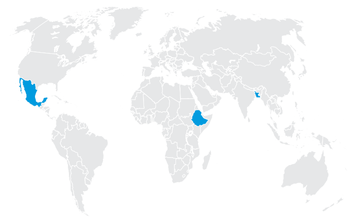
Accounts for demographic and socioeconomic (or development) trends, geographic factors and climate impacts applied at grid cell level for modeling shifts in population distribution at country level

ESTIMATES OF INTERNAL CLIMATE MIGRANTS PRESENTED FOR SELECT REGIONS

Estimates of climate migrants derived by comparing grid-cell level population for each of the three "climate impact" scenarios with that of the "no climate impact" scenario (derived from the development only pathway i.e. SSP2, SSP4). The positive difference across all grid cells are aggregated to the national level (and then regional) to produce the estimated number of climate migrants under each of the three scenarios



Three regions with sub-regional focus for deeper analysis: Sub-Saharan Africa (East Africa); South Asia in entirety; and Latin America (Mexico and Central America)



Three illustrative country examples for deeper narrative: **Ethiopia** (Sub-Saharan Africa), **Bangladesh** (South Asia), and **Mexico** (Latin America)

Note: ISIMIP = Inter-Sectoral Impact Model Intercomparison Project

For the higher emissions scenarios, temperatures rise by 1.4°–2.6°C by 2050, and by 2.6°–4.8°C by 2100 (IPCC 2014). In this report, the lower emissions pathway is a world in which temperatures are likely to peak at 0.25°–1.5°C above recent baseline levels by 2050 and then stabilize through the end of the century. In the higher emissions scenario, temperatures rise by 0.5°–2°C by 2050 and by 3°–5.5°C by 2100. The slight variation in the projected range of temperature change associated with each RCP between AR5 and our report, reflects the choice of two general circulation models used to drive the ISIMIP climate impact models, whereas the AR5 figures represent the entire Climate Model Intercomparison Project (CMIP5; Taylor and others 2012) model ensemble.

The development-only scenarios include population and urbanization trends in a population gravity model that assesses the attractiveness of different locales over time. Future population distributions are influenced by climate impacts, which reflect impacts on the water and agriculture sectors and sea level rise in the coastal zone augmented by an increment for storm surge.[8] The model estimates the number of climate migrants and their future locations by comparing population distributions that incorporate climate impacts with scenarios based on development trajectories only. Figure 3.1 summarizes the basic steps of the modeling process.

STATE OF THE ART ON CLIMATE MIGRATION MODELING

Climate migration modeling is a new but growing field (de Sherbinin and Bai forthcoming; McLeman 2013). This section overviews recent developments in the field, describes the approach to gravity modeling, and reviews the antecedents to this report's work.

Review of climate migration modeling efforts

The simplest approach to modeling climate migration is exposure mapping. This approach usually involves overlaying a climate-related hazard on a population distribution map. In some cases, assumptions are made about the number of people who will be displaced if that hazard occurs. Hazards that have been mapped in this way include sea level rise, for which there is a large and growing body of literature (for example, McGranahan and Anderson 2007; Mondal and Tatem 2012; CIESIN 2013; Neumann and others 2015); floods (Hirabiyashi and others 2013); multiple climate hazards (Christensen and others 2014); and multiple climatic and nonclimatic hazards (Dilley and others 2005; Peduzzi, Herold, and Mouton 2009). Although useful to illuminate the potential risks to human populations, these approaches generally make fairly simplistic assumptions about who will stay or go.

Empirical and theoretical advances from studies of the influence of climate variability and change on recent migration have helped ground recent modeling efforts. These studies generally employ statistical models of migration as it relates to environmental phenomena (for example, Henry, Schoumaker, and Beauchemin 2004; Afifi and Warner 2008; Feng, Krueger, and Oppenheimer 2010; Massey, Axinn, and Ghimire 2010; Nawrotzki and others 2012; Backhaus, Martinez-Zarzoso, and Murus 2015; Gray and Wise 2016) to develop coefficients related to climate parameters as they influence migration. These studies need to carefully control for known determinants of migration. Field studies and surveys that delve into household decision making can illuminate perceptions of environmental change and the appropriateness of a decision to migrate (or not).

Agent-based models build on this empirical and theoretical understanding of environmental and other influences on human migratory behavior. They model the behavior of autonomous decision makers when confronted with environmental, economic, or other changes. The theory of planned behavior, coming out of cognitive psychology, provides a basis that can be used to break down the reasoning process relating to the development of a behavioral intention. In this theory, a decision to take an action is related to three factors: the individual's attitude toward the behavior, subjective norms governing the behavior in that society, and the individual's perceived capacity to act on the desired behavior (Ajzen 1991). Agent-based models consider

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[8] Impacts on water availability, crop productivity, and sea level rise/storm surge are likely to have the greatest impacts on migration. Future modeling efforts could include additional climate impacts.

the migration decision in terms of the rules of behavior that govern the response of individuals to complex combinations of multilevel stimuli. They are often parameterized using extensive household survey research and data on migration. Agent-based models for environmental migration have been developed for Burkina Faso (Kniveton, Smith and Wood 2011) and Thailand (Walsh and others 2013).

A significant strength of agent-based models is the explicit modeling of micro-level demographic behavior based on theory and empirical evidence. This feature is a strength for local analyses for which sufficient data exist but is a limitation for regions for which empirical evidence on migration and migration intention is scarce.

Another limitation of agent-based models is the limited spatial definition (or resolution) of the migration pathways. Models typically produce volumes of flows out of one location. They may identify flows into alternative locations, but they do not typically identify source or destination areas with spatial precision, making it difficult to map changes in population that may result from the migration decision making of individual actors.

System dynamics models have been developed to examine environmental migration and displacement. The International Displacement Monitoring Center (IDMC) developed a model that simulates the impacts of droughts, floods, and climate change on the displacement of pastoralists in northern Kenya. It simulates what happens when different measures are implemented to prevent, mitigate, or respond to displacement (Ginnetti 2015). They can be used to develop "what if" scenarios involving complex econometric models and utility functions. However, work on system dynamics models of climate migration is still in its early stages, and these models tend to lack spatial specificity.

Gravity modeling

Derived from Newton's law of gravity, gravity models are used to predict the degree of interaction between two places. "Bodies" and "masses" in Newton's law are replaced by "locations" and "importance," where importance can be measured in terms of population numbers, GDP, or other variables.

A gravity model of migration is based on the idea that as the importance of two locations increases, movement between them increases. Movement between two locations is lower the greater the distance or geographic and political barriers between them. This phenomenon is known as "distance decay."

Gravity models in demography seek to simulate aggregate human behavior. Population potential, a type of gravity model, can be interpreted as a measure of the influence the population at one point in space exerts on another point. Population potential can be considered an indicator of the potential for interaction between the population at a given point in space and all other populations (Rich 1980). This potential will be higher at points closer to large populations. Population potential is also often considered a proxy for accessibility, indicating the relative ease with which populations may be accessed from a given point.

In the aggregate, locational choice can be tied to factors such as economic opportunity, transportation infrastructure, proximity to family, the presence of social amenities, and intangibles, such as place attachment (Gustafson 2001; Clark and Davies 2002; Kim, Horner, and Marans 2005). Changes in spatial distributions over time reflect changing perceptions. The tendency of populations to gravitate toward larger urban agglomerations, reflected in high rates of urbanization globally, supports the notion that the presence of population is indicative of relative attractiveness.

Gravity modeling has been carried out for the United States using population and land use change scenarios (Bierwagen and others 2010), which were used to estimate land-based emissions from certain settlement patterns. Also for the United States, McKee and others (2015) projected population to 2030 and 2050 using a spatial population projection model that incorporates gravity and multivariate methods. Their model considers factors that affect population distribution, such as land cover, the steepness of local terrain, distances to larger cities, and a moving average of the current population. A novelty of their model is the inclusion of population projections, variables, and weights that are adapted to address local characteristics of each of the 3,109 counties in the United States. Their model has the ability to examine “what if” scenarios, such as significant economic decline or climate impacts. The work described here shares in common with McKee and others (2015) the introduction of environmental factors into gravity models that affect the relative attractiveness of locations and, by extension, the implicit migration that contributes to population distribution.

The work in this report builds on Jones and O’Neill (2016), who produced scenario-based global population projections to 2100 by downscaling national-level projections of urban and rural population change to a 7.5 arc-minute grid framework. The population projections include explicit international and domestic migration modules. For domestic migration, they downscaled projected national-level urban and rural population change using the National Center for Atmospheric Research - CUNY Institute for Demographic Research (NCAR-CIDR) gravity-based approach (Jones and O’Neill 2013). This model is described below.

Gravity model approaches are largely silent on the question of individual motivations for migration. These models can help illuminate the relative importance of push factors (environmental or economic factors at origin that influence the decision to migrate) versus pull factors (factors at destination such as higher wages that influence the decision to migrate), because modeling the attractiveness of locations in terms of economic or demographic agglomeration factors fits with existing theory.

Climate migration modeling: conclusions

Each approach to modeling is fit-for-purpose and faces different constraints. Exposure mapping is useful to illuminate the potential risks to human populations, but generally makes fairly simplistic assumptions about movements. Agent-based models and systems dynamics models depend on rich data on individual- and household-level decision-making processes as well as empirical grounding. They generally lack a strong spatial definition of movements. Gravity models address some of these constraints and are based on past aggregate behavior of human populations. It can be difficult, within the gravity framework, to tease out the specific factors—job opportunities, social amenities, or social networks—that result in population redistribution, as well as the relative contribution of those factors, if specific indicators related to drivers of movement are absent as they all contribute to the agglomeration effect captured by population potential. When specific data related to economic, demographic, or environmental drivers are available and incorporated into the model, however, it becomes easier to infer causality. This shortcoming notwithstanding, gravity modeling is one of the few approaches available to take climate migration modeling to scale.

MODELING INPUTS

The Representative Concentration Pathways

The magnitude of future global warming can be framed through Representative Concentration Pathways (RCPs). Developed in advance of the IPCC Fifth Assessment Report, RCPs represent the latest generation of global scenarios for climate change research (van Vuuren at al. 2014). RCPs are trajectories of greenhouse gas concentrations resulting from human activity corresponding to a specific level of radiative forcing in 2100.[9] For example, the low greenhouse gas concentration RCP2.6 and the high greenhouse gas concentration RCP8.5 employed in this analysis imply futures where radiative forcing of 2.6 and 8.5 watts/m^2, respectively, are achieved by the end of the century.[10] The additional warming implied by these RCPs is 0.3 °C (RCP2.6) to 2.5°C (RCP8.5) by 2050, with far more warming anticipated (about 4°C) by 2100 under RCP8.5.

RCPs do not rely on a fixed set of scenario-specific assumptions on economic development, technological change, or population growth. Many different socioeconomic futures or pathways may lead to the same level of radiative forcing. This framework allows researchers to consider alternative policy decisions

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9. Radiative forcing is the measurement of the capacity of a gas or other forcing agent to affect that energy balance, thereby contributing to climate change.
10. These RCPs are sometimes referred to in this report as “emissions scenarios.” They are actually “warming scenarios,” as they reflect the radiative forcing (in watts per square meter) associated with various emissions levels. Technically, low to moderate emissions could produce RCP8.5 should the climate system prove to be more sensitive to emissions than anticipated. Climate sensitivity reflects the degree of warming associated with a doubling of atmospheric CO$_2$ from pre-industrial levels. The potential range is 1.5°–4.5°C.

with combinations of social, economic, and technological change. A future with high population growth but rapid development of clean technology may achieve the same level of radiative forcing as a world characterized by low population growth but continued reliance on fossil fuels. This framework allows researchers to specify certain levels of temperature change and then explore alternative policy options to achieve greenhouse gas concentration levels consistent with the goal. A previous process (the Special Report on Emissions Scenarios) specified the socioeconomic conditions that drove the climate change models, from which impacts were then calculated.

Low (RCP2.6) and high (RCP8.5) emissions scenarios were chosen. They drive the indicators of water and agriculture sector change, which are incorporated in projections of future population distributions.

Under RCP2.6, greenhouse gas emissions begin to decline by 2020, and radiative forcing peaks by midcentury before declining to near current levels by 2100. This scenario is consistent with the extremely rapid adoption of cleaner technologies, slower population growth, and strong environmental policies. To achieve RCP2.6, new technologies would need to be widely deployed over the next 5–10 years. The extended RCP2.6 scenario assumes "negative emissions" by 2070, meaning that humans remove more carbon dioxide (CO_2) and methane (CH_4) from the atmosphere than they release. RCP2.6 is thus consistent with the Paris Agreement, which seeks to limit temperature rise to 2°C.

RCP8.5 is characterized by increasing greenhouse gas emissions, leading to high atmospheric concentrations. It is a future consistent with scenarios of energy-intense development, continued reliance on fossil fuels, and a slow rate of technological development. Pathways characterized by rapid population growth and land use intensification (croplands and grasslands) are also consistent with this scenario. RCP8.5 implies little to no climate policy. It is characterized by significant increases in carbon dioxide (CO_2) and methane (CH_4) emissions.

Shared Socioeconomic Pathways

To create scenarios illuminating different possible development pathways, this analysis builds on spatial population projections by Jones and O'Neill (2016) that are based on Shared Socioeconomic Pathways (SSPs). SSPs represent a set of scenarios—or plausible future worlds—that underpin climate change research and permit the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation (Ebi and others 2014). They can be categorized by the degree to which the different scenarios represent challenges to mitigation (reducing the sources or enhancing the sinks of greenhouse gases) and societal adaptation to climate change.

The analysis uses SSPs as story lines to guide the development of spatial population projections at a 7.5 arc-minute resolution (grid cells of about 14 square kilometers at the equator). The five SSPs developed by O'Neill and others (2014) span a wide range of possible future development pathways for the world and describe trends in demographics, human development, economy, lifestyles, policies, institutions, technology, the environment, and natural resources. They are the scenario benchmarks used for adaptation planning purposes. Table 3.1 summarizes the SSP narratives; Figure 3.2 relates the SSPs to one another. National-level estimates of population, urbanization, and GDP have been released for each SSP and are available through the SSP database.[11]

The model used in this report builds on SSP2 and SSP4. Under SSP4 only low income countries experience high population growth, coupled with substantial inequality leading to adaptation challenges. Middle income countries experience low population growth much like high income countries. SSP2 is a moderate development scenario between SSP1 ("sustainability") and SSP3 ("fragmentation") with a slow reduction in inequalities among world regions and more moderate trends in population growth, urbanization, income, and education. These scenarios were chosen because they represent divergent development pathways. They were also selected for consistency, or the ability to be paired, with the high and low emissions pathways (RCPs) used in this report. The high emissions pathway (RCP8.5) can be paired with both SSP4 and SSP2; the low emissions pathway (RCP2.6) can be paired with SSP4.

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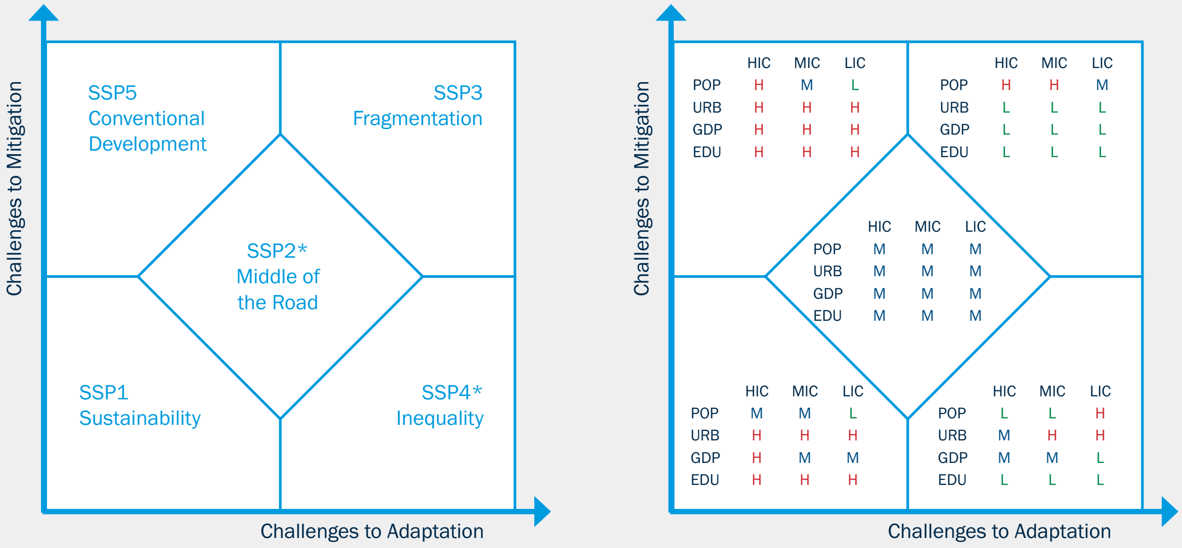
[11] See IIASA's website https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about.

Table 3.1: Shared Socioeconomic Pathway (SSP) narratives

SSP	Illustrative starting points for narrative	Level of challenge
SSP1	Sustainable development proceeds at a reasonably rapid pace, inequalities are reduced, and technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and higher productivity of land.	Low for mitigation and adaptation
SSP2*	Intermediate case between SSP1 and SSP3.	Moderate
SSP3	Unmitigated emissions are high, as a result of moderate economic growth, rapid population growth, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.	High for mitigation and adaptation
SSP4*	A mixed world, with relatively rapid technological development in low-carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it matters most to global emissions. However, in other regions, development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving them highly vulnerable to climate change with limited adaptive capacity.	High for adaptation, low for mitigation
SSP5	In the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Economic development is relatively rapid, driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.	High for mitigation, low for adaptation

Source: Based on O'Neill and others (2014).
Note: * SSP2 and SSP4 used in the model for this report.

Figure 3.2: Qualitative SSP narratives (left) and the underlying assumptions (right) on various indicators for countries by income group.



	HIC	MIC	LIC
POP	H	M	L
URB	H	H	H
GDP	H	H	H
EDU	H	H	H

	HIC	MIC	LIC
POP	H	H	M
URB	L	L	L
GDP	L	L	L
EDU	L	L	L

	HIC	MIC	LIC
POP	M	M	M
URB	M	M	M
GDP	M	M	M
EDU	M	M	M

	HIC	MIC	LIC
POP	M	M	L
URB	H	H	H
GDP	H	M	M
EDU	H	H	H

	HIC	MIC	LIC
POP	L	L	H
URB	M	H	H
GDP	M	M	L
EDU	L	L	L

Source: Jiang (2014).
Note: H = high, M = medium, L = low, POP = population, URB = urbanization, GDP = gross domestic product, EDU = education, HIC = high income countries, MIC = medium income countries, LIC = low income countries; * = SSPs used in the model for this report.

The SSP population projections include cross-border movements, but these do not include climate change as a potential driver of future migration flows. As this study builds on the SSPs, by definition it also includes the bilateral migration flows included in the national-level population projections that correspond to each SSP (Samir and Lutz 2014). For both SSP2 and SSP4, these flows are in the middle of the range.[12] They are based on an existing global-level matrix of in- and out-migration (Abel and Sander 2014) that is adjusted to reflect assumptions regarding, for example, conflict and political changes and the degree of openness of national borders in each SSP (O'Neill and others 2014).

Scenario combinations used in the model

Three plausible future internal climate migration scenario combinations are examined (see Figure 1.2):

- A pessimistic reference scenario (SSP4 and RCP8.5), in which low income countries are characterized by high population growth, high rates of urbanization, low GDP growth, and low education levels. High emissions generally drive greater climate impacts. This scenario poses high barriers to adaptation because of the slow pace of development and isolation of regional economies.

- A more inclusive development scenario (SSP2 and RCP8.5), which holds emissions as they are in the pessimistic reference scenario but combines them with reduced inequalities among world regions and more moderate trends in population growth, urbanization, income, and education than under SSP4. Population growth is lower than in SSP4 for low income countries and higher for middle income countries.

- A more climate-friendly scenario (SSP4 and RCP2.6), which has a lower emissions pathway, but holds the development scenario as it is in the pessimistic reference scenario.

Climate impact scenarios

Many studies seeking to understand the effects of climate change on mobility have used climate variables such as temperature and precipitation rather than actual climate impacts on different sectors. A key innovation of this research project is that, rather than simply incorporating likely future climate trajectories, it incorporates actual impacts on two critical sectors, water and agriculture, as well as sea level rise in coastal zones, augmented by storm surge.

Inter-Sectoral Impact Model Intercomparison Project

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) is a climate-impact modeling initiative aimed at contributing to a quantitative and cross-sectoral synthesis of the differential impacts of climate change, including uncertainties. The ISIMIP project uses a subset of the general circulation models used in the IPCC AR5 process. This leads to slight variations in the projected temperature range associated with RCP2.6 and RCP8.5 used in this report. ISIMIP has compiled a database of state-of-the-art computer model simulations of biophysical climate impacts. It offers a framework for consistently projecting the impacts of climate change across affected sectors and spatial scales.

The analysis for this study used outputs of the ISIMIP Fast Track modeling effort, which covers 1970–2010, as well as projections for 2010–50 (Piontek and others 2013).[13] Under the Fast Track, the future sectoral impact models are driven by a range of general circulation models. This project used two general circulation models that provide a good spread for the temperature and precipitation parameters of interest: the HadGEM2-ES climate model developed by the Met Office Hadley Centre for Climate Change (in the United Kingdom) and the IPSL-CM5A-LR climate model developed by the Institut Pierre Simon Laplace Climate Modeling Center (in France) (see Appendix A for details).

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[12] Migration flows are considered medium across all SSPs except SSP3 ("fragmentation"), where they are low, and SSP5 ("conventional development"), where they are high. A more sophisticated set of SSP projections is under development.

[13] See the ISIMIP website https://www.isimip.org/gettingstarted/fast-track-simulation-protocol/.

Climate impacts addressed in the model

The ISIMIP collection of sectoral models includes a range of systems and sectors, such as health, coastal infrastructure, forests, and other ecosystems. The focus of this study is on water availability and crop production, as well as sea level rise scenarios that were developed outside the ISIMIP framework. The global simulations—at a relatively coarse spatial scale (0.5 degrees or roughly 55 kilometers at the equator)—are an advance over purely climate model–based indicators of rainfall and temperature, because they represent actual resources of relevance to development. These climate impacts were selected because the literature shows that water scarcity and declining yields, along with sea level rise, are among the major potential slow-onset climate impacts facing low income countries and these impacts will also be very important drivers of migration.[14]

The model leaves out many important impacts, including the impacts of flood, drought, and cyclones (except to the extent that they affect water availability and crop yields). As devastating as they may be for rural livelihoods, short-duration, rapid-onset events are not directly included. This first-ever attempt to introduce climate impacts into a model of future population distribution over large areas starts with the most important sectoral impacts on migration as a first step, but future efforts could also incorporate more sectoral models. For these reasons, the results should be seen as a lower-bound estimate of the likely impact of climate change on migration.

The focus of this work is not on short-term climate variability or extremes—which are not as well captured by the impact models—but on deviations from baseline conditions over decades. There are compelling theoretical reasons to focus on trends rather than extremes.

- Extremes are more likely to result in short-term displacement (followed by population return to affected areas) (Kälin 2010; Black and others 2011; Brzoska and Fröhlich 2015).
- Longer-term trends in crop yields or water availability are more likely to contribute to out-migration (Bohra-Mishra, Oppenheimer and Hsiang 2014; Nawrotzki and others 2017).
- The impact of successive climate shocks may erode household assets and therefore the ability to adapt locally, eventually affecting decisions to migrate (Warner and others 2012; IDMC 2016).
- Successive shocks over several years will affect the index values described below, because they represent more prolonged deviations from the mean.

The analysis also considers sea level rise projections from the IPCC Fifth Assessment Report, augmented by an increment for storm surges. The figures in Table 3.2 represent the lower-, middle-, and upper-bound sea level rise by 2030 and 2050, as reported by the IPCC (Church and others 2013) but do not take storm surge into account. According to Dasgupta and others (2007, 6), “Even a small increase in sea level can significantly magnify the impact of storm surges, which occur regularly and with devastating consequences in some coastal areas.” A comprehensive assessment of the likely levels of storm surge for all the coastal areas covered by this report was beyond the scope of this project.

Two scenarios meant to be representative of changes in sea level by 2050 associated with RCP2.6 and RCP8.5 were adapted by adding an increment storm surge to account for storm surge on top of the estimates in Table 3.2. Under RCP2.6, the increment was 0.85–0.90 meters, for a total of one meter; under RCP8.5, the increment storm surge was 1.68–1.85 meters, for a total of two meters. These assumptions are applied to all coastlines for 2050; they represent the loss of habitable land as a result of sea level rise plus storm surge in each coastal grid cell. Both the one and two meter sea level rises are based on NASA Shuttle Radar Topography Mission data, as modified by the Center for International Earth Science Information Network (CIESIN 2013). Although the addition of the increments is technically sound and based on past work (Dasgupta and others 2007; Hallegatte and others 2011), the one and two meter bands were chosen partly as an expedient (the global sea level rise layers were developed in earlier work) and partly because at the 14-kilometer modeling resolution, smaller sea level rise increments would have barely registered.

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[14] Water availability is influenced by rainfall and rising temperatures. Crop production is a function of rainfall, temperature, CO_2 concentrations, irrigation, and other management practices that are incorporated in the ISIMIP models.

Photo Credit: Shutterstock

Table 3.2: Projected rise in sea level under low and high Representative Concentration Pathways (RCP) (meters above current mean sea level)

	RCP 2.6			RCP 8.5		
Year	Lower	Middle	Upper	Lower	Middle	Upper
2030	0.092	0.127	0.161	0.098	0.132	0.166
2050	0.157	0.218	0.281	0.188	0.254	0.322

Source: Church and others (2013).
Note: Sea level rise was augmented with storm surge increments under RCP 2.6 (0.85-0.9m); and RCP 8.5 (1.68-1.85m).

Water and crop models used in the gravity model

Data on water availability and crop production were integrated into the gravity model using the following approach. The water sector model outputs represent river discharge, measured in cubic meters per second in daily/monthly time increments. The crop sector model outputs represent crop yield in tons per hectare on an annual time step at a 0.5° x 0.5° grid cell resolution. Crops include maize, wheat, rice, and soy beans; for regions with multiple cropping cycles, yield reflects only the major crop production period.[15] The data were converted to decadal average water availability and crop production (in tons) per grid cell.[16] An index was then calculated that compares those values with the 40-year average for water availability and crop production for 1970–2010:

$$Index = (D_{avg} - B_{avg}) / B_{avg} \qquad \text{(Equation 3.1)}$$

where D_{avg} is the decadal average crop production/water availability and B_{avg} is the baseline average crop production/water availability for the 40-year period 1970–2010. The indexes for water availability and crop production represent deviations from the long-term averages (0.2 indicates 20 percent above the baseline average; –0.6 indicates 60 percent below the baseline average).

The ISIMIP models are based on different combinations of climate, crop, and water models. Applying the combinations—two global climate models driven by two different emissions scenarios, which in turn drive two sets of sectoral impact models (described below)—provides a range of plausible population projections. It also gives a sense of the level of agreement across scenarios. Because the population modeling process is time consuming and computationally intensive, it was important to work with a reduced set of ISIMIP inputs.[17] The modeling employed the HadGEM2-ES and IPSL-CM5A-LR global climate models, which drive combinations of the two water models and two crop models: the LPJmL water and crop models, the WaterGAP2 water model, and the GEPIC crop model (Table 3.3). Appendix A provides detailed information on model selection.

The crop and water models were selected based on several criteria, including model performance over the historical period, diversity of model structure, diversity of signals of future change, and availability of both observationally driven historical (ISIMIP2a) and global climate model-driven historical and future (ISIMIP fast-track) simulations. Table 3.3 presents the combinations of models used.

For each of the three climate migration scenarios (Figure 1.2)—pessimistic reference, more inclusive development, and more climate-friendly model outputs were averaged to generate a mean or "ensemble." Figure 3.3 shows how the four model results for the pessimistic reference scenario (SSP4-RCP8.5) were averaged to create an ensemble for Ethiopia.

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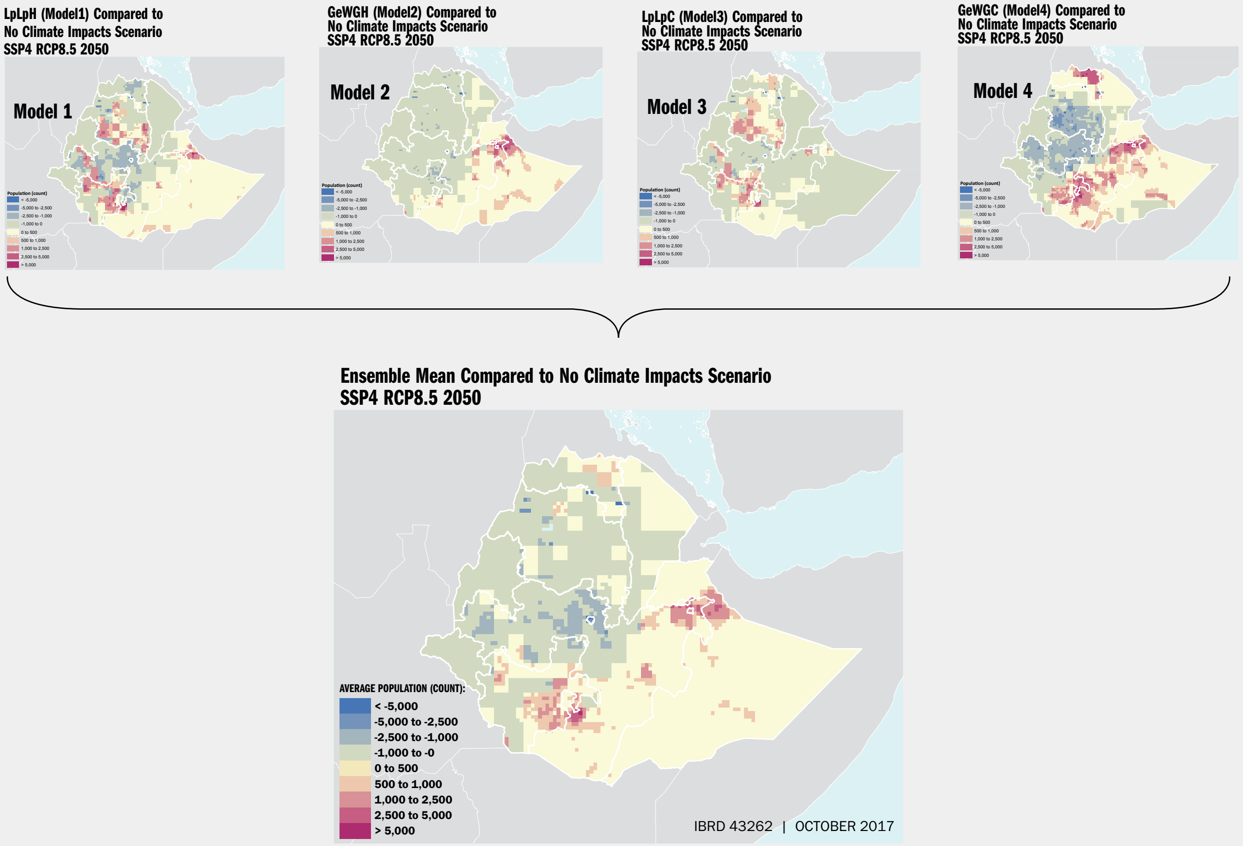
15. The ISIMIP models seek to assess the risk that climate change will affect the potential for agriculture in a given location. For this purpose, the relative changes in average yield potential are useful.
16. The models report "pure crop yields" in tons per hectare (that is, they assume that a given crop is grown everywhere, irrespective of growing conditions or the location where crops are actually grown). These yields were multiplied by observations-based growing areas (in 2005), separately for rainfed and irrigated yields, to obtain grid cell-level production (in metric tons) (Portmann, Siebert, and Döll, 2010).
17. Feeding all potential ISIMIP water and crop model outputs into the gravity model would have yielded 12,500 model runs: 2 RCPs * 5 GCMs * 25 crop model outputs * 50 water model outputs =12,500.

Photo Credit: Petr Kapuscinski / World Bank

Table 3.3: Matrix of climate, crop and water model combinations used in this report.

	Crop simulation			
Water simulation	GCM1, LPJmL (crop)	GCM1, GEPIC	GCM2, LPJmL (crop)	GCM2, GEPIC
HadGEM2-ES, LPJmL (water)	Model 1			
HadGEM2-ES, WaterGAP2		Model 2		
IPSL-CM5A-LR, LPJmL (water)			Model 3	
IPSL-CM5A-LR, WaterGAP2				Model 4

Figure 3.3: Illustrative example for Ethiopia: Combining four model outputs into one ensemble



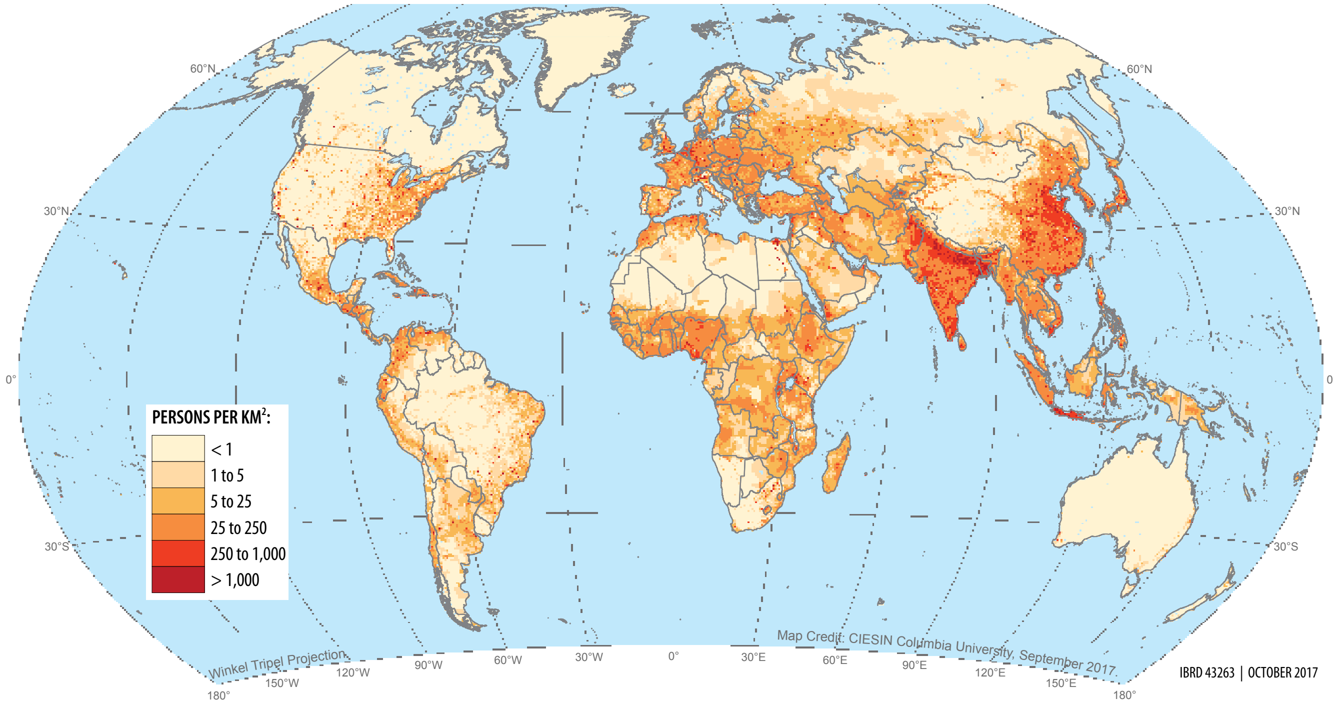
ISIMIP water and crop model results

Climate impacts on water availability and crop production have important impacts on the population potential of locations in the gravity model. Appendix B presents the water and crop production indexes in the context of climate trends and projections for each of the regions. The climate impacts are an input to the gravity model; when combined with parameters derived from the development scenarios (the SSPs), they directly affect the population potential of regions within countries. Chapters 4 and 5 translate this information into regional and country-specific estimates of climate migration.

Population data

The population baseline used is the 2010 baseline in the Center for International Earth Science Information Network (CIESIN) Gridded Population of the World Version 4 (GPWv4) (CIESIN 2016) (Map 3.1). The gravity model was calibrated based on population change estimates for 1990-2000 from GPW version 3 (CIESIN and others 2005) and for 2000–10 from GPWv4. GPW versions 3 and 4 model the distribution of the population on a continuous global surface based on the highest spatial resolution census data available from the 2000 and 2010 rounds of censuses, respectively. In this work, population count grids were used that were adjusted to national-level estimates from the United Nations World Population Prospects reports. GPWv3 and v4 are gridded data products with output resolutions of 2.5 arc-minutes (a square approximately four kilometers on a side at the equator) and 30 arc-seconds (a square approximately one kilometer on a side at the equator), respectively. For model calibration and the baseline population for the future projections, the data were aggregated to 7.5 arc-minutes (a square approximately 14 kilometers on a side at the equator [i.e. grid cells with an area of 196 square kilometers]). Uncertainties about these data are discussed in Appendix A.

Map 3.1: Global population density, 2010



Source: Gridded Population of the World Version 4 (CIESIN 2016).

POPULATION MODELING METHODS

The modeling work is based on a modified version of the National Center for Atmospheric Research-CUNY Institute for Demographic Research (NCAR-CIDR) gravity model (Jones and O'Neill 2016).[18] Technical details on the model specification are in Appendix A.[19]

The gravity model

The original NCAR-CIDR model is a gravity-based approach that downscales national population projections to subnational raster grids (Jones and O'Neil 2013, 2016) as a function of geographic, socioeconomic, and demographic characteristics of the landscape and existing population distribution. Gravity-type approaches are commonly used in geographic models of spatial allocation and accessibility. They take advantage of spatial regularities in the relationship between population agglomeration and spatial patterns of population change. These relationships can be described as a function of the characteristics known to correlate with spatial patterns of population change.

The NCAR-CIDR model uses a modified form of population potential, a distance-weighted measure of the population taken at any point in space that represents the relative accessibility of that point. For example, higher values indicate a point more easily accessible by a larger number of people. Summed over all points within an area, population potential represents an index of the relative influence that the population at a point within a region exerts on each point within that region, and can be considered an indicator of the potential for interaction between the population at a given point in space and all other populations (Rich 1980). This potential will be higher at points closer to large populations; potential is thus also an indicator of the relative proximity of the existing population to each point within an area (Warntz and Wolff 1971). Such metrics are often used as a proxy for attractiveness, under the assumption that agglomeration is indicative of the various socioeconomic, geographic, political, and physical characteristics that make a place attractive.

Adding climate impacts

The calculation of potential was modified by adding local characteristics, including climate impacts. Figure 3.4 is a flowchart of the modeling steps; boxes in red show the addition of climate impacts or results incorporating climate impacts. Population potential is a relative measure of agglomeration, indicating the degree to which amenities and services are available. In the original model, this value shifts over time as a function of the population; of assumptions regarding spatial development patterns (for example, sprawl versus concentration); and of certain geographic characteristics of the landscape.

Beginning with the 2010 gridded urban/rural population distribution for each country, the modeling done for this report incorporated the influence of climate impacts on relative attractiveness in the following manner:

a. Calculate an urban population potential surface (a distribution of values reflecting the relative attractiveness of each grid cell).
b. Calculate a rural population potential surface.
c. Allocate projected urban population change to grid cells proportionally based on their urban potentials.
d. Allocate changes in the projected rural population to grid cells proportionally based on their rural potential.
e. Because the allocation procedure can lead to some redefinition of population from rural to urban (for example, rural population allocated to a cell with an entirely urban population is redefined as urban), this step entails redefining population as urban or rural as a function of density and contiguity of fully urban or rural cells to match projected national level totals.

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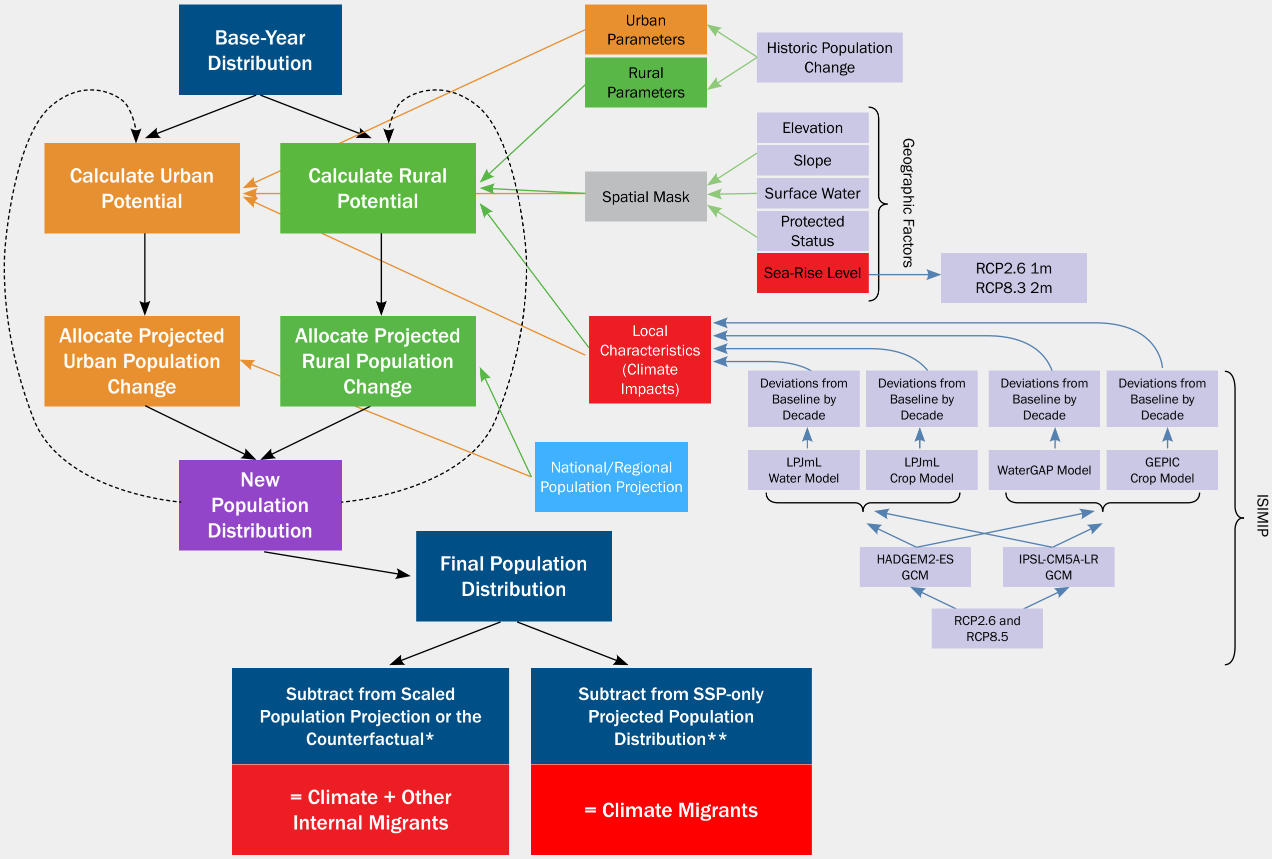
[18] Data for the original SSP-only population projections are available for download via the NASA Socioeconomic Data and Applications Center (SEDAC) at https://doi.org/10.7927/H4RF5S0P. These projections are produced using a baseline 2010 population of GPWv3 rather than GPWv4, as used here.

[19] Climate and social scientists conducted a technical review of the modeling approach in March 2017. A number of useful suggestions were incorporated.

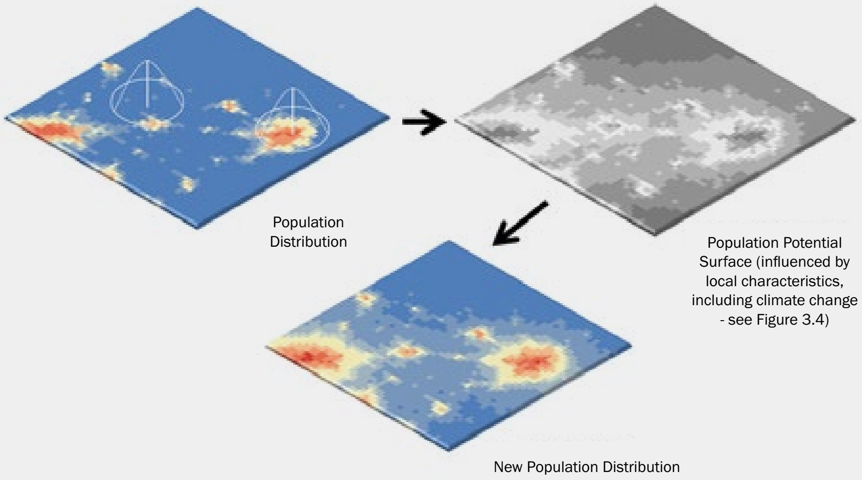
These steps are then repeated for each decadal time interval. Figure 3.5 illustrate steps “c” and “d” for a hypothetical population distribution. Note that population potential surfaces, urban and rural, are continuous across all cells; each cell may thus contain urban and rural populations.

Figure 3.4: Flowchart of modeling steps



Note: Boxes in red represent the addition of climate impacts into the modeling framework or results that reflect climate impacts.
* The counterfactual population projection simply scales the population distribution in 2010 to country-level population totals appropriate to each SSP.
** The SSP-only population projection represents the population projection without climate impacts (i.e., based only on the development trajectories embodied in the SSPs).

Figure 3.5: Hypothetical example of the gravity-based population projection model for a single time step



Based on the modified NCAR-CIDR population potential (v_i) is calculated as a parametrized negative exponential function:

$$v_i = A_i l_i \sum_{j=1}^{m} P_j^{\alpha} e^{-\beta d_{ij}} \qquad \text{(Equation 3.2)}$$

Where:

A_i = Local characteristics

l_i = Spatial mask

a = Population parameter etc.

P = Population
β = Distance parameter
d = Distance

It is weighted by a spatial mask[20] (*l*) that prevents population from being allocated to areas that are protected from development or unsuitable for human habitation, including areas that will likely be affected by sea level rise between 2010 and 2050. P_j is the population of grid cell *j*; *d* is the distance between two grid cells. The distance and population parameters (α and β) are estimated from observed patterns of historical population change. The β parameter is indicative of the shape of the distance–density gradient describing the broad pattern of the population distribution (for example, sprawl versus concentration). The α parameter captures returns on agglomeration externality, interpreted as an indicator of the socioeconomic, demographic, and political characteristics that make a place more or less attractive.

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[20] Spatial masks are used in geospatial processing to exclude areas from consideration. The effect is that the algorithm is not applied in these areas. Examples in this instance would include protected areas or places where the terrain is too rugged to inhabit.

The SSPs include no climate impacts on aggregate total population, urbanization, or the subnational spatial distribution of the population. The NCAR-CIDR approach was modified by incorporating additional spatial data in the form of the ISIMIP sectoral impacts likely to affect population outcomes. The index A_j is a weight on population potential that is calibrated to represent the influence of the crop and water sectoral impact indicators on spatial patterns of population change. The ISIMIP data, which represent decadal deviation from long-term baseline conditions, are incorporated into the model as gridded spatial layers. The value A_j is calculated as a function of these indicators; it represents an adjustment to the relative attractiveness of (or aversion to) specific locations (grid cells), reflecting current water availability and crop yields relative to “normal” conditions. The model is calibrated over two decadal periods (1990–2000 and 2000-10) of observed population change relative to deviations of water availability and crop production from the 1970–2010 average for a subset of representative countries in each region.[21] For the three focus regions, the countries include Ethiopia, Mozambique, and Tanzania for East Africa; Mexico for Mexico and Central America; and Bangladesh and India for South Asia. For the additional regions of Sub-Saharan Africa and Latin America, the countries include Guinea and Mauritania for West Africa, the Democratic Republic of Congo for Central Africa, and Botswana for Southern Africa as well as Argentina and Brazil for South America.

Details on the modeling methodology, including the methods used for calibration, are in Appendix A.2. Proposals for additional model enhancements in the future are in Appendix A.3. Summary methods for data visualization are in Section 4.2, with details in Appendix A.4.

Characterizing the model

This modeling provides transparent, spatially explicit estimates of changes in the population distribution (and indirectly migration) as a function of climate and development trends. It is important to understand what the model does and does not do.

Gravity models can be used to model past evolutions of population distributions based on observed agglomeration effects over large geographic regions, under varying conditions, and at alternative spatial scales. They can also be refined to incorporate additional details, such as environmental parameters that affect the relative attractiveness of locations.

Gravity models do not directly model internal migration. Instead, deviations between the population distributions in model runs that include the crop and water impacts and the development-only (also referred to as the SSP or “no climate impact”) model runs are assumed to be driven primarily by differences in climate change–induced internal migration. Migration is a “fast” demographic variable compared with fertility and mortality; it is responsible for much of the decadal-scale redistributions of population. Without significant variation in fertility and mortality rates between climate-migrant populations and nonmigrant populations, it is fair to assume that differential population change between the climate impact scenarios and the development-only scenarios occur as a function of migration. Another way of saying this is that the model assumes that fertility and mortality rates are relatively consistent across populations in a locale.

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[21] Accurate spatial data from censuses on the location of populations or the change in population over time are not available for most low and middle income countries before 1990.

For each climate migration scenario, the model produces a range of estimates that reflect variation in the underlying inputs to the model, which in turn reflect scientific uncertainty over likely future climate projections and impacts and development trajectories. In any scenario, outcomes are a function of the global climate models and the sectoral impact models that drive climate impacts on population change. For each of the three scenarios, there are four models, consisting of different global climate models and ISIMIP combinations. The ensemble mean (or average) of the four models is reported as the primary result for each scenario. Uncertainty is reflected in the range of outcomes (across the four models) for each grid cell and at different levels of aggregation. While some may prefer to have just one figure, in a complex issue like climate-related migration, a scenario-based approach is preferable. It would be desirable to have even more scenarios, to better assess the uncertainty (or conversely confidence) in the results (Box 3.1). However, for the reasons noted above, time and resource constraints prevented more than four realizations for the model per climate-development combination.

Box 3.1: Sources of uncertainty in modeling climate migration

The climate migration modeling results incorporate six main sources of uncertainty that can affect the estimated number of climate migrants or the differences between the three scenarios and the development-only scenario.

1. ISIMIP impacts vary across models. In Central America, for example, the combined LPJmL water and crop models have generally lower impacts than the WaterGAP-GEPIC combination of water and crop models, though these differences vary across the region. The differences result in different effects in the gravity model; models with the highest impacts repel more people from affected areas in the former set of outputs than in the latter set.

2. Variations between the two global climate models—HadGEM2-ES and IPSL-CM5A-LR—can amplify the ISIMIP differences. The global climate models were selected in part because their future precipitation trends differ substantially in magnitude, and partly even in sign, for the focus regions (see Appendix A). This variance in precipitation has an impact on both the water and crop models.

3. The modeling has a temporal component that can influence population distribution trajectories. Stronger sectoral impacts early in the 40-year projection period will have greater influence than the same impacts later in that period, because those early impacts affect the gravitational pull of locations, creating "temporal" momentum over which later climate impacts may have less influence. Similarly, the timing of population change (growth or decline) projected by the SSPs relative to the development of sectoral impacts can influence outcomes. For example, for most countries in the study, projected population growth is greatest during the first decade; if conditions are also predicted to deteriorate severely during that period, the impact on migration will be greater than if the deterioration took place during a more demographically stable period.

4. If the SSP-only model finds that a place is relatively attractive and the sectoral climate impacts are positive or neutral (relative to other areas that see negative impacts), it will have the effect of reinforcing the attractiveness of that area. Conversely, in remote areas experiencing population decline and negative climate impacts, "push" factors will be reinforced. This phenomenon creates spatial momentum.

5. Model parameterization affects the results. The model was calibrated using actual population changes in association with actual climate impacts (represented by ISIMIP model outputs) for two periods, 1990–2000 and 2000–10. This calibration was done using the two separate sets of model combinations: the LPJmL water and crop models and the WaterGAP water and GEPIC crop models. Different parameters correspond to the different models. If the parameter estimates are close together across the different crop or water models, there will be less variation in the population distribution projected by each model; the uncertainty around the ensemble mean (measured using the coefficient of variation) will therefore be lower. Conversely, if parameter estimates are not close together, there will be greater uncertainty around the ensemble mean.

6. Countries within regions are at different stages of economic development, which can have a significant impact on the population totals by 2050 for the two groups.

This “top-down” model shows the results of household-level decisions that influence migration (de Sherbinin and others 2008), but it does not build directly on the evidence (or data) from microlevel studies. It considers such factors only at an aggregate level. In an effort to connect this work to household-level migration research, Chapter 5 provides case study narratives for Ethiopia, Bangladesh, and Mexico—three countries on which there is a rich body of literature on household-level decision making and environmental migration. Those illustrative country examples situate, and to some degree validate, this work in the context on the household dimension.

The model is run at spatial and temporal scales that capture migration well. With grid cells of about 14 square kilometers at the equator, population shift can be considered a form of short-distance migration. The temporal scale of decadal increments from 2010–50 is adequate to capture the longer-term shifts in population caused by slow-onset changes in water availability, crop conditions, and sea level rise. The model does not capture movements over shorter time periods.

This period represents a meaningful planning horizon, especially when considering the social dimension of migration. Chapter 4 considers water and agriculture sector impacts beyond 2050 by examining ISIMIP outputs for 2050–2100. They suggest that, if anything, the climate signal will become far stronger toward the end of the 21st century.

The model cannot forecast all future adaptation efforts or conflict, cultural, political, institutional, or technological changes. Discontinuities are likely to arise as a result of political events and upheavals that can heavily influence migration behavior. Armed conflict itself may have links to climate variability and change (Box 2.4), but models have generally failed to forecast armed conflict or state failure with any precision. The scenario framework is not designed to predict shocks to any socioeconomic or political system, such as war or market collapse. The models also cannot anticipate new technologies that may dramatically affect adaptation efforts to the degree that climate impacts become negligible. The SSPs, as well as output from the global climate model and ISIMIP, reflect plausible futures that span a wide range of global trajectories, with the caveat that extremely unpredictable or unprecedented events are explicitly excluded.

Photo Credit: Shutterstock

REFERENCES

Abel, G. J., and N. Sander. 2014. “Quantifying Global International Migration Flows.” *Science* 343, no. 6178 (2014): 1520-22. doi:10.1126/science.1248676.

Afifi, T., and K. Warner. 2008. “The Impact of Environmental Degradation on Migration Flows across Countries.” Working Paper, United Nations University Institute for Environment and Human Security, Bonn, Germany.

Ajzen, I. 1991. “The Theory of Planned Behavior.” *Organizational Behavior and Human Decision Processes* 50 (2): 179–211.

Backhaus, A., I. Martinez-Zarzoso, and C. Muris. 2015. “Do Climate Variations Explain Bilateral Migration? A Gravity Model Analysis.” *IZA Journal of Migration* 4 (3): 1–15.

Bierwagen, B. G., D. M. Theobald, C. R. Pyke, A. Choate, P. Groth, J. V. Thomas, and P. Morefield. 2010. “National Housing and Impervious Surface Scenarios for Integrated Climate Impact Assessments.” *Proceedings of the National Academy of Sciences* 107 (49): 20887–20892.

Black, R., W. N. Adger, N. W. Arnell, S. Dercon, A. Geddes, and D. Thomas. 2011. “The Effect of Environmental Change on Human Migration.” *Global Environmental Change* 21 (S1): S3–11

Bohra-Mishra, P., M. Oppenheimer, and S.M. Hsiang 2014. Nonlinear permanent migration response to climatic variations but minimal response to disasters. *Proceedings of the National Academy of Sciences* 111(27): 9780-9785

Brzoska, M., and C. Fröhlich. 2015. “Climate Change, Migration and Violent Conflict: Vulnerabilities, Pathways and Adaptation Strategies.” *Migration and Development* 5 (2): 190–210.

Church, J. A., P. U. Clark, A. Cazenave, J. M. Gregory, S. Jevrejeva, A. Levermann, M. A. Merrifield, G. A. Milne, R. S. Nerem, P. D. Nunn, A. J. Payne, W. T. Pfeffer, D. Stammer, and A. S. Unnikrishnan. 2013. “Sea Level Change.” In *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, 1137-1216. Cambridge, UK, and New York, NY: Cambridge University Press.

CIESIN (Center for International Earth Science Information Network) - Columbia University. 2013. “Low Elevation Coastal Zone (LECZ) Urban-Rural Population and Land Area Estimates, Version 2.” Palisades, NY: NASA Socioeconomic Data and Applications Center. doi:http://dx.doi.org/10.7927/H4MW2F2J.

———. 2016. “Gridded Population of the World, Version 4 (GPWv4): Population Count.” Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4X63JVC

CIESIN (Center for International Earth Science Information Network) - Columbia University, Centro Internacional de Agricultura Tropical (CIAT), and United Nations Food and Agriculture Programme (FAO). 2005. “Gridded Population of the World, Version 3 (GPWv3): Population Count Grid.” Palisades, NY: NASA Socioeconomic Data and Applications Center. http://dx.doi.org/10.7927/H4639MPP.

Clark, W. A. V., and S. D. Davies. 2002. “Changing jobs and changing houses: Mobility outcomes of employment transitions.” *Journal of Regional Science* 39 (4): 653–673.

Dasgupta, S., B. Laplante, C. Meisner, D. Wheeler, and J. Yan. 2007. “The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis.” *Policy Research Working Paper* 4136, World Bank, Washington, DC.

de Sherbinin, A., and L. Bai. Forthcoming. *Handbook on Environmental Displacement and Migration: Section on Geospatial Modelling and Mapping*. New York: Routledge.

de Sherbinin, A., L. K. VanWey, K. McSweeney, R. Aggarwal, A. Barbieri, S. Henry, L. M. Hunter, W. Twine, and R. Walker. 2008. “Rural household demographics, livelihoods and the environment.” *Global Environmental Change* 18 (1): 38–53.

Dilley, Maxx, Robert Chen, Uwe Deichmann, Arthur Lerner-Lam, Margaret Arnold, Jonathan Agwe, Piet Buys, Oddvar Kjevstad, Bradfield Lyon, and Gregory Yetman. 2005. *Natural disaster hotspots: A global risk analysis*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/621711468175150317/Natural-disaster-hotspots-A-global-risk-analysis

Ebi, K. L., S. Hallegatte, T. Kram, N. W. Arnell, T. R. Carter, J. Edmonds, E. Kriegler, R. Mathur, B. C. O'Neill, K. Riahi, H. Winkler, D. P. van Vuuren, and T. Zwickel. 2014. "A new scenario framework for climate change research: background, process, and future directions." *Climatic Change* 122 (3): 363–372.

Feng, S., A. B. Krueger, and M. Oppenheimer. 2010. "Linkages among Climate Change, Crop Yields and Mexico–US Cross-Border Migration." *Proceedings of the National Academy of Sciences* 107 (32): 14257–14262.

Ginnetti, J. 2015. "Modelling Displacement." *Forced Migration Review* 49: 10–11.

Gray, C., and E. Wise. 2016. "Country-specific effects of climate variability on human migration." *Climatic Change* 135 (3-4): 555–568.

Gustafson, P. 2001. "Retirement migration and transnational lifestyles." *Ageing & Society* 21 (4): 371–394.

Hallegatte, Stéphane, Nicola Ranger, Olivier Mestre, Patrice Dumas, Jan Corfee-Morlot, Celine Herweijer, and Robert Muir Wood. "Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen." *Climatic Change* 104 (1): 113-137.

Henry, S., B. Schoumaker, and C. Beauchemin. 2004. "The Impact of Rainfall on the First Out-Migration: A Multi-Level Event-History Analysis in Burkina Faso." *Population and Environment* 25 (5): 423–460.

IDMC (Internal Displacement Monitoring Center). 2016. Global Estimates 2015: People Displaced by Disasters. Geneva.

IPCC (Intergovernmental Panel on Climate Change). 2014. *Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed. Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White , 1-32. Cambridge, United Kingdom and New York, NY, USA : Cambridge University Press.

Jiang, Leiwen. 2014: Internal consistency of demographic assumptions in the shared socioeconomic pathways. *Population and Environment* 35(3): 261-285.

Jones, B., and B. C. O'Neill. 2013. "Historically Grounded Spatial Population Projections for the Continental United States." *Environmental Research Letters* 8 (4): 44021. doi:10.1088/1748-9326/8/4/044021

———. 2016. "Spatially Explicit Global Population Scenarios Consistent with the Shared Socioeconomic Pathways." *Environmental Research Letters* 11 (8): 84003. doi:10.1088/1748-9326/11/8/084003

Kälin, W. 2010. "Conceptualising climate-induced displacement." In *Climate Change and Displacement: Multidisciplinary Perspectives*, ed. J. McAdam, 81–103. Oxford, UK: Hart Publishing.

Kim, T.-K., M. W. Horner, and R. W. Marans. 2005. "Life cycle and environmental factors in selecting residential and job locations." *Housing Studies* 20 (3): 457–473.

Kniveton, D. R., C. Smith, and S. Wood. 2011. "Agent-Based Model Simulations of Future Changes in Migration Flows for Burkina Faso." *Global Environmental Change* 21 (Supp. 1): S34–S40.

Massey, D., W. G. Axinn, and D. J. Ghimire. 2010. "Environmental Change and out-Migration: Evidence from Nepal." *Population and Environment* 32 (2/3): 109–136.

McGranahan, G., D. Balk, and B. Anderson. 2007. "The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones." *Environment and Urbanization* 19 (1): 17–37.

McKee J. J., A. N. Rose, E. A. Bright, T. Huynh, and B. L. Bhaduri. 2015. "Locally Adaptive, Spatially Explicit Projection of US Population for 2030 and 2050." *Proceedings of the National Academy of Sciences* 112 (5): 1344–1349.

McLeman, R. 2013. “Developments in Modelling of Climate Change-Related Migration.” *Climatic Change* 117 (3): 599–611. doi:10.1007/s10584-012-0578-2

Mondal, P., and A. J. Tatem. 2012. “Uncertainties in Measuring Populations Potentially Impacted by Sea Level Rise and Coastal Flooding.” *PLoS ONE* 7 (10): e48191. doi:10.1371/journal.pone.0048191

Nawrotzki, R. J., J. DeWaard, M. Bakhtsiyarava, and J. Trang Ha. 2017. “Climate Shocks and Rural-Urban Migration in Mexico: Exploring Nonlinearities and Thresholds.” *Climatic Change* 140 (2): 243–258. doi:10.1007/s10584-016-1849-0

Nawrotzki, R. J., L. M. Hunter, and T. W. Dickinson. 2012. “Rural livelihoods and access to natural capital: Differences between migrants and non-migrants in Madagascar.” *Demographic Research* 26: 661–699.

Neumann, B., J. Zimmermann, R. J. Nicholls, and A. T. Vafeidis. 2015. “Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding—A Global Assessment.” *PLoS ONE* 10 (3): e0118571. doi:10.1371/journal.pone.0118571

O’Neill, Brian C., Elmar Kriegler, Keywan Riahi, Kristie L. Ebi, Stephane Hallegatte, Timothy R. Carter, Ritu Mathur, and Detlef P. van Vuuren. 2014. “A new scenario framework for climate change research: the concept of shared socioeconomic pathways.” *Climatic Change* 122 (3): 387-400.

Peduzzi, P., H. Dao, C. Herold, and F. Mouton. 2009. “Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index.” *Natural Hazards and Earth System Sciences* 9 (4): 1149–1159.

Piontek, F., C. Müller, T. A. M. Pugh, D. B. Clark, D. Deryng, J. Elliott, F. de Jesus Colón González, M. Flörke, C. Folberth, W. Franssen, K. Frieler, A. D. Friend, S. N. Gosling, D. Hemming, N. Khabarov, H. Kim, M. R. Lomas, Y. Masaki, M. Mengel, A. Morse, K. Neumann, K. Nishina, S. Ostberg, R. Pavlick, A. C. Ruane, J. Schewe, E. Schmid, T. Stacke, Q. Tang, Z. D. Tessler, A. M. Tompkins, L. Warszawski, D. Wisser, and H. J. Schellnhuber. 2013. “Multisectoral climate impact hotspots in a warming world.” *Proceedings of the National Academy of Sciences* 11 (9): 3233–3238. doi: 10.1073/pnas.1222471110

PRB (Population Reference Bureau). 2017. World Population Data Sheet. Washington, DC.

Portmann, Felix T., Stefan Siebert, and Petra Döll. “MIRCA2000—Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling.” *Global Biogeochemical Cycles* 24 (1).

Rich, D. C. 1980. “Potential models in human geography.” *Concepts and Techniques in Modern Geography* 26.

Samir, K.C. and Lutz, W., 2017. “The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100.” *Global Environmental Change*, 42, pp.181-192.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl. 2012. “An Overview of CMIP5 and the Experiment Design.” *American Meteorological Society*, pp.485-498.

van Vuuren, D. P., E. Kriegler, B. C. O’Neill, K. L. Ebi, K. Riahi, T. R. Carter, J. Edmonds, S. Hallegatte, T. Kram, R. Mathur, and H. Winkler. 2014. “A new scenario framework for climate change research: scenario matrix architecture.” *Climatic Change* 122 (3): 373–386.

Walsh, S. J., G. P. Malanson, B. Entwisle, R. R. Rindfuss, P. J. Mucha, B. W. Heumann, P. M. McDaniel, B. G. Frizzelle, A. M. Verdery, N. Williams, Y. Xiaozheng, and D. Ding. 2013. “Design of an Agent-Based Model to Examine Population-Environment Interactions in Nang Rong District, Thailand.” *Applied Geography* 39: 183–98.

Warner, K., K. van der Geest, S. Kreft, S. Huq, S. Harmeling, K. Koesters, and A. de Sherbinin. 2012. “Evidence from the Frontlines of Climate Change: Loss and Damage to Communities Despite Coping and Adaptation.” Bonn, Germany: United Nations University.

Warntz, W., and P. Wolff, ed. 1971. *Breakthroughs in geography*. New York: New American Library.

Chapter 4

Climate Migration Projections for Regions and Subregions of Focus

This chapter presents modeling results across three regions—Sub-Saharan Africa, South Asia, and Latin America. As per the approach used in this report, modeling of climate induced shifts in population distribution is applied at a country level, and results are then aggregated at the broader regional level. The chapter starts by presenting a more in-depth analysis for the three focus subregions—East Africa, South Asia (in its entirety), and Mexico and Central America—which have contrasting climatic, livelihood, demographic, migration, and development patterns. Results underscore the potential for an increase in the number of climate migrants through 2050. Results are then aggregated at the regional level for Sub-Saharan Africa and Latin America. For Sub-Saharan Africa, this includes results from the East, West, Central, and Southern Africa subregions. For Latin America, this includes aggregated results for Mexico and Central America, and South America. The emergence of climate in-migration and out-migration hotspots in each of the subregions through to 2050 are also discussed. The chapter concludes with a discussion of how climate impact trends will evolve beyond 2050 and what this means for the potential intensification of climate migration levels. In Chapter 5, these results are further contextualized for deeper narrative through illustrative country examples from the three regions—Ethiopia, Bangladesh, and Mexico.

The results underscore the potential for upward trends in the number of climate migrants through 2050, with an emergence of climate migration hotspots across the landscape. The geographic distribution of climate in- and out-migration hotspots will vary widely across the three subregions. Many in-migration hotspots are in cooler highland areas that will become even more densely populated. Out-migration of varying degrees is projected from coastal zones (defined as areas within 10 kilometers of the coast) in all three subregions. Mexico and Central America will see the largest proportion of migration from coastal areas and South Asia the lowest, though the absolute numbers are higher in South Asia than in the other two subregions. East Africa, and Mexico and Central America, will see climate out-migration from rainfed cropping areas, indicating that climate impacts on crop productivity in these subregions may potentially disproportionately affect farming households.

Climate migration trends are likely to become more intense in the second half of the century, when climate impacts become more prominent. For some subregions, particularly Mexico and Central America, but also India under certain models, negative deviations from baseline conditions become much more marked. Given the sensitivity of population shifts to climate impacts in the historical period (used to calibrate the model) and through 2050, it is highly likely that climate migration numbers will go up dramatically after 2050 unless significant mitigation and adaptation efforts are put in place.

DESCRIPTION OF THE SUBREGIONS

East Africa

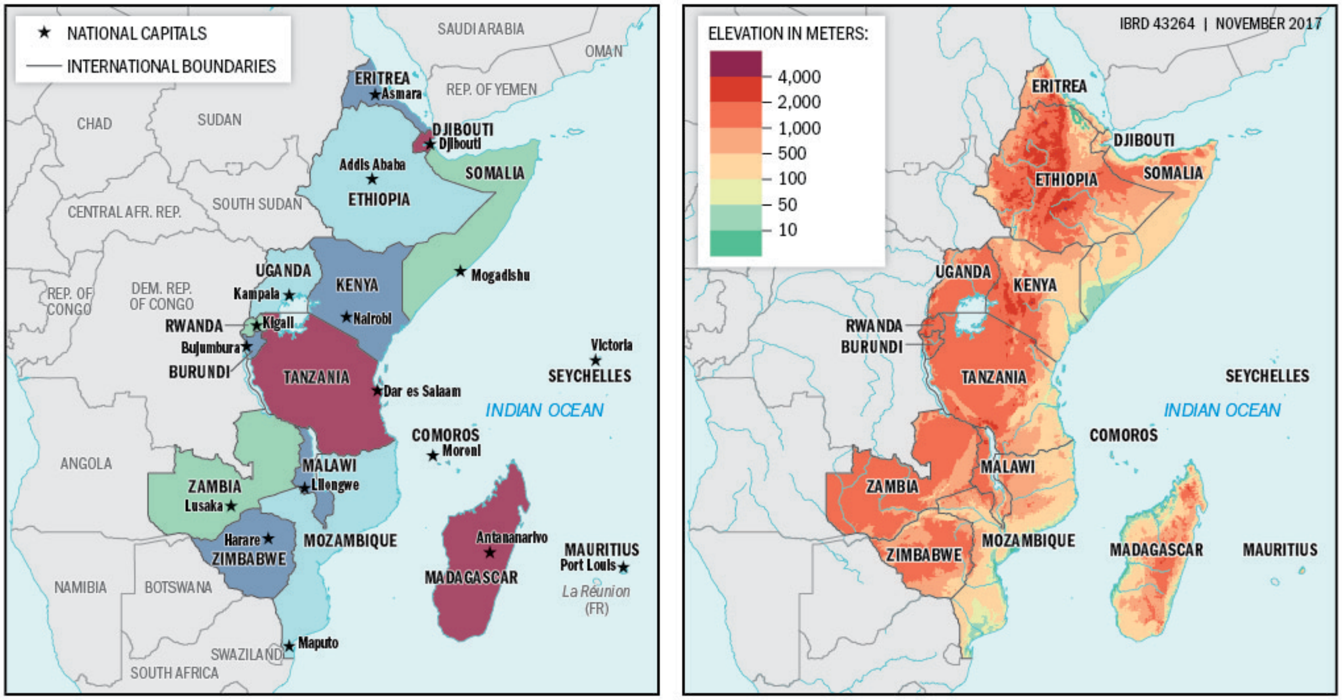
Much of East Africa is semi-arid, with large swaths of grasslands, shrublands, and savannahs. The region has patches of flooded grasslands and savannahs. In the more humid highlands (of, for example, Burundi, Ethiopia, Madagascar, Rwanda, and Uganda) and along a coastal belt, tropical broadleaf forests dominate (Olson and others 2001). The nonarable shrublands are generally thinly settled, although countries in the subregion have reasonably high fertility rates (and by extension, population growth rates) as shown in Table 4.1. The urban share of the population is also relatively low, though like much of the developing world, it is rapidly urbanizing. Except for Kenya and Zambia, the rest of the countries in the subregion are in the lowest human development category (UNDP 2016). Map 4.1 shows the political boundaries and elevation in East Africa.

Table 4.1: Demographic indicators and projected population in 2050 by subregion under the Shared Socioeconomic Pathways (SSPs)

Subregion	Population in 2017 (millions)	Total fertility rate (births per woman)	Urban share of population (percent)	Projected population in 2050 (millions)	
				SSP4	SSP2
East Africa	422	4.7	27	786	675
West Africa	371	5.3	46	792	678
Central Africa	163	5.9	44	391	349
Southern Africa	65	2.5	62	66	73
South Asia	1,885	2.4	35	2,290	2,373
Mexico and Central America	177	2.3	74	204	211
South America	423	1.9	83	461	491

Source: The first three columns are from Population Reference Bureau (PRB 2017); the last two columns are based on Shared Socioeconomic Pathways (SSPs).
Note: SSP2 = moderate development and SSP4 = unequal development (Jiang 2013).

Map 4.1: Political boundaries and elevation in East Africa



a. Political boundaries

b. Elevation

Photo Credit: Dominic Chavez/World Bank

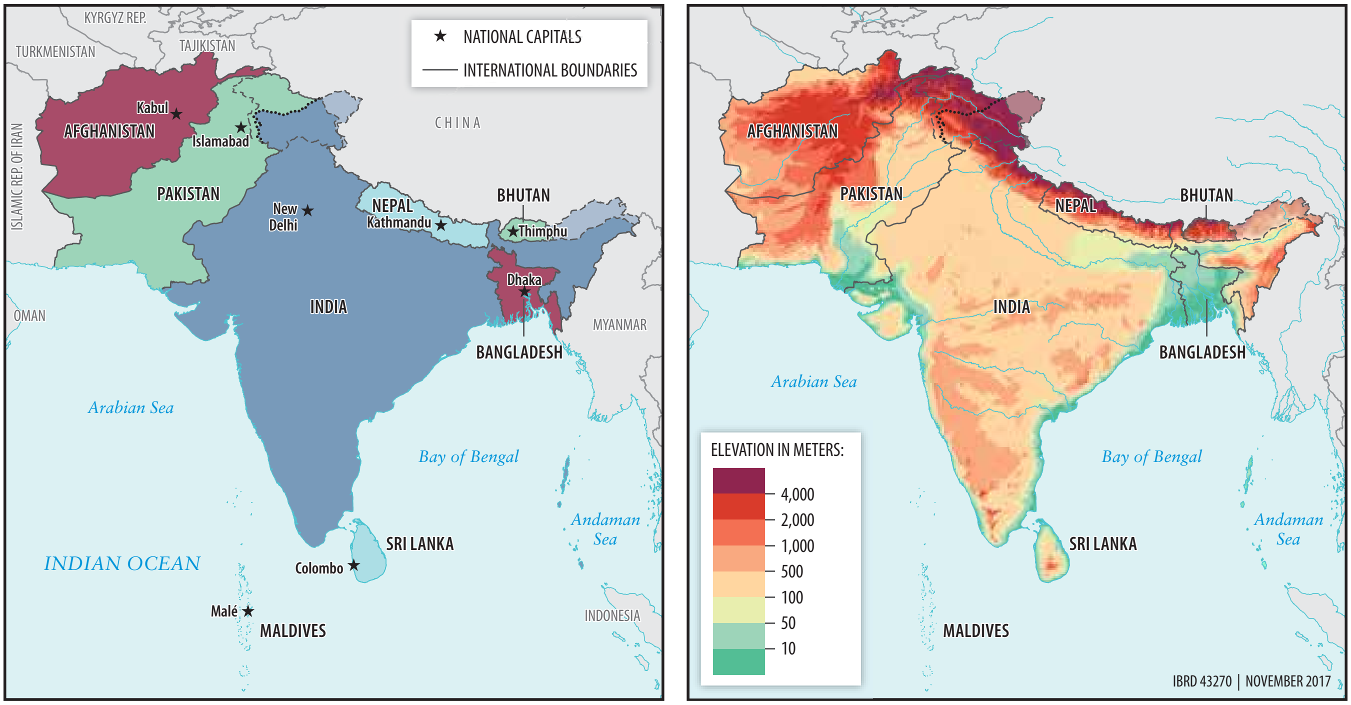
South Asia

With a population of 1.9 billion people in 2017, South Asia has a high population density, with 855 people per square kilometer of arable land (PRB 2017). Population in South Asia will increase to about 2.3 billion by 2050 (Table 4.1).

The subregion's climate is characterized by annual monsoon rains, which typically arrive in May and June. It has a wide diversity of climate and vegetation zones. Bangladesh and the eastern portions of India are tropical humid. The climate is drier to the south and in the west of India, which features dry broadleaf forests in the southern highlands. Much of Afghanistan, Pakistan, and the northwestern areas of India are semi-arid to arid, with deserts and scrublands. The Himalayan region features cooler climates at altitude, with high montane grasslands and coniferous forests. Lower elevations have broadleaf and mixed forests. Map 4.2 shows the political boundaries and elevation in South Asia.

South Asian countries are in the middle human development category except for Afghanistan, the subregion's poorest country (UNDP 2016). Fertility rates in the subregion have fallen in the past 20 years and now stand slightly above replacement.

Map 4.2: Political boundaries and elevation in South Asia



a. Political boundaries

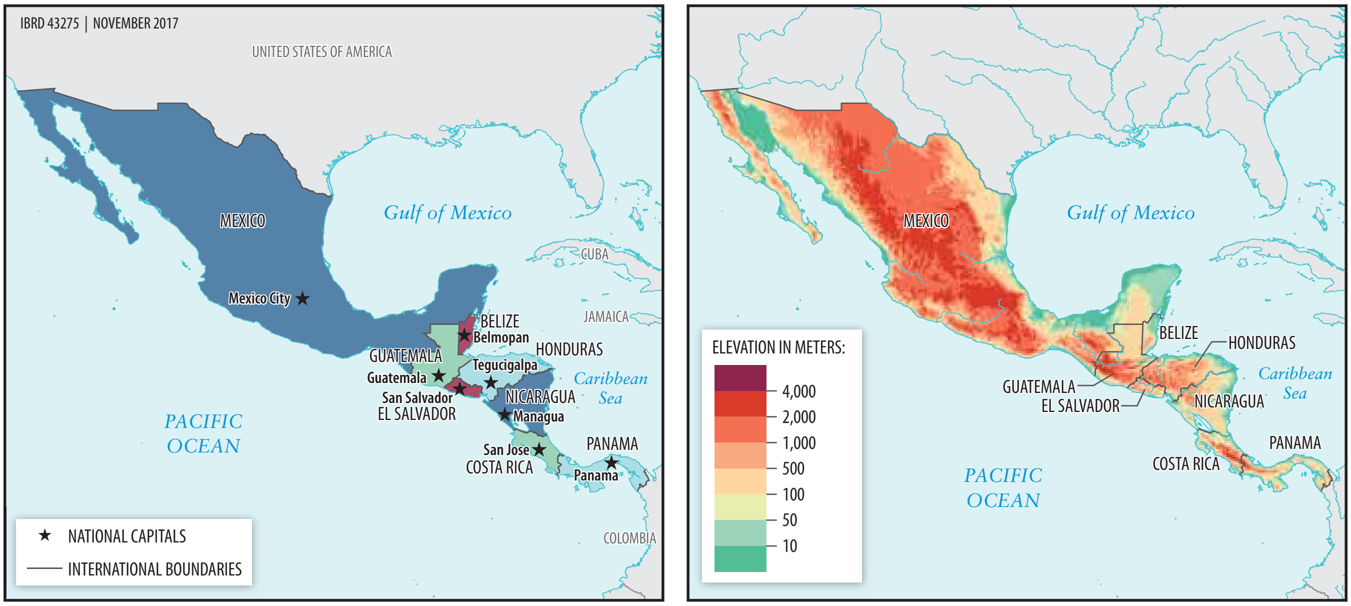
b. Elevation

Mexico and Central America

The subregion comprising Mexico and Central America is mountainous, with a spine of mountains running from Panama in the south to the central plateau of Mexico, bracketed by mountain chains to the east and west in the north. To the east of the mountains are moist tropical broadleaf forests, the presence of which indicate higher rainfall; to the west are patches of dry broadleaf and coniferous forests. A dry corridor extends from the southeastern corner of Guatemala through much of El Salvador and southern Honduras. In the southernmost countries—Panama, Costa Rica, and Nicaragua—the climate is humid and the dominant biome is moist tropical broadleaf forests. In central and northern Mexico, the climate becomes progressively drier, with deserts and dry shrublands in parts of the central plateau and across the border with the United States. Map 4.3 shows the political boundaries and elevation in Mexico and Central America.

Belize, Costa Rica, Mexico, and Panama have high human development indicators; the remaining countries are in the medium category (UNDP 2016). Fertility rates (and therefore population growth rates) are lower in this subregion. The population in this subregion will increase from 177 million in 2017 to over 200 million by 2050 (Table 4.1). Guatemala has the subregion's highest total fertility rate, at 2.9 births per woman (PRB 2017). Nearly three-quarters of the subregion's population live in urban areas.

Map 4.3: Political boundaries and elevation in Mexico and Central America



a. Political boundaries

b. Elevation

Shared characteristics

All three subregions have areas of water scarcity and large shares of population that depend on agriculture, although there are country-specific variations. Large areas of South Asia (excluding Bangladesh, Nepal, and Bhutan) and Mexico have high to extremely high baseline water stress (WRI 2013).[22] South Asia has the largest proportion of arable land under irrigation (FAO 2011). Some of this water comes from rivers, but in northwestern India much irrigation depends on subterranean aquifers, and the water table has fallen substantially (Tiwari and others 2009). Water resources are less of a constraint in East Africa. They remain largely undeveloped there, but some areas are prone to periodic severe droughts.

Dependency on agriculture—especially rainfed agriculture—is high in all three subregions. Data on agricultural employment for East Africa are incomplete, but the share of people employed in agriculture appears to be above 60 percent in Tanzania, Zambia, and Zimbabwe; about 70 percent in Rwanda and Uganda; and 73 percent in Ethiopia (ILO 2017). In South Asia, about half the labor force works in agriculture. The rate is lower (about 15 percent) in Latin America and the Caribbean. In Mexico and Central America the proportion ranges from 13 percent in Mexico to more than 30 percent in Guatemala, Honduras, and Nicaragua. In comparison, the rate in high-income countries is about three percent. These high rates suggest a high degree of sensitivity to climate variability and change.

METRICS USED FOR DISCUSSION OF INTERNAL CLIMATE MIGRATION

Each of the three plausible climate migration scenarios—pessimistic reference, more inclusive development, and more climate-friendly—was compared with a no climate change impact population distribution scenario to generate estimates of climate migration.[23] Areas where population numbers exceeded the no climate impact scenario were assumed to have grown as a result of in-migration; areas where numbers are lower than the no climate impact scenario are assumed to have experienced slower rates of growth (or lost population) as a result of out-migration.

Four types of results are presented for each subregion:

- The total number of climate change–induced internal migrants (“climate migrants”) under the three scenarios.
- The number of internal climate migrants as a share of the number of total internal migrants.
- Maps of hotspots of climate in- and out-migration[24].
- Net in- and out-migration for three types of zones (rural livelihood zones, coastal zones, and urban areas) within subregions and trends in population projections under different scenarios.

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[22] Baseline water stress measures the ratio of total annual water withdrawals to total available annual renewable supply, accounting for upstream consumptive use. Higher values indicate more competition among users.

[23] Chapter 3 describes the modeling methods, data inputs, and resulting scenarios. Appendix A describes the data visualization methodology used.

[24] The report provides spatial estimates of where people could come from and go to within a country and identifies climate in-migration “hotspots” (areas of particularly high in-migration as a result of climate change) and climate out-migration “hotspots” (areas of particularly high out-migration as a result of climate change, although the overall population in these areas still tends to grow).

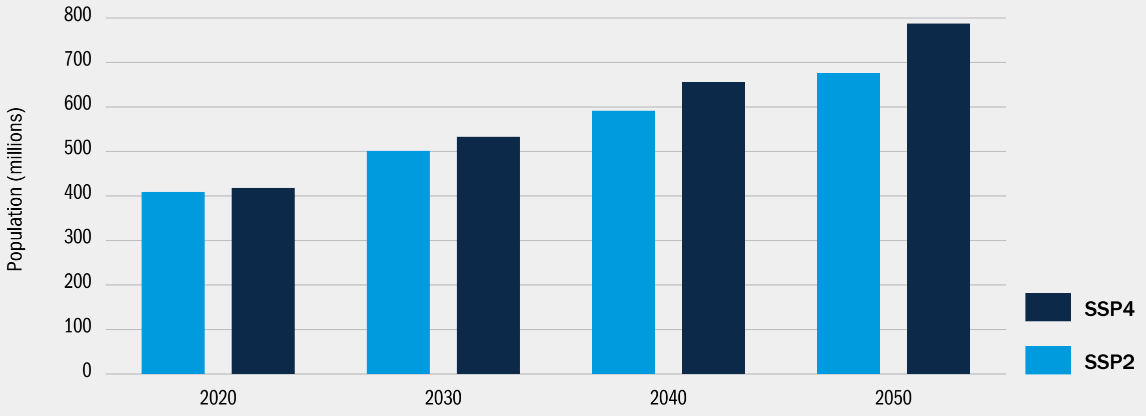
PROJECTIONS FOR EAST AFRICA

Results for this subregion suggest the following:

- The subregion could see an average of 10.1 million climate migrants by 2050 under the pessimistic reference scenario, with numbers steadily increasing from 2.6 million in 2020. The share of climate migrants in the population is projected to rise from 0.6 percent to 1.3 percent in the same period.
- The more climate-friendly scenario has lower numbers of climate migrants. Under this scenario, the number of climate migrants rises from 1.8 million in 2020 to 6.9 million in 2050.
- The share of climate migrants in other internal migrants will increase across the scenarios albeit at a slower pace. The largest shares occur in the pessimistic reference scenario.
- The Lake Victoria Basin will be an in-migration hotspot, as will the eastern highlands of Ethiopia and the area around Lilongwe, the capital of Malawi.
- Out-migration climate hotspots include coastal regions of Kenya and Tanzania, western Uganda, and parts of the northern highlands of Ethiopia.
- Rainfed croplands are likely to see declines in populations as a result of out-migration. In contrast, pastoral and rangeland areas will see dramatic increases due to more favorable climate conditions.
- Population growth under both the moderate (SSP2) and unequal (SSP4) development pathways will be rapid across the subregion, creating challenges for development that will be magnified by the future impacts of climate change.

East Africa's population in 2017 was 422 million (PRB 2017). It is projected to increase rapidly to 675 million under SSP2 (a moderate development pathway) and 786 million under SSP4 (an unequal development pathway) by 2050 (Figure 4.1).[25] These SSPs are used to derive the development-only or no climate impact scenarios.

Figure 4.1: Projected population in East Africa under two Shared Socioeconomic Pathways (SSPs), 2020–50



Source: Jones and O'Neill (2016).
Note: SSP2 = moderate development and SSP4 = unequal development.

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[25] See also Figure 3.2, which provides the qualitative narratives and assumptions for each SSP.

Climate trends

East Africa comprises four main climatic regions: the Horn, highland, coastal, and southern regions. In the Horn, the climate is semi-arid to arid, with rainfall during the June–October monsoon season. Temperatures have risen and monsoonal precipitation has declined throughout much of the Horn over the past 60 years (Niang and others 2014), rendering this region hotter and drier. In the highlands (Great Lakes) region, temperatures tend to be more moderate, with limited seasonal variation. Rainfall has a bimodal distribution, with peaks in March–May and October–December; the climate is humid to sub-humid. The coastal region has the same bimodal distribution but is characterized mostly by a semi-arid climate. The southern portions of East Africa have experienced a significant increase in temperature since the beginning of the early 1980s (Anyah and Qiu 2012), but rainfall increases over the past century are deemed "very likely" (Niang and others 2014).

The Horn has been beset by frequent droughts in recent years. There is considerable uncertainty in climate projections for the Horn and the rest of coastal East Africa, largely because of the limited ability of global climate models to capture the effect of sea surface temperature gradients (Yang and others 2015). Models predict this area to get wetter, but evidence shows that it has gotten drier over the past century (Williams and Funk 2011). The southern parts of East Africa are likely to get drier, in part because of increased temperature trends (Christensen and others 2014). There is medium confidence in projections showing reduced precipitation in the austral winter in this region. Overall, given projected increases in temperature in East Africa, even modest increases in rainfall are likely to be offset by increases in potential evapotranspiration, rendering much of the region hotter and drier (World Bank 2013).

Except in the highlands, interannual and intra annual variability in rainfall is marked throughout East Africa. This variability puts stress on livelihood systems, ranging from pastoralism in the northern portions to subsistence farming and domestic livestock-keeping in the rest of the region. Rising temperatures and extremes are also putting stress on water availability and cropping systems. Climate variability, and particularly drought in dryland areas, has been a common driver of migration in the region (Morrissey 2014). Cottier (2017) finds a curvilinear relationship between precipitation and rural to urban migration across a large sample of countries in Sub-Saharan Africa, with higher than normal levels of migration for extreme floods and extreme droughts.

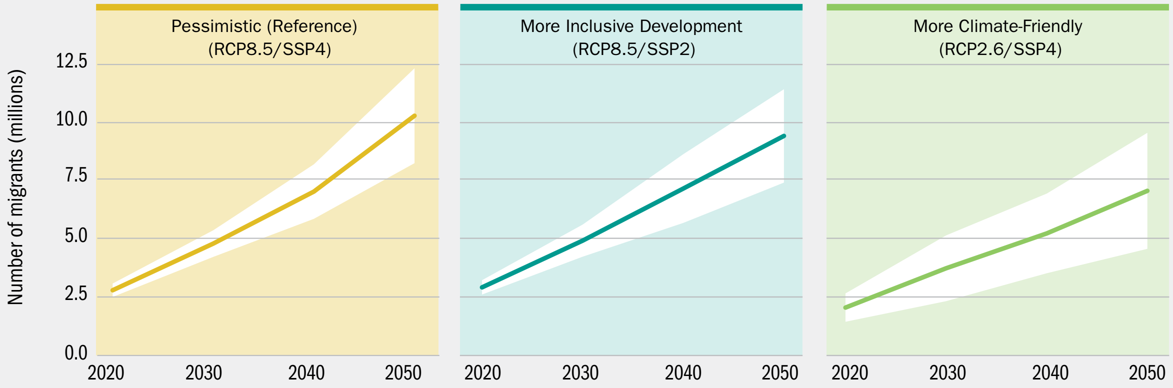
Seasonal and circular patterns of migration take advantage of different climate zones, including across national borders (Morrissey 2014). The East African Community protocol on the common market and the relaxation of visa restrictions by the Common Market for East and Southern Africa (COMESA) have facilitated transboundary movements (Morrissey 2014). Rapid population growth in the region has contributed not only to land fragmentation, which has spurred rural to urban migration, but also to rapid urbanization through natural increase. The region also has had a history of internal displacement and refugee flows, as a result of conflict and major droughts (IOM 2015).

Projected numbers of climate migrants

The number of climate migrants is projected to increase from 1.9–2.7 million (0.4–0.7 percent of the population) in 2020 to 6.9–10.1 million (0.9–1.4 percent of the population) by the middle of the century across scenario averages.

The largest numbers are under the pessimistic reference scenario, followed by the more inclusive development scenario, and the lowest numbers are under the more climate-friendly scenario (Figure 4.2). The projected increase under the pessimistic reference scenario is from 2.6 million in 2020 to 10.1 million by 2050 (1.3 percent of the population) on average. The number of climate migrants under the more inclusive development and more climate-friendly scenarios are slightly lower, but comparable at 9.2 million (1.4 percent of the population) and 6.9 million (0.9 percent of the population), on average by 2050, respectively.

Figure 4.2: Projected numbers of internal climate migrants in East Africa under three scenarios, 2020–50



Climate migrants as a percentage of the total population

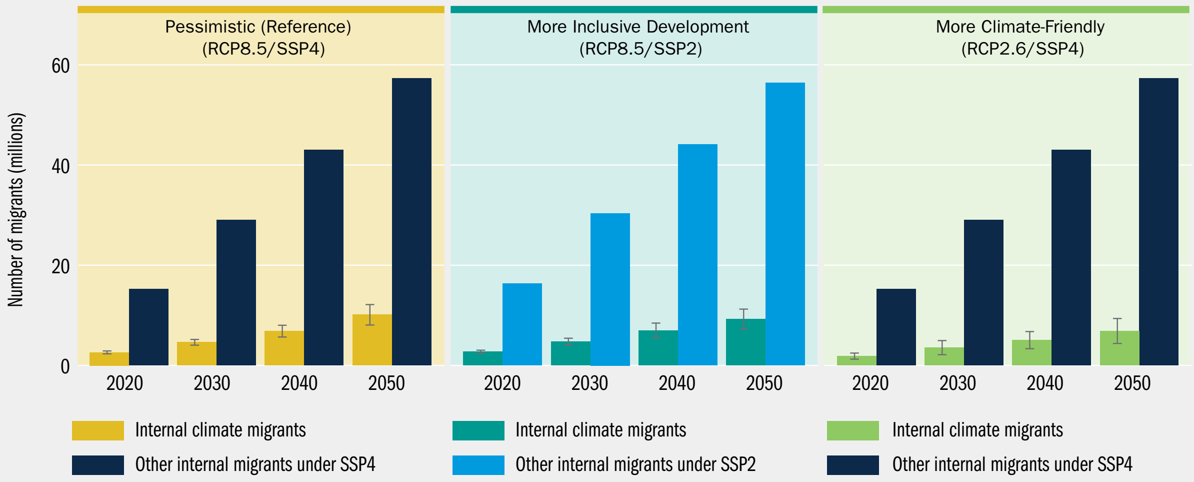
Year	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
%	0.62	0.87	1.04	1.28	0.67	0.95	1.18	1.37	0.44	0.67	0.77	0.87

Note: Dark lines represent the average runs for each scenario. Unshaded white areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

Numbers of other internal migrants grow from about 15.3 million in 2020 to 57.3 million in 2050 across scenario averages (Figure 4.3). Climate migrants as a share of all internal migrants will also increase across scenarios albeit at a slower pace. The largest shares occur in the pessimistic reference scenario. The shares under the more inclusive development and more climate-friendly scenarios are lower but comparable.

Photo Credit: World Bank

Figure 4.3: Projected number of climate and other internal migrants in East Africa under three scenarios, 2020-50



Note: The whiskers on the climate migrant bars represent the 95th percentile confidence interval for the four model runs that comprise each scenario. There are no confidence intervals for other migrants, because only a single development trajectory is used in each scenario (SSP2 or SSP4).

Projected spatial patterns of climate migration

East Africa's population is projected to rise steeply by 2050, from 422 million to 676 million (in SSP2) or 786 million (in SSP4), increasing population densities across most of the subregion (Figure 4.4). Figure 4.5 displays the change between the baseline 2010 population density and the 2050 population density projection for the pessimistic reference scenario, in terms of both the absolute change and the percentage change. Areas with small population baselines tend to have higher percentage changes.

The increases in population density will exert immense pressure on natural resources and institutions. Even in areas of climate out-migration, the population will grow in absolute terms, albeit more slowly than it would without climate change impacts. Comparing shifts in population density under the climate impact scenarios with the no climate impact scenario reveals the climate in- and climate out-migration hotspots (Figure 4.6).

Figure 4.4: Baseline population density 2010, and projected population density under the pessimistic reference scenario 2050, East Africa

a. 2010 b. 2050

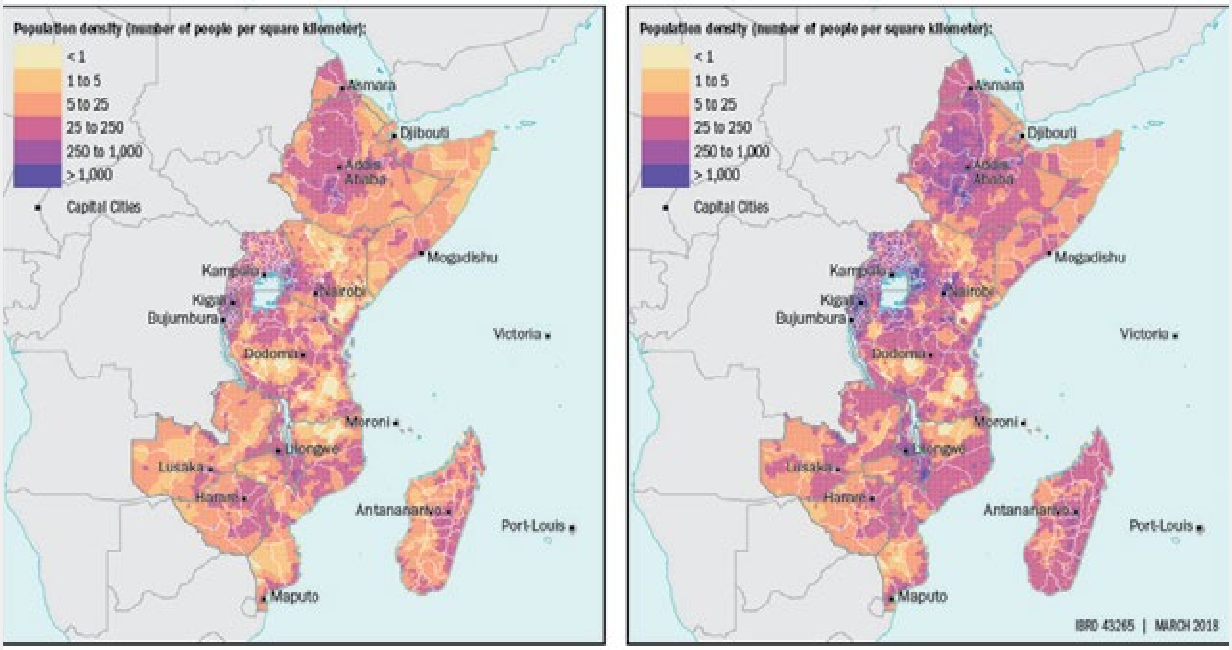
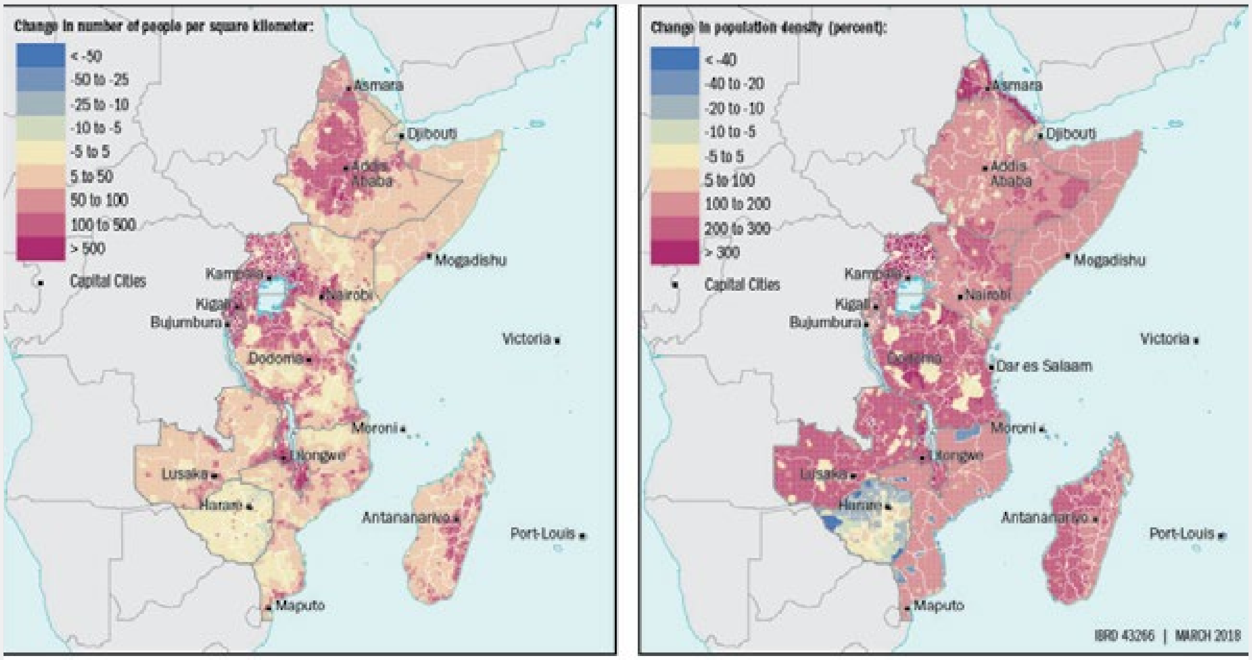


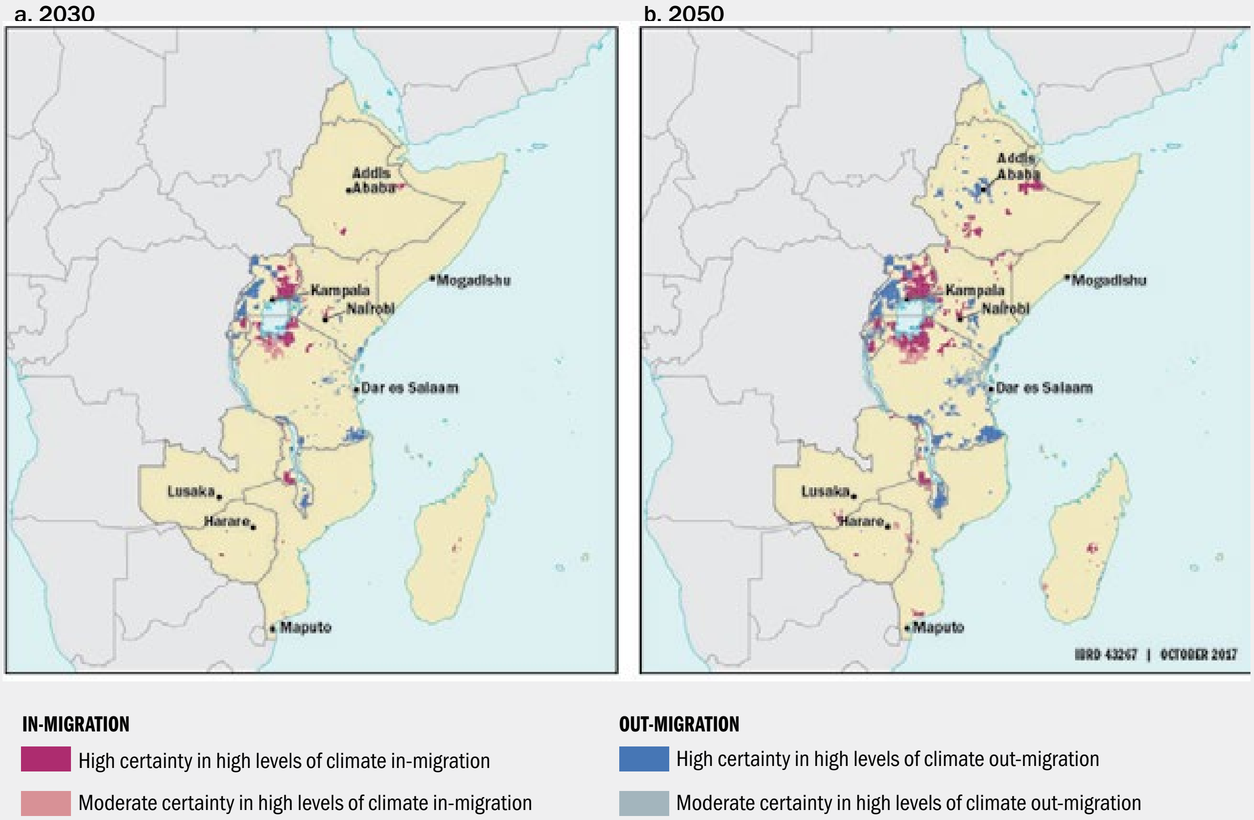
Figure 4.5: Absolute and percentage change in population density in East Africa under the pessimistic reference scenario, 2010-50

a. Change in population density b. Percentage change in population density



Note: The results for Zimbabwe differ strikingly from the results for the rest of the subregion, because Zimbabwe had a population of only about 12 million in 2010 and has a projected population increase that is lower compared to other East African countries (11.5 million under the SSP4 scenario by 2050).

Figure 4.6: Hotspots projected to have high levels of climate in-migration and climate out-migration in East Africa, 2030 and 2050


a. 2030

b. 2050

Note: High certainty reflects agreement across all three scenarios modeled, and moderate certainty reflects agreement across two scenarios. In- and out-migration hotspots are thus areas in which at least two scenarios concur on density changes in the top 10th percentile of the density distribution, which in East Africa represents an increased population density in 2050 of about 4.2 to 4.8 people per square kilometer, depending on the scenario. For decreased population density, it is about minus 3.6 to minus 5.5 people per square kilometer.

By 2030 climate migration hotspots begin to emerge, and by 2050 these begin to spread and intensify all over the region (Figure 4.6). Climate out-migration hotspots, which reflects convergence of at least two of the three scenarios, include northern parts of the Ethiopian highlands; parts of western Uganda, southern Rwanda, and southern Malawi; and coastal stretches of Kenya and Tanzania. These hotspots reflect deteriorating water availability and crop yields in out-migration areas. In the coastal zone, declining land availability, reflecting sea level rise and storm surges, is also a factor.

Climate in-migration hotspots are largely in the southeastern highlands of Ethiopia, the Lake Victoria basin, and the region near Lilongwe, Malawi, as well as isolated pockets of other countries. The change in population density highlights strong changes, generally in excess of 100 people per square kilometer. The increases in the highland areas are driven by relatively favorable climate conditions with lesser impacts of climate change relative to coastal areas. These areas already have very high population densities.

These projections do not take into account the current carrying capacity of agricultural lands in the highlands.[26] If the model placed limits to growth in already heavily populated rural subsistence agriculture regions, it is likely that migrants would be pushed elsewhere, perhaps to cities.

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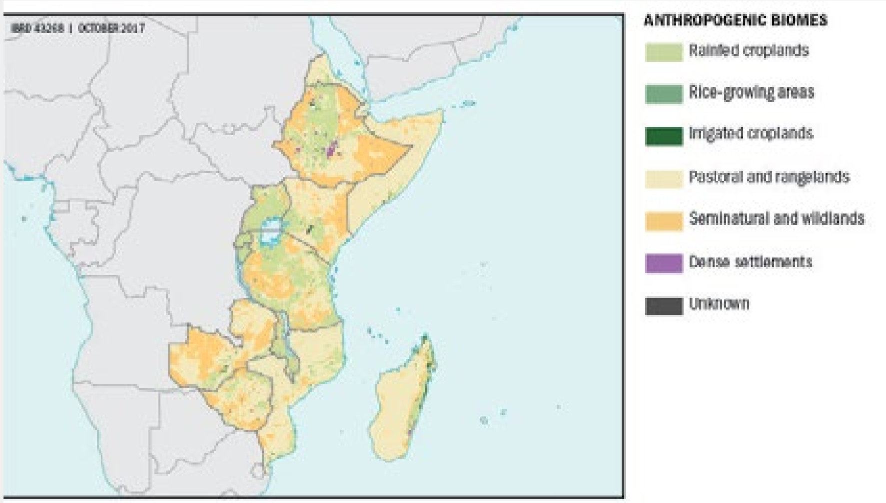
[26] They also ignore technological advances or adaptation responses that might make these regions better able to sustain large populations.

Many of the climate in- and out-migration hotspots in 2050 run along national borders, especially around Lake Victoria. Although the model does not explicitly include cross-border movements as a result of climate change impacts (only the continuance of transboundary movements based on historical precedent), climate change could amplify or inhibit cross-border movements depending on the contexts that propel individuals to decide to move.

Trends in livelihood zones

The distribution of livelihood zones in accordance with anthropogenic biomes is presented in Figure 4.7 for the baseline year of 2015. Significant out-migration from rainfed croplands is projected under all three climate impact scenarios (Figures 4.7 and 4.8).[27] It ranges from more than 300,000 by 2050 under the two high emissions scenarios (pessimistic reference and more inclusive development) to more than 500,000 under the more climate-friendly scenario. Under all scenarios, pastoral and rangeland areas, as well as semi-natural and wildland areas, see potential in-migration, induced by generally improved water availability in those areas.[28]

Figure 4.7: Livelihood zones in East Africa, by anthropogenic biome, 2015



Source: Ellis and others (2010).

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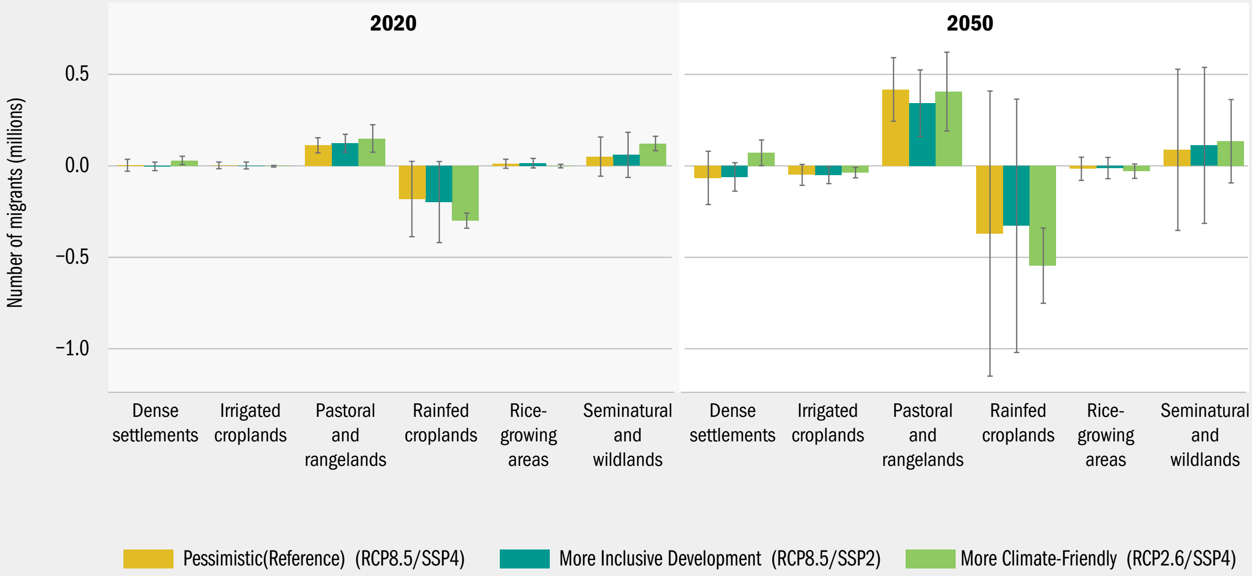
[27] Given the large number of livelihood zones, the focus here is on the central tendency rather than the spread (as represented by the confidence intervals).

[28] There is considerable uncertainty about rainfall projections in many parts of East Africa, but these generally point to wetter conditions, with the exception of the southern region comprising Zimbabwe, Zambia and southern Madagascar, which is likely to become drier. See Appendix B.

Figure 4.8: Projected net climate migration in and out of livelihood zones in East Africa under three scenarios, 2020–50

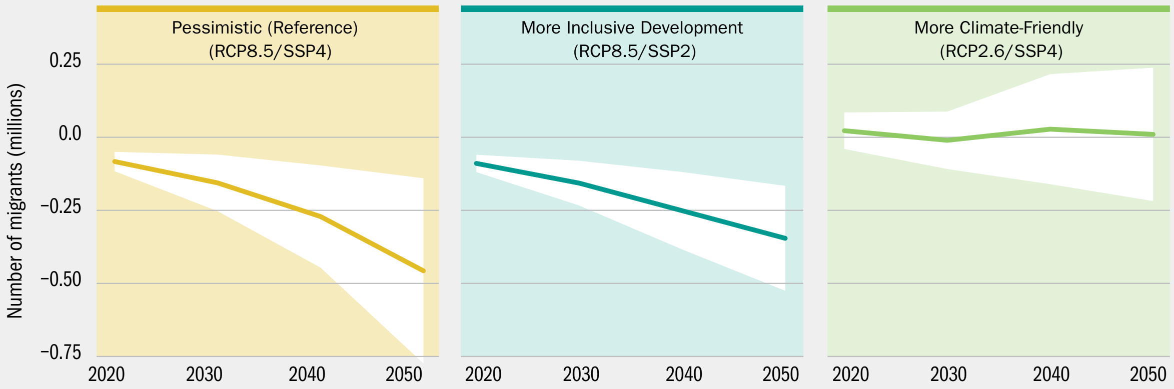


Note: Whiskers show 95th percentile confidence intervals for climate migrants.

Trends in coastal zones

The number of people living in coastal zones is expected to decrease as a result of climate change, with the highest levels of out-migration (150,000–750,000 people) under the pessimistic reference and more inclusive development scenarios, which are based on the high emissions pathway (Figure 4.9). The high emissions pathway, RCP8.5, is projected to result in combined sea level rise and storm surge of two meters, against one meter under RCP2.6 on which the more climate-friendly scenario is based (for details on sea level rise, see Table 3.2 in Chapter 3). This outcome reflects the combined impacts of sea level rise and declining water availability in large swaths of coastal Kenya and Tanzania. On average, the more climate-friendly scenario sees no strong in- or out-migration, but the spread is wide, from –200,000 to +200,000 people.

Figure 4.9: Projected net climate migration in and out of coastal zones in East Africa under three scenarios, 2020-50



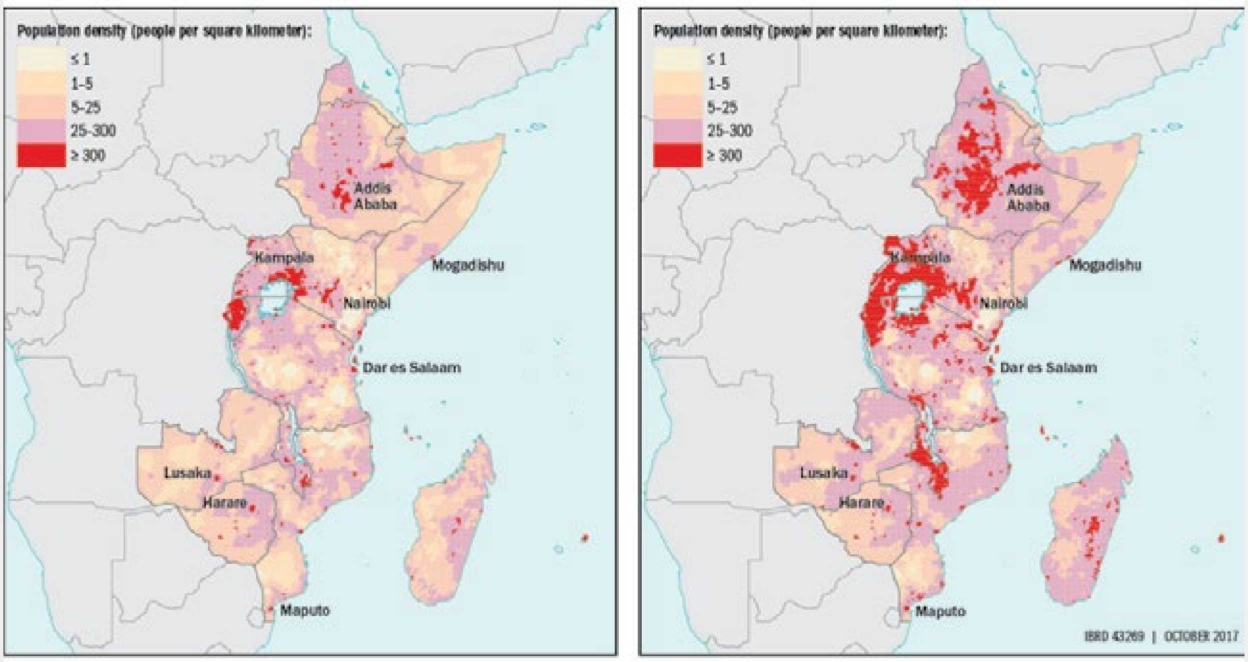
Note: Dark lines represent the average runs for each scenario. Unshaded white areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

Trends in urban areas

Given high population growth across East Africa, the spatial extent of urban areas will grow substantially in all three scenarios by 2050 (Figure 4.10), mainly in the more temperate highlands. This sprawl may constitute high-density areas that are functionally rural, whereas in other cases it will represent an extension of the urban fabric. The urban population is projected to roughly quadruple, from 100 million in 2010 to 350 million in 2050 under the more inclusive development scenario and to more than 450 million under the pessimistic reference and more climate-friendly scenarios. Urban populations will increase to more than 50 percent across scenarios, up from the current average of 27 percent. Under all three scenarios, cities in East Africa will potentially face significant challenges because of this population growth, even before climate change is taken into account.

Urban areas of East Africa are likely to see increases in populations as a result of climate change impacts. More people are driven to cities under the climate impact scenarios than under the no climate impact scenarios (Figure 4.11), with the largest increases under the high emissions pathway (pessimistic reference and more inclusive development scenarios), with roughly 750,000 additional people by 2050. However, the extra 750,000 figure equates to only 0.16 percent of East Africa's total urban population of more than 450 million people by 2050. Under the more climate-friendly scenario, the projection is for 300,000 additional people.

Figure 4.10: Baseline and projected population density in urban areas of East Africa, 2010 and 2050

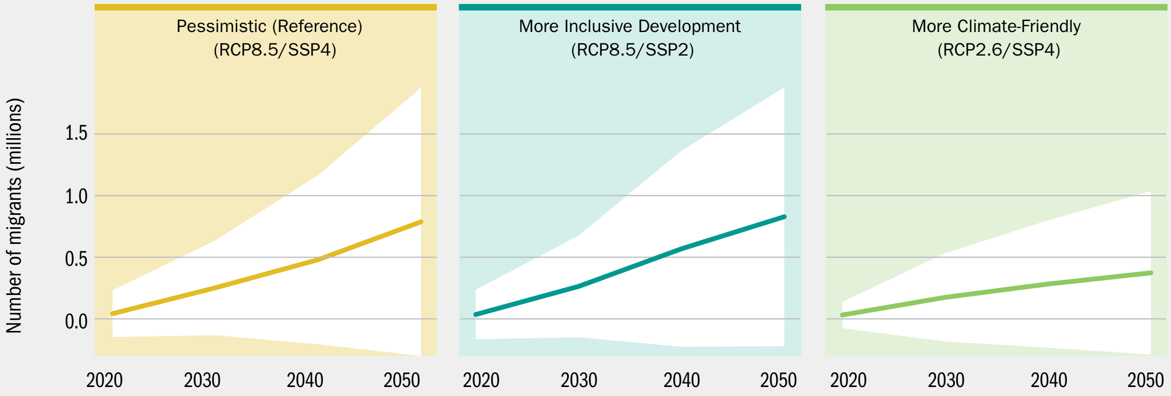


a. 2010

a. 2050

Note: An "urban" area is an area with density of at least 300 people per square kilometer. The map for 2050 shows all areas in which any one of the three scenarios has populations of such density. It thus represents plausible urbanization outcomes rather than its most likely spread.

Figure 4.11: Projected net climate migration in and out of urban areas in East Africa under three scenarios, 2020-50



Note: Dark lines represent the average runs for each scenario. Unshaded white areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

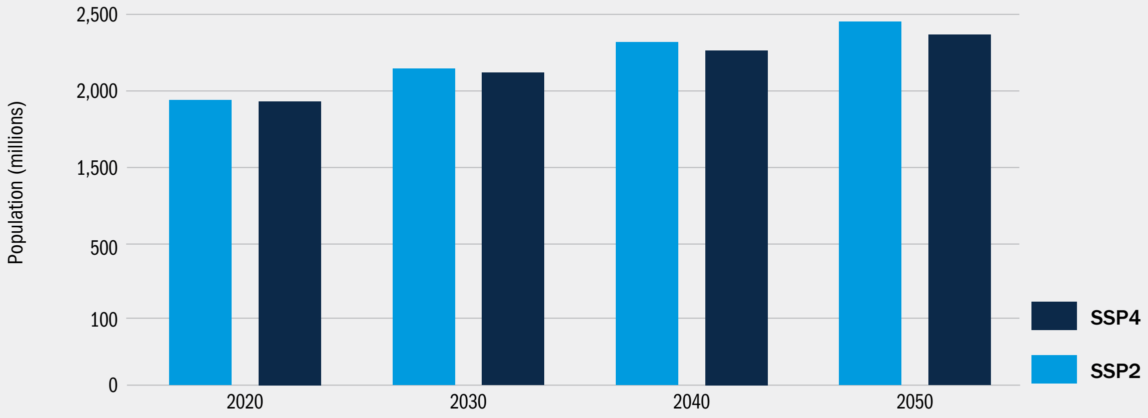
PROJECTIONS FOR SOUTH ASIA

The results for this subregion suggest the following:

- South Asia could see an average of 35.7 million climate migrants by 2050 under the pessimistic reference scenario. The share of climate migrants in the population is projected to rise from about 1 percent in 2020 to 1.6 percent in 2050 under this scenario.
- The more climate-friendly scenario results in lowest numbers of climate migrants, ranging from 11.4 to 22.4 million people, or 0.5 to 1 percent of the total population.
- By 2050, climate migrants make up about 23 percent of all internal migrants under the pessimistic reference scenario.
- The southern Indian highlands, especially between Bangalore and Chennai will be climate in-migration hotspots. Parts of Nepal, as well as northwestern India, also see climate in-migration.
- Climate out-migration hotspots include eastern and northern Bangladesh, the northern part of the Gangetic Plain, and the corridor from Delhi to Lahore. Climate out-migration will also occur from coastal metropolitan areas such as Mumbai, Dhaka, and Chennai as a result of sea level rise and storm surge impacts.
- Irrigated areas and rice-growing areas are likely to see population dampening as a result of out-migration. In contrast, rainfed cropping areas are likely to see population increases.

The South Asia population will increase from 1.9 billion in 2017 to about 2.3 billion inhabitants by 2050 under both the unequal (SSP4) and moderate (SSP2) development pathways. Most countries in South Asia (except Nepal and Afghanistan) fall in the middle-income category. Population projections for middle-income countries are slightly higher under SSP2 than under SSP4 (Figure 4.12), under which population growth for these countries is low.[29]

Figure 4.12: Projected population of South Asia under two Shared Socioeconomic Pathways, 2020-50



Source: Jones and O'Neill (2016).
Note: SSP2 = moderate development and SSP4 = unequal development.

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[29] Under SSP4 population growth is particularly high in low income countries (LICs), but low in middle income countries (MICs) (see Figure 3.2 in Chapter 3). But under SSP2, population growth is moderate in MICs, meaning that for most of South Asia, there is slightly higher population growth under the more inclusive development scenario.

Climate trends

The summer monsoon is the predominant feature of the climate system in South Asia. Depending on the location, the monsoon extends from April through December, with lower latitudes experiencing earlier onset and a later end. In Delhi the onset is in June and peak rains end in September. The region saw increasing annual mean temperature trends during the 20th century (Hijioka and others 2014). Changes in the summer monsoon dominate annual rainfall (Christensen and others 2014). Seasonal mean rainfall shows interdecadal variability, noticeably a declining trend with more frequent below-normal monsoons (Hijioka and others 2014). The proportion of rainfall coming in heavy rainfall events is increasing.

There is medium confidence in an increase in summer monsoon precipitation in South Asia (Christensen and others 2014). Projections indicate that more rainfall will be very likely at higher latitudes of South Asia by the mid-21st century under the RCP8.5 scenario. Under the RCP2.6 scenario, more rainfall at higher latitudes is likely by midcentury; substantial changes in rainfall patterns are not likely at low latitudes. In addition to these long-term average trends, rainfall variability both within the rainy season and between years is projected to increase in the South Asian monsoon region (Menon and others 2013a, 2013b), consistent with observational evidence (Singh and others 2014).

The high dependency on rainfed agriculture makes the population of South Asia particularly sensitive to climate variability and change. Projections suggest that South Asia will have the largest numbers of food-insecure people by the middle of the century (Hijioka and others 2014). Significant levels of rural to urban migration can be attributed to the impacts of droughts and floods on agricultural production (Hugo and Bardsley 2014).

From 2005 to 2010 about 8.5 million people migrated out of South Asia to other regions. More than half of them (4.6 million) travel to the Persian Gulf, a destination for largely unskilled migrants (Abel and Sander 2014). Another 2.9 million more highly skilled migrants travel to Europe and North America.

As large as these international flows are, internal migration is still the main form of migration in South Asia (ADB 2012). Although urbanization remains relatively low, there is increasing temporary, circular migration between rural and urban areas. Dyson and others (2005) show that the low level of urbanization in India is misleading, because many people in rural areas depend on family members who work in urban areas.

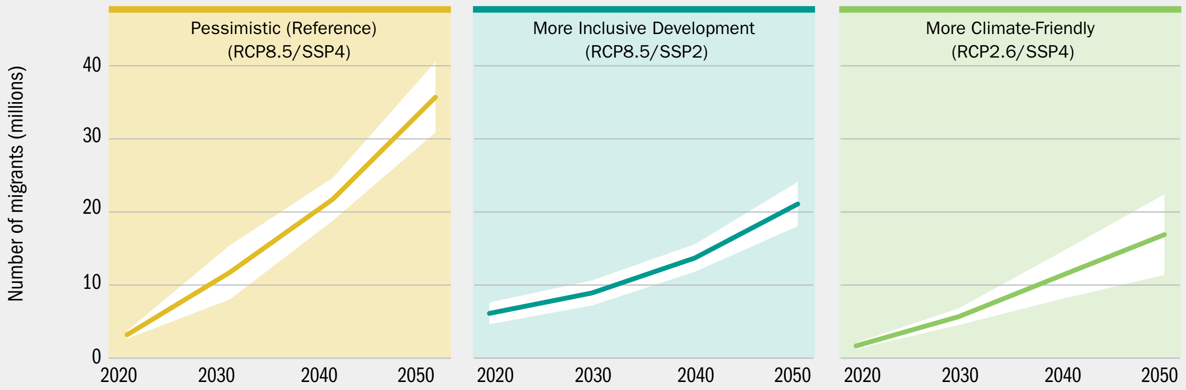
Projected numbers of climate migrants

Changes in population distribution in South Asia have historically been a story of continued densification in a subregion with already very high densities (World Bank 2017c). The fastest growth has been along the Indus River and on the Gangetic Plain. Major urban areas such as Delhi, Dhaka, Lahore, and Karachi have seen particularly rapid growth, fueled by migrants from rural areas.

The subregion experiences natural disasters such as glacial-lake outburst floods, storm surges, droughts, cyclones, and heavy precipitation (IOM 2017). These disasters displace hundreds of thousands of people every year, regularly making India one of the countries with the largest numbers of people displaced in this way (IDMC 2017). The subregion's high dependency on agricultural livelihoods means that climate variability, late-onset or failed monsoons, and other climate hazards have large impacts on farming households. As a result, an increasing number of households send at least one member to urban areas to seek alternative livelihoods (ADB 2012).

The number of climate migrants is projected to increase from 1.7–6.1 million people (0.1–0.3 percent of the population) in 2020 to 16.9–35.7 million by 2050 (0.7–1.6 percent of the population) by 2050 across scenario averages (Figure 4.13). The largest numbers are under the pessimistic reference scenario, with 35.7 million climate migrants by 2050 on average (1.6 percent of the population). The numbers are lower under the more inclusive development scenario with 21.1 million climate migrants (0.9 percent of the population) and lowest under the more climate-friendly scenario with 16.9 million climate migrants (0.7 percent of the population) on average by 2050. These lower numbers suggest positive effects of better development policies and lower global emissions, but are still significant nevertheless.

Figure 4.13: Projected number of internal climate migrants in South Asia under three scenarios, 2020–50



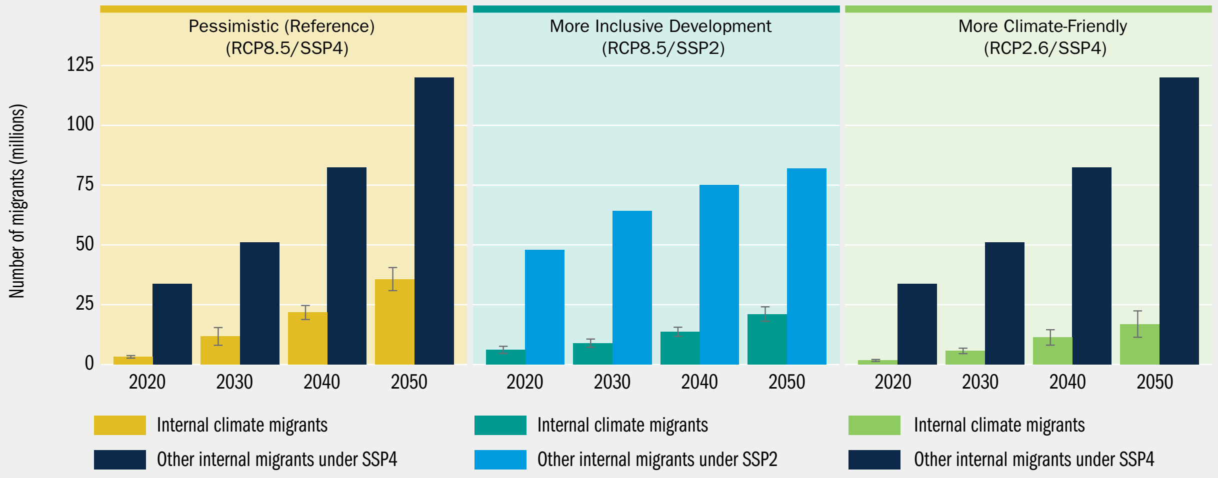
Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
%	0.17	0.58	0.99	1.56	0.33	0.43	0.61	0.89	0.09	0.28	0.52	0.74

Note: Dark lines represent the average runs for each scenario. Unshaded white areas represent the 95th percentile confidence intervals. The intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

Climate migration will not occur in isolation, and the subregion will see rising numbers of other internal migrants (Figure 4.14), growing from 33.8 million in 2020 to 119.9 by 2050 across scenario averages. While the total population of the subregion is higher for the SSP2 development pathway, the number of other internal climate migrants is lower reflecting the positive impact of inclusive development. The share of climate migrants in all internal migrants is projected to increase across all scenarios, with the largest shares occurring under the pessimistic reference scenario. The shares under the more inclusive development and more climate-friendly scenarios are lower.

Figure 4.14: Projected number of climate and other internal migrants in South Asia under three scenarios, 2020-50



Note: The whiskers on the climate migrant bars represent the 95th percentile confidence interval for the four model runs that comprise each scenario. There are no confidence intervals for other migrants, because only a single development trajectory is used in each scenario (SSP2 or SSP4).

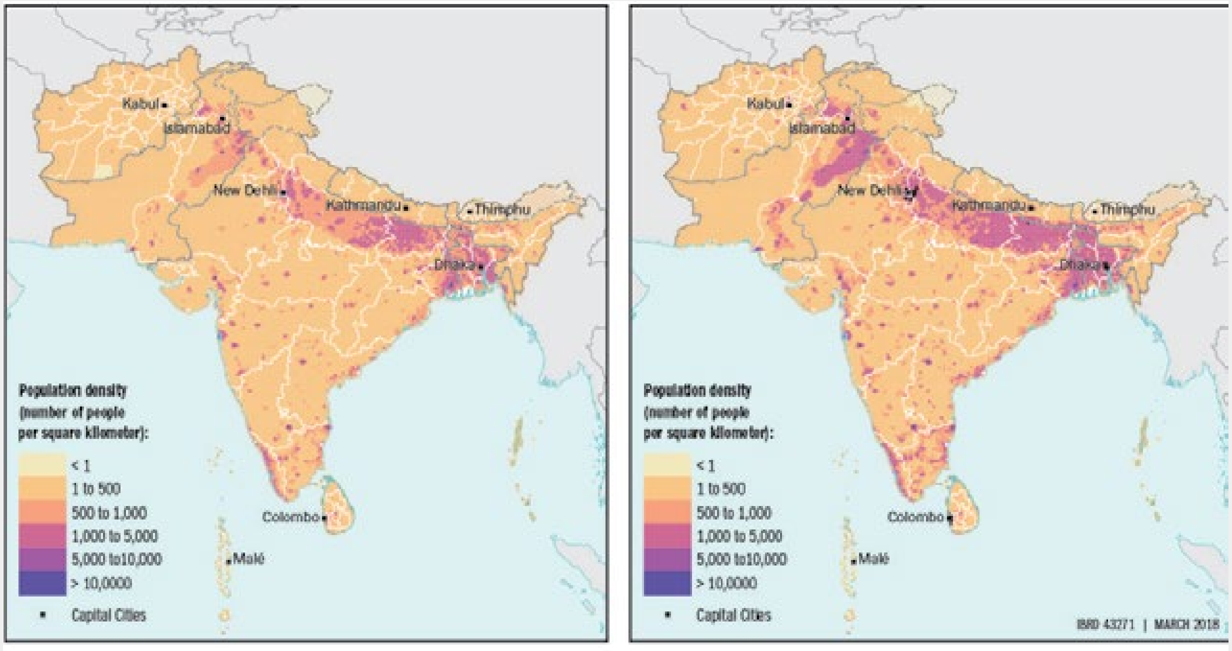
Projected spatial patterns of climate migration

The subregion's population is likely to grow by 25 percent by 2050, from about 1.9 billion in 2017 to about 2.3 billion under both SSPs by 2050. Population density in many parts of the subregion that are already heavily populated will increase by 2050 (Figure 4.15).

Figure 4.16 displays the change between the baseline 2010 population density and the 2050 population density projection for the pessimistic reference scenario, in terms of both the absolute change and the percentage change. Areas with small population baselines tend to have higher percentage changes.

Comparing the shifts in population density under the climate impact scenarios with the no climate impact scenario reveals the climate in- and climate out-migration hotspots.

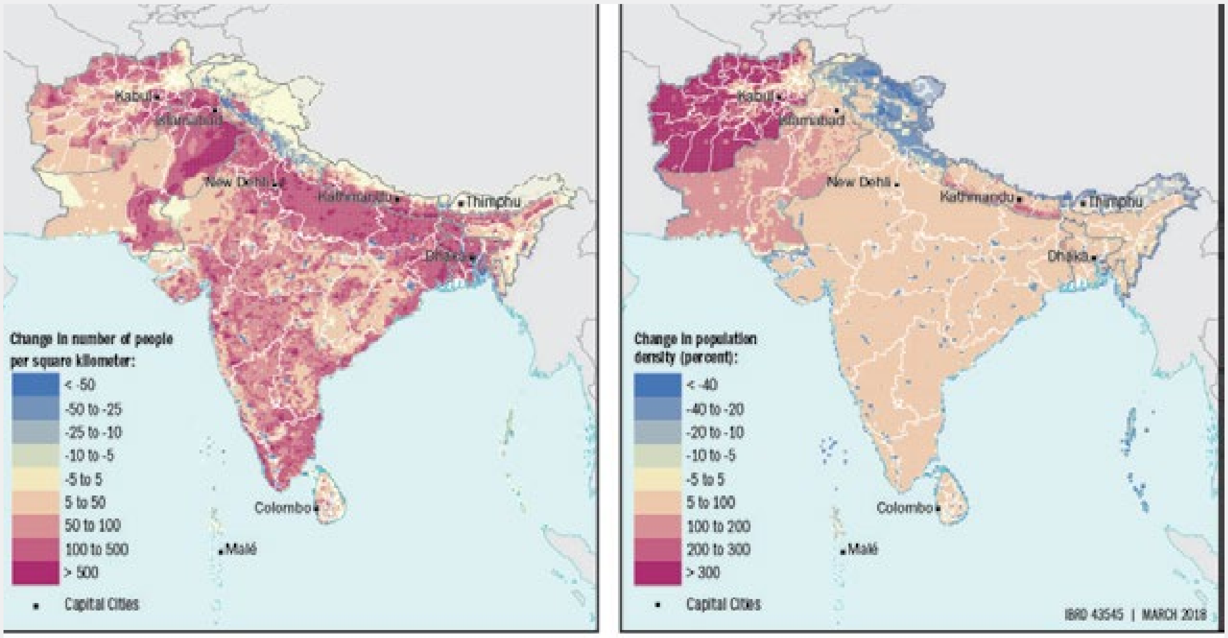
Figure 4.15: Baseline population density 2010, and projected population density under the pessimistic reference scenario 2050, South Asia



a. 2010

b. 2050

Figure 4.16: Absolute and percentage change in population density in South Asia under the pessimistic reference scenario, 2010-50



a. Change in population density

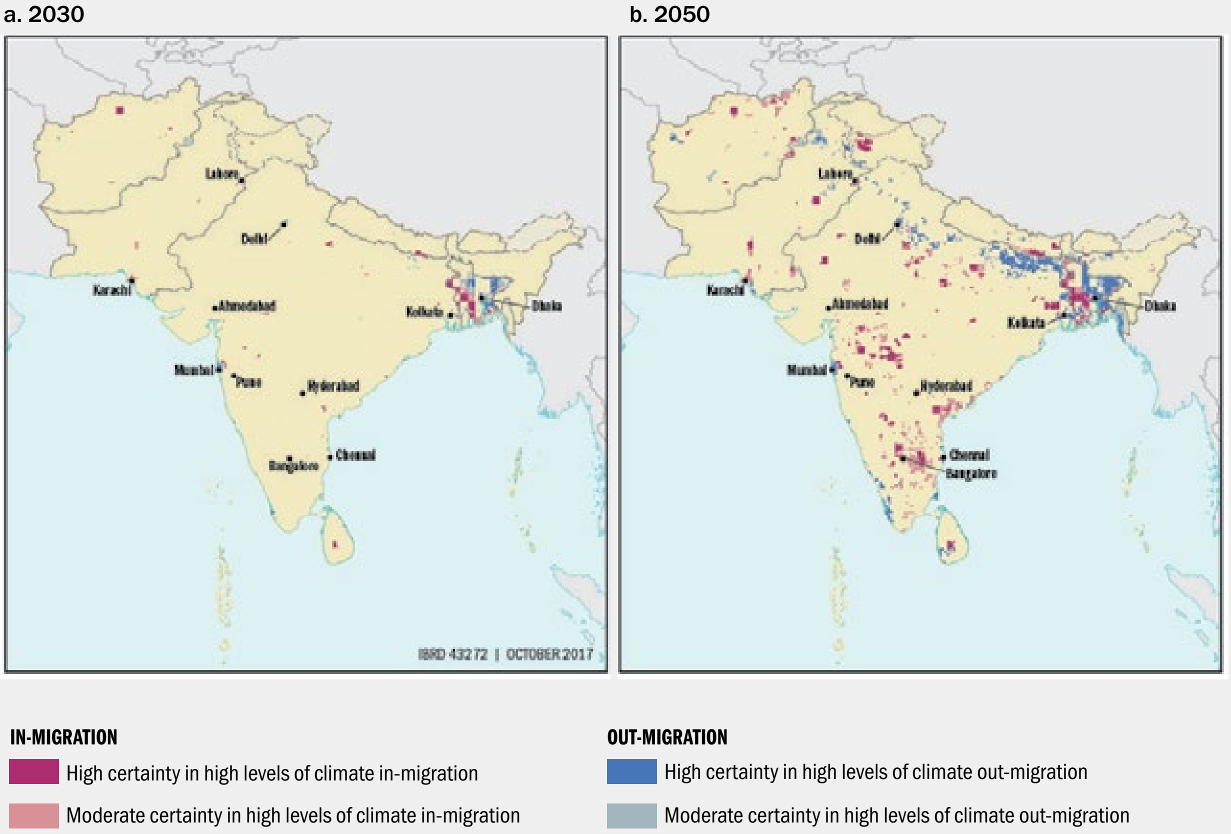
b. Percentage change in population density

By 2030 climate in-migration hotspots begin to emerge on the Gangetic Plain and in western Bangladesh (Figure 4.17). By 2050 these hotspots begin to spread and intensify all over South Asia, with large migration destination areas seen throughout India's regions, especially in the south; as well as in western Bangladesh. These regions will generally see more favorable climate conditions. The WaterGAP water model in particular shows improved water availably over the historical baseline in southeastern India, between Bangalore and Chennai, one of the larger in-migration hotspots (see Appendix B).

Climate out-migration hotspots for 2050 include eastern and northern Bangladesh and the northern part of the Gangetic Plain, as well as some spots of the broader Gangetic Plain, the corridor from Delhi to Lahore, and even Mumbai (Figure 4.17).

Bangladesh is a site of both major out-migration hotspots (in the east) and an in-migration hotspot (in the west) and is discussed in more detail in Chapter 5.

Figure 4.17: Hotspots projected to have high levels of climate in-migration and climate out-migration in South Asia, 2030 and 2050



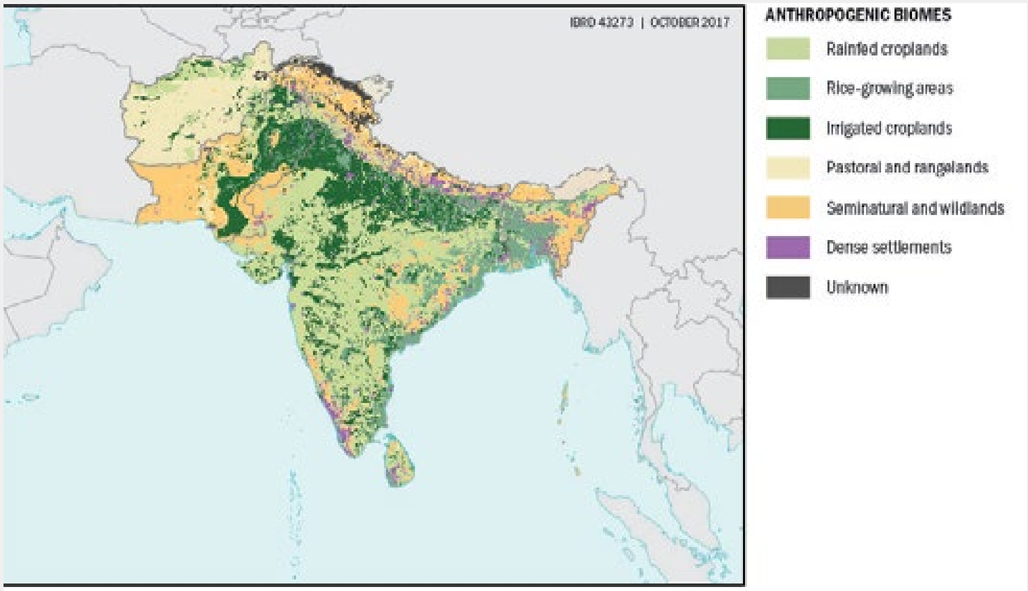
Note: High certainty reflects agreement across all three scenarios modeled, and moderate certainty reflects agreement across two scenarios. In- and out-migration hotspots are thus areas in which at least two scenarios concur on density changes in the top 10th percentile of the density distribution, which in South Asia represents an increased population density in 2050 of about 8 to 14 people per square kilometer, depending on the scenario. For decreased population density, it is about minus 10 to minus 25 people per square kilometer.

Trends in livelihood zones

Livelihood zones in South Asia are dominated by rainfed croplands (Figure 4.18). Figure 4.19 shows net climate migration by livelihood zones. Under the pessimistic reference scenario, rainfed croplands will see up to 5.5 million net migrants by 2050, potentially putting pressure on regions where land is already facing degradation. The more inclusive development and more climate-friendly scenarios project about half as many new migrants, but with wide confidence intervals. Under the pessimistic reference scenario, there is also significant out-migration from dense settlements (about 3.0 million people), irrigated croplands (about 1.4 million people), and rice croplands (about 1.1 million people), effectively compensating for the movement toward rainfed croplands.

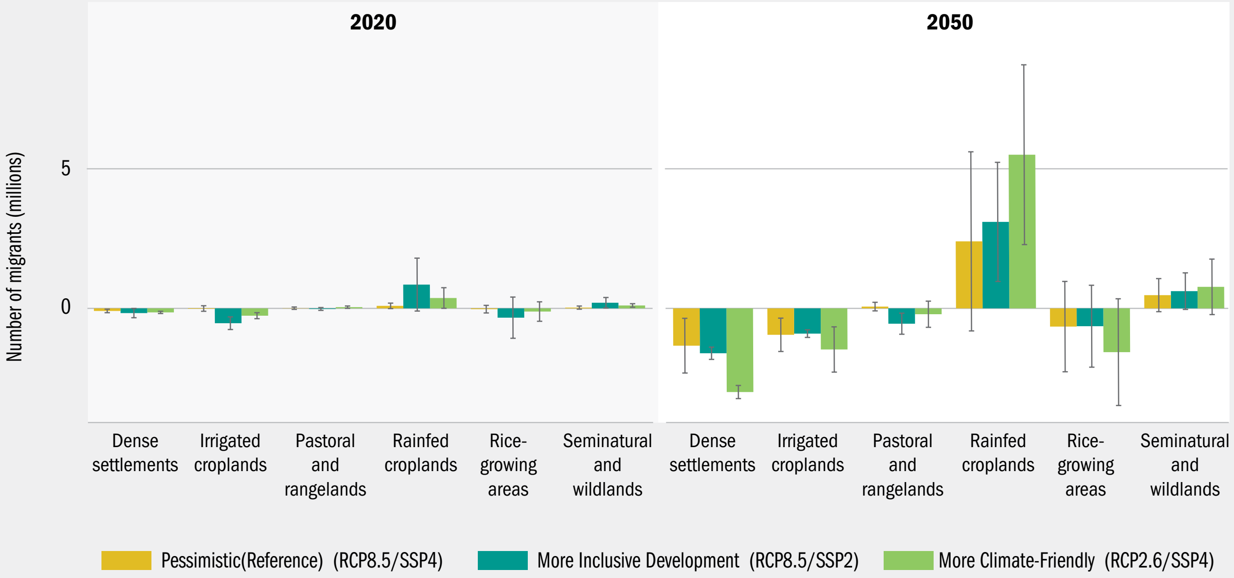
In all three scenarios, South Asia will see strong climate in-migration to rainfed cropland areas and relatively strong climate out-migration from dense settlements, irrigated areas, and rice-growing areas. Anticipation and preparedness for migration to rainfed areas is vital, especially given the relatively low historical productivity of these areas compared with irrigated and rice-growing areas.

Figure 4.18: Livelihood zones in South Asia, by anthropogenic biome, 2015



Source: Ellis and others (2010).

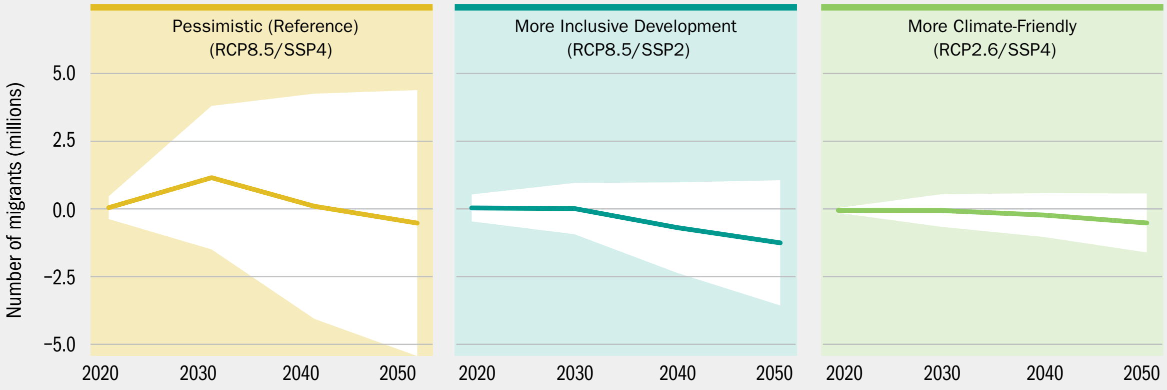
Figure 4.19: Projected net climate migration in and out of livelihood zones in South Asia under three scenarios, 2020–50



Trends in coastal zones

Results for coastal zones suggest net out-migration of 0.5–1.5 million people by 2050, depending on the scenario (Figure 4.20). The more inclusive development scenario, which is based on the high emissions pathway, sees the highest levels of out-migration (1.5 million on average), suggesting that the combination of development patterns and high sea level rise will drive many people from the coast. The range is widest for the pessimistic reference scenario, from negative 5.4 million to positive 4.4 million by 2050. This spread can be explained by a disagreement across the general circulation models as to water availability in South Asia's coastal areas, and moderate disagreement across the climate impact models as to crop productivity. Sea level rise also acts as a factor that pushes people away from coastal areas. Different combinations of these three factors lead to a wide variation in outcomes, resulting in the observed spread. In no case do climate migrants make up more than 0.1–0.3 percent of the population of the coastal zone. These areas would benefit from more customized analysis to examine how these factors would play out at a local level and the subsequent impacts on the scale and pattern of climate migration.

Figure 4.20: Projected net climate migration in and out of coastal zones in South Asia under three scenarios, 2020-50

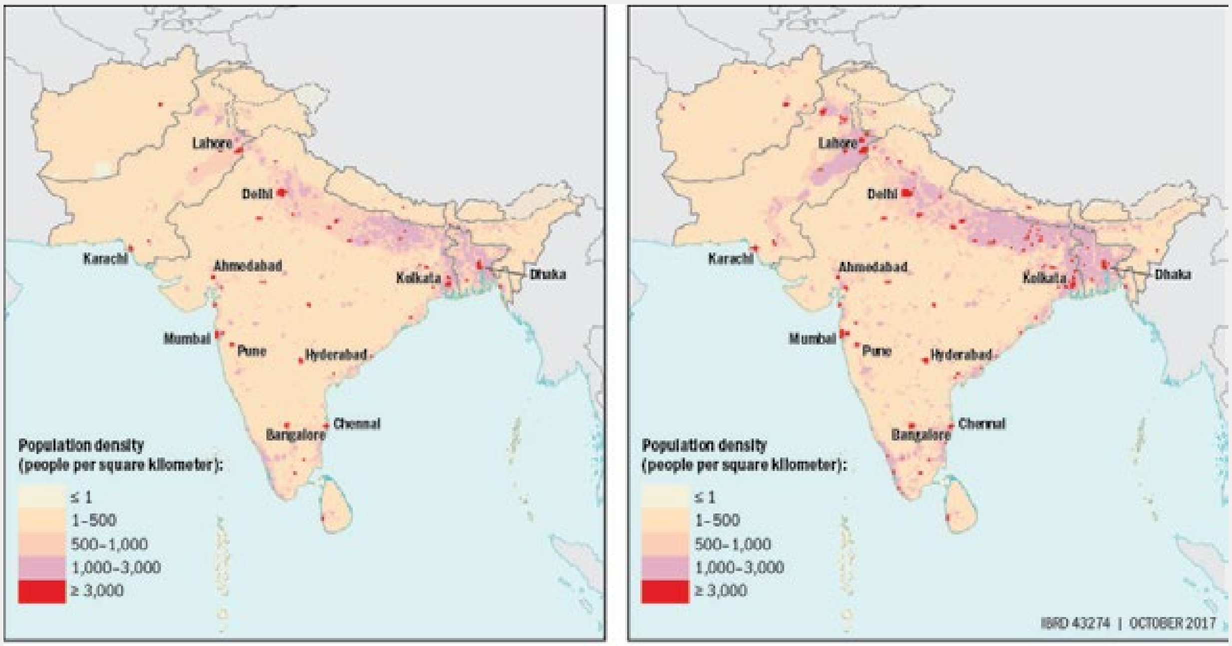


Note: Dark lines represent the average runs for each scenario. Unshaded white areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

Trends in urban areas

A far higher population density threshold (3,000 people per square kilometer) was applied to define urban areas in South Asia, because density is so much higher in this region (if the 300 people per square kilometer density threshold used for East Africa were applied, much of South Asia would be represented as urban). Despite this higher threshold, urban areas in South Asia still expand by 2050, particularly in peri-urban areas, around existing metropolitan areas, and in some smaller conurbations in the eastern portion of the Gangetic plain in India (Figure 4.21). The number of people living in urban areas is projected to grow from roughly 150 million in 2010 to 264 million under SSP2 and 325 million under SSP4. However, while urban areas will grow overall, climate out-migration is expected to occur from certain coastal cities, such as Dhaka, parts of Karachi and parts of Mumbai, as a result of sea level rise and storm surge impacts (Figure 4.17). This will dampen overall population growth in these major metropolitan areas.

Figure 4.21: Baseline and projected population density in urban areas of South Asia, 2010 and 2050



a. 2010

b. 2050

Note: An "urban" area is an area with density of at least 3,000 people per square kilometer. The map for 2050 shows all areas in which any one of the three scenarios has populations of such density. It thus represents plausible urbanization outcomes rather than its most likely spread.

Photo Credit: World Bank

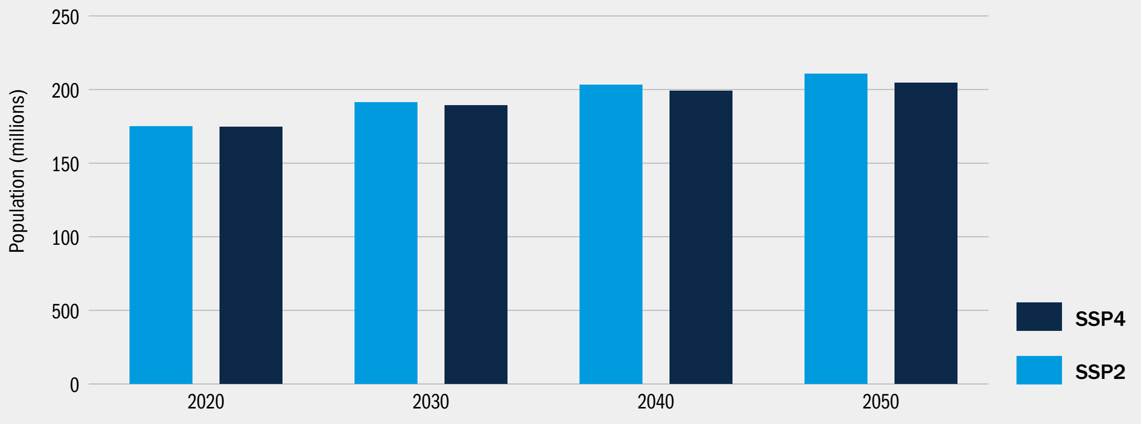
PROJECTIONS FOR MEXICO AND CENTRAL AMERICA

Results for Mexico and Central America suggest the following:

- The number of climate migrants will increase from 2020 to 2050 across all scenarios. The region could see an average 1.4 to 2.1 million climate migrants by 2050, depending on the scenario.
- There is a significant range around the average estimates in Mexico and Central America—from a low of 0.2 million to a high of 3.9 million—because of the heterogeneity in development levels between Mexico and the rest of the subregion.
- The pessimistic reference scenario sees the largest numbers of climate migrants reaching a high of 3.9 million by 2050. Under this scenario, climate migrants make up about one percent of the population by 2050.
- Climate migrants as a share of other internal migrants are projected to rise from 6.3 to 8.9 percent in 2020 to 8.5 to 12.6 percent by 2050.
- Under the high emissions pathway, Mexico and Central America could potentially see dramatic increases in climate migration toward the end of the century, because of steadily worsening impacts for water availability and crop productivity.
- The Central Plateau of Mexico and the highlands of Guatemala will be climate in-migration hotspots. People will leave the hotter, lower-lying areas of these two countries and move toward climatically more favorable highland areas.
- Climate out-migration hotspots include low-lying coastal areas along the Gulf of Mexico and the Pacific coast of Guatemala. Some cities, such as Monterrey and Guadalajara in Mexico will see climate out-migration.
- Rainfed cropping areas are likely to see declines in population as a result of climate out-migration. In contrast, pastoral and rangeland areas are likely to see increases.

There are large population increases in most of Central America and moderate increases in Mexico under the unequal development pathway scenario SSP4. The subregion includes several middle-income countries (Mexico, Panama, and Costa Rica). Population growth therefore appears slightly higher under SSP2 than under SSP4, as the latter assumes low population growth in middle-income countries (Figure 4.22).

Figure 4.22: Projected population of Mexico and Central America under two Shared Socioeconomic Pathways, 2020-50



Source: Jones and O'Neill (2016).
Note: SSP2 =moderate development and SSP4 = unequal development.

Climate trends

The region's topography creates large gradients in temperature, precipitation, humidity, and wind, determined in part by interactions with neighboring oceans (Karmalkar and others 2011). The region is characterized by extremes, including drought and tropical storms, with attendant heavy rainfall and high winds. The frequency and intensity of extremes have increased (Kaenzig and Piguet 2014; Magrin and others 2014). Summer rainfall has been starting later and become more irregular and the intensity of rainfall has been increasing during the onset season (Magrin and others 2014). The higher share of rainfall in extremes increases the destructive potential of rainfall events. However, there is also a high level of agreement on decreasing mean annual runoff and discharge, particularly in northern parts of the region (Reyer and others 2016).

The Intergovernmental Panel on Climate Change (IPCC) has medium confidence that Mexico and Central America will experience a decrease in precipitation over the coming century. Ensemble mean projections indicate a decrease in precipitation between October and March in northern Central America and Mexico by the end of the century (Christensen and others 2014). CMIP5[30] global climate models and regional models project reductions in precipitation over all of Mexico and Central America from June to September in the region.

The El Niño Southern Oscillation (ENSO) is the main driver of interannual climate variability. El Niño is generally associated with dry conditions in the southern part of the region and wet conditions in the northern part; La Niña has the opposite pattern (Mason and Goddard 2001). ENSO will continue to influence the climate in Mexico and Central America, but changes in the frequency or intensity of ENSO remain uncertain, although there is some evidence for more extreme El Niño events in the future (Wenju and others 2014). Projected drier conditions may also be related to the decreased frequency of tropical cyclones, though the associated rainfall rate of these systems is higher in projections.

For climate change trends and the ISIMIP water and crop model projections for Mexico and Central America, see Appendix B.

Projected numbers of climate migrants

The general pattern of changes in population distribution historically has been a story of rapid population growth, driven by high fertility in the highlands of Guatemala and urbanization in Mexico's Central Plateau and other urban centers. The subregion is known for its international migration to the United States, and studies have demonstrated that Mexican migration (Nawrotzki and others 2013; Feng and others 2010) and Central American migration (WFP and others 2017) fluctuate in response to climate variability. The literature finds that households dependent on rainfed agriculture are particularly sensitive to drought events and to cyclone impacts, forcing family members to seek alternative livelihoods in cities and abroad (Warner and others 2009).

The food system is heavily dependent on maize and bean production. Long-term climate change and variability will significantly affect the productivity of these crops in Honduras, El Salvador, and Nicaragua; less dramatic effects are expected in Guatemala (Etzinger and others 2013). Climate change effects will translate into significant economic losses for smallholder farmers, including farmers involved in market crops like coffee, as well as likely higher rates of both internal and international migration (Tucker and others 2010; WFP and others 2017).

The number of climate migrants in Mexico and Central America are projected to rise over time, reaching 1.4 to 2.1 million or 0.7–1 percent of the population by 2050 (Figure 4.23). The pessimistic reference scenario sees the largest numbers, growing from 0.6 million (0.4 percent of the population) in 2020 to

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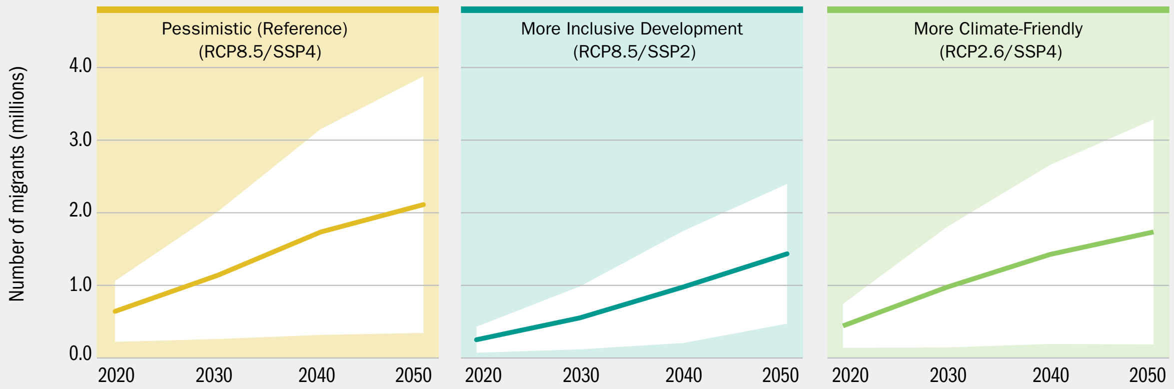
[30] Coupled Model Intercomparison Project Phase 5

Figure 4.23: Projected number of internal climate migrants in Mexico and Central America under three scenarios

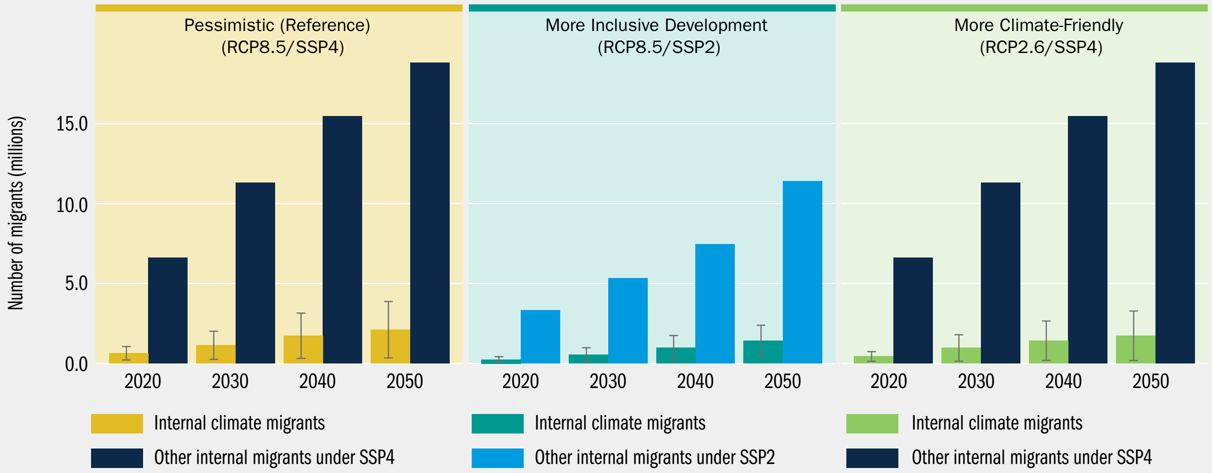


Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
%	0.37	0.60	0.87	1.03	0.14	0.29	0.48	0.68	0.25	0.51	0.72	0.85

Note: Dark lines represent the average runs for each scenario. Unshaded white areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

Figure 4.24: Projected number of climate and other internal migrants in Mexico and Central America under three scenarios, 2020–50



Note: The whiskers on the climate migrant bars represent the 95th percentile confidence interval for the four model runs that comprise each scenario. There are no confidence intervals for other migrants, because only a single development trajectory is used in each scenario (SSP2 or SSP4).

2.1 million by 2050, but also has the widest spread, ranging from 0.3 to 3.9 million. Under this scenario, climate migrants make up about 1 percent of the subregion's population by 2050, with a range of 0.2–1.9 percent. The more inclusive development and more climate-friendly scenarios yield somewhat lower numbers of climate migrants at 1.4 million (0.7 percent of the population) and 1.7 million (0.9 percent of the population), on average by 2050, respectively. These lower numbers suggest positive effects of better development policies and lower global emissions. The lowest numbers under the more inclusive development scenario could reflect the outcome of the stronger adaptive capacities of countries in the subregion—driven largely by Mexico and other middle-income countries.

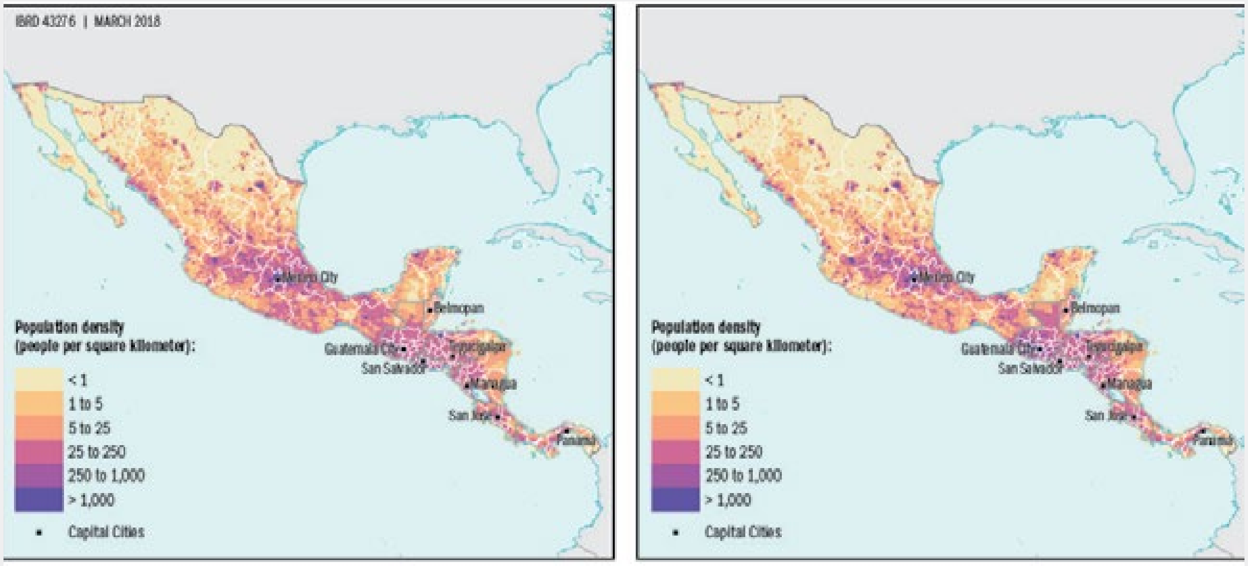
The subregion will see a marked increase in the number of other internal migrants (Figure 4.24) ranging from a low of 3.3 million in 2020 to a high of 18.8 million by 2050. These numbers are higher under SSP4 (unequal development pathway), which is shared by the pessimistic reference and more-climate friendly scenarios. Climate migrants as a share of all internal migrants are projected to increase across all scenarios, albeit at a slower rate.

Projected spatial patterns of climate migration

Figure 4.25 displays the change between the baseline 2010 population density and the 2050 population density projection for the pessimistic reference scenario, in terms of both the absolute change and the percentage change. The pessimistic reference scenario projects increases of more than 1,000 people per square kilometer during 2010–50 for most of Guatemala and El Salvador and increases of 500–1,000 people per square kilometer for Mexico and the rest of Central America. Under SSP4 there are large population increases in most of Central America and moderate increases in Mexico. Significant challenges await the low-income countries of Central America if they follow the SSP4 population growth scenario, regardless of the climate impacts they experience (Figure 4.26).

Photo Credit: shutterstock

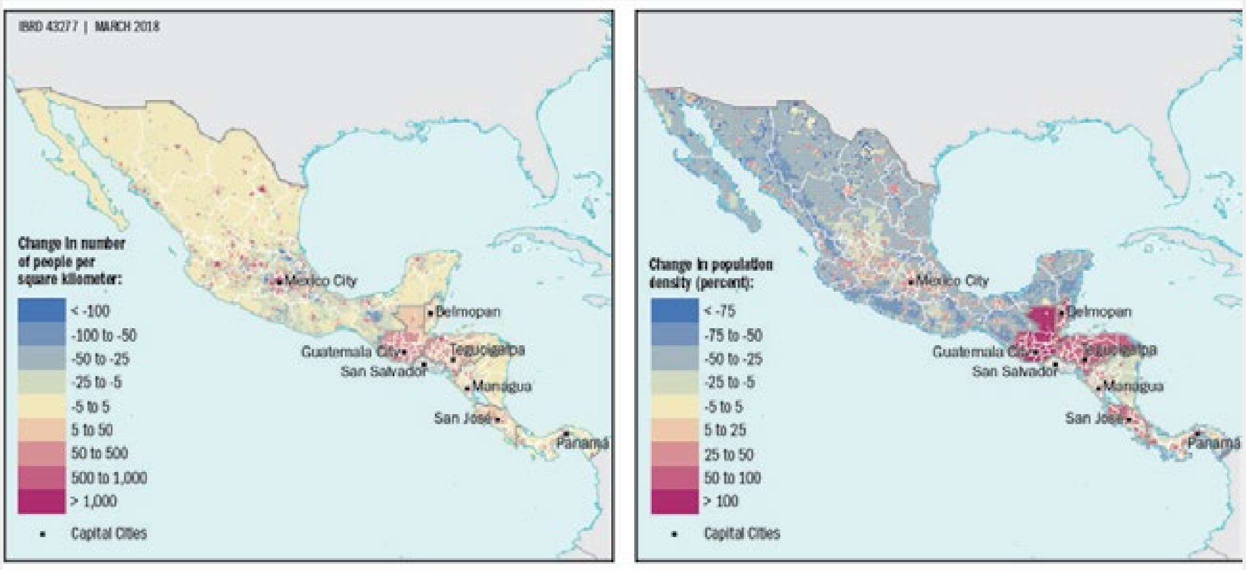
Figure 4.25: Baseline population density 2010, and projected population density under the pessimistic reference scenario 2050, Mexico and Central America



a. 2010

b. 2050

Figure 4.26: Absolute and percentage change in population density in Mexico and Central America under the pessimistic reference scenario, 2010-50

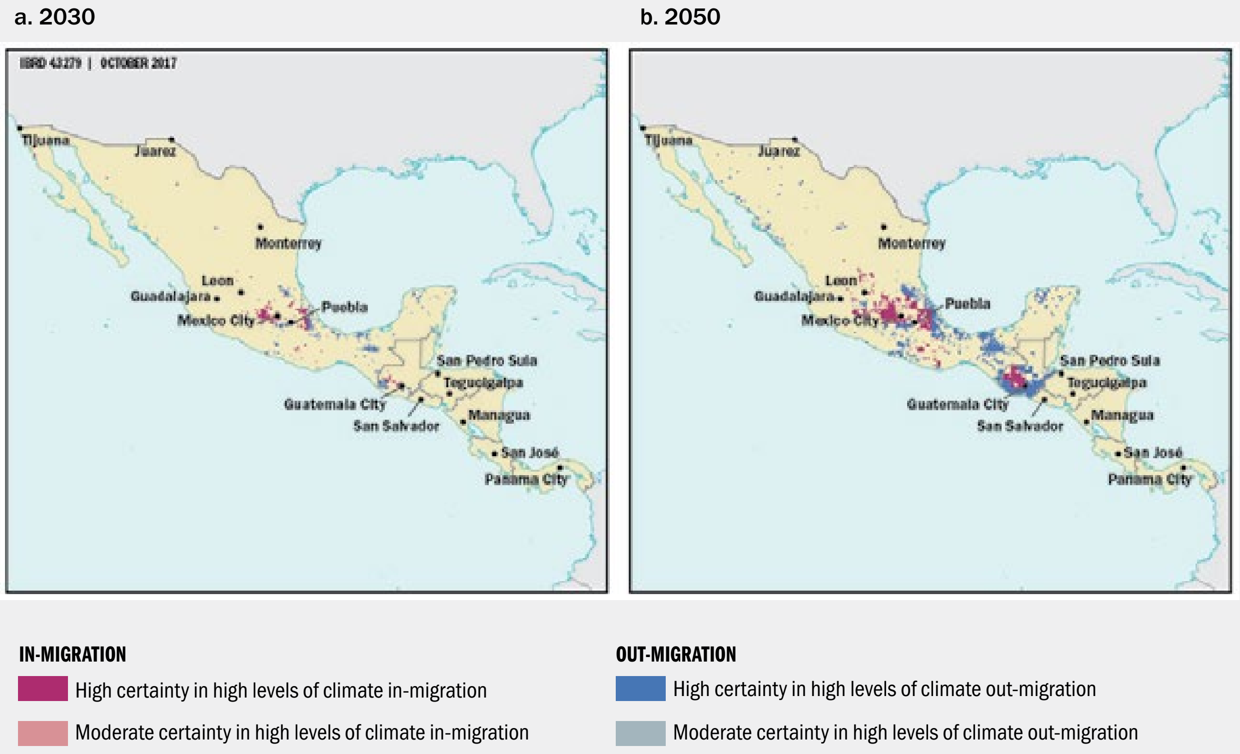


a. Change in population density

b. Percentage change in population density

Climate out-migration hotspots include lowland areas along the Gulf of Mexico and the Pacific coast of Guatemala (Figure 4.27). Some cities, such as Monterrey and Guadalajara in Mexico, are out-migration hotspots. The hotspots of climate in-migration are in the Central Plateau of Mexico and the highlands of Guatemala. Some people will thus leave the hotter, lower-lying areas of these two countries and move toward climatically more favorable highland areas. The results for Guatemala are consistent with the results of a study by Etzinger and others (2013), which finds that climate impacts on future maize and bean productivity will be less pronounced in Guatemala than in other parts of the subregion.

Figure 4.27: Hotspots projected to have high levels of climate in-migration and climate out-migration in Mexico and Central America, 2030 and 2050



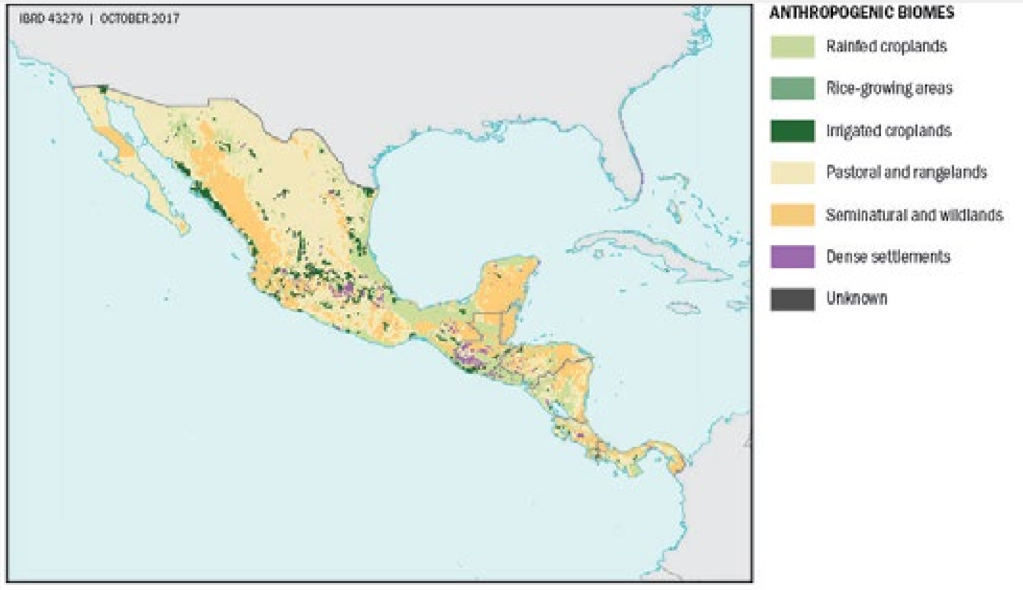
Note: High certainty reflects agreement across all three scenarios modeled, and moderate certainty reflects agreement across two scenarios. In- and out-migration hotspots are thus areas in which at least two scenarios concur on density changes in the top 10th percentile of the density distribution, which in Mexico and Central America represents an increased population density in 2050 of about 3.3 to 6.8 people per square kilometer, depending on the scenario. For decreased population density, it is about minus 1.8 to minus 3 people per square kilometer.

Trends in livelihood zones

Mexico and Central America have large pastoral and rangeland areas, semi-natural and wild areas, and arid and forested land (Figure 4.28). Rainfed croplands are found along Mexico's Gulf coast and sprinkled throughout the other countries. Belts of irrigated croplands are found along Mexico's northern Pacific coast, in the Central Plateau, and in parts of southern Guatemala.

Net migration trends by livelihood zone show general out-migration from rainfed cropping areas of 200,000–500,000 people, with the largest out-migration projected under the pessimistic reference scenario (Figure 4.29). This outcome may relate to the marginality of some agricultural areas, particularly mountainous areas. There is a corresponding increase in dense settlements and pastoral and rangeland areas. The numbers are generally not significant for irrigated croplands and rice-growing areas, given their limited geographic scope.

Figure 4.28: Livelihood zones in Mexico and Central America, by anthropogenic biome, 2015



Source: Ellis and others (2010).

Figure 4.29: Projected net climate migration in and out of livelihood zones in Mexico and Central America under three scenarios, 2020–50

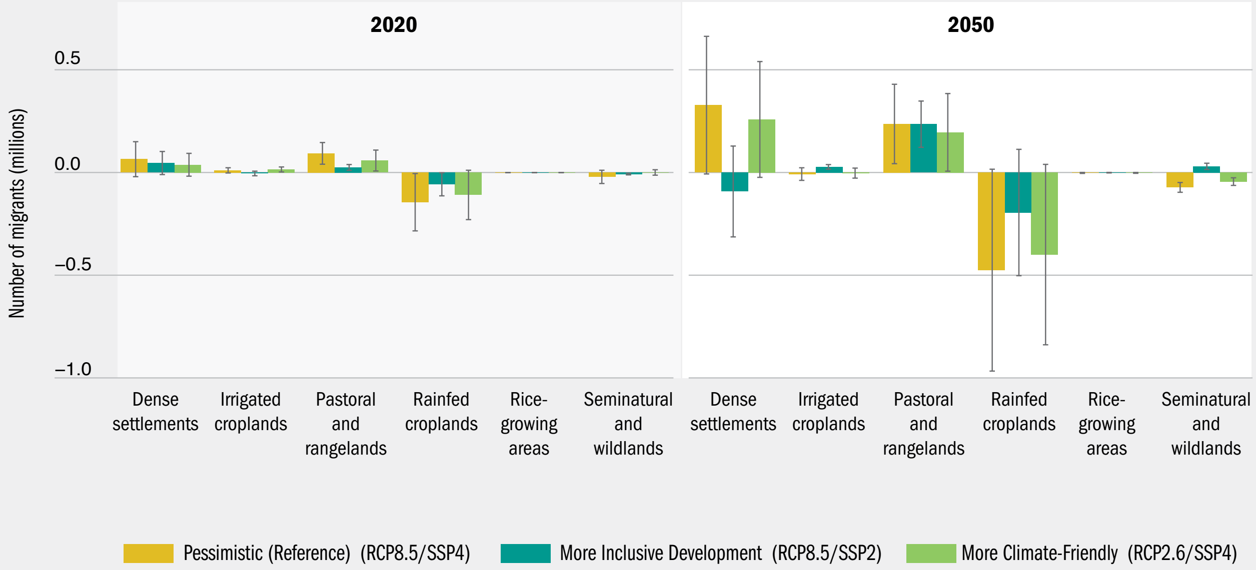
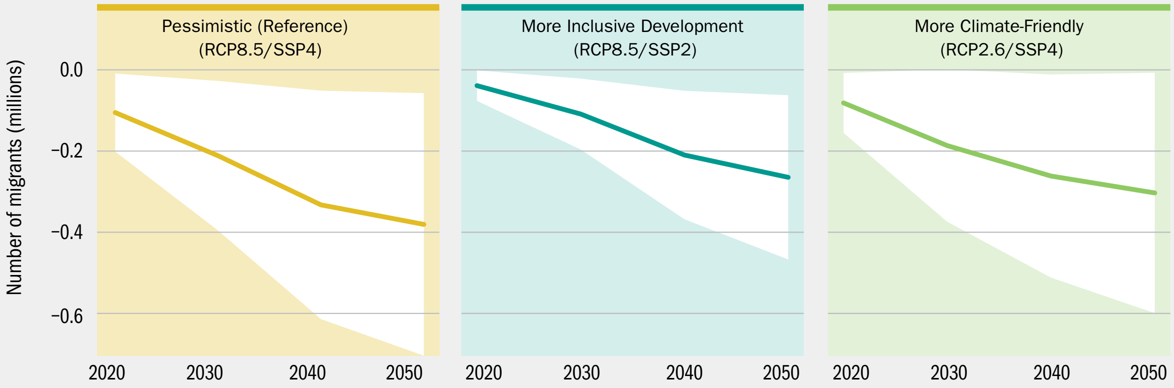


Figure 4.30: Projected net climate migration in and out of coastal zones in Mexico and Central America under three scenarios, 2020-50



Note: Dark lines represent the average runs for each scenario. Unshaded white areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

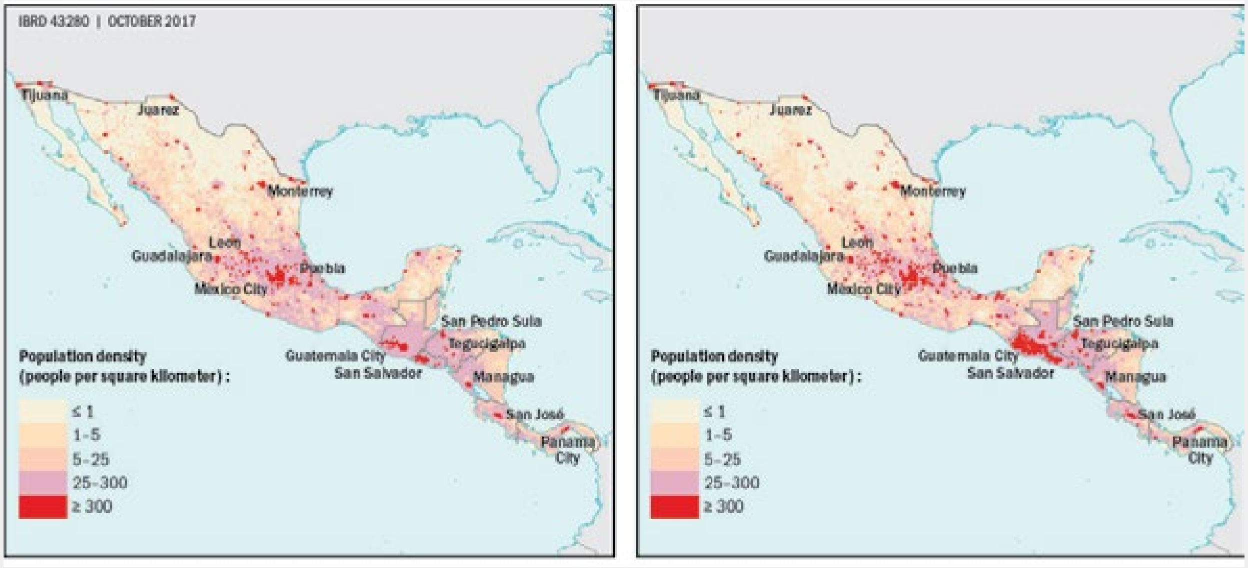
Trends in coastal zones

Mexico and Central America see out-migration in the coastal zone (Figure 4.30). Out-migration is greatest in the pessimistic reference scenario, projecting close to 400,000 fewer people on average in the coastal zone by 2050. The other two scenarios show lower coastal out-migration—between 250,000 –300,000 people—on average by 2050. The confidence interval across the scenarios is wide, however, ranging from 0 to 700,000. As a percentage of the population in the coastal zone in 2050, the range for the central tendency is 1–1.5 percent. The complexity of factors in coastal areas which coincides with a number of urban areas coupled with sea level rise and storm surge suggests the need for more customized analysis to understand the local context and subsequent impacts on the scale and pattern of climate migration.

Trends in urban areas

The spatial extent of urban areas is projected to grow by 2050 (Figure 4.31). Growth in urban areas is consistent across the three scenarios: It is projected to rise from 90 million people in 2010 to about 140 million people in 2050. Climate migration to cities generally trends upward with increases of roughly 225,000–300,000 people compared to the no climate impact scenarios—a very small change given projected urban populations of about 140 million. These findings concur with the work by Nawrotzki and others (2015) on climate change as a driver of rural to urban migration.

Figure 4.31: Population density in 2010 and projected population density in 2050 in urban areas of Mexico and Central America



a. 2010

b. 2050

Note: An "urban" area is an area with density of at least 300 people per square kilometer. The map for 2050 shows all areas in which any one of the three scenarios has populations of such density. It thus represents plausible urbanization outcomes rather than its most likely spread.


Photo Credit: shutterstock

PROJECTIONS OF CLIMATE MIGRATION IN FOUR ADDITIONAL SUBREGIONS

Modeling was conducted for three additional subregions of Africa (West, Central, and Southern) and for South America, in order to get a better sense of broader regional trends in Sub-Saharan Africa and Latin America. The modeling results were not analyzed as closely as the results for the three focus subregions. The main objective was to assess the scale of migration across these regions by 2050.

Table 4.2 shows the climate migration numbers and percentages of the population for the four additional subregions by 2050, which together with the subregions of East Africa and Mexico and Central America give a complete picture of all subregions within Sub-Saharan Africa and Latin America. West Africa has the highest levels and percentages of climate migrants, suggesting that climate impacts will have a particularly pronounced impact on migration in a region that has long been a bellwether of climate-related migration (UNEP 2011). In all subregions, the more climate-friendly scenario has the lowest climate migration levels. In all subregions except South America, the pessimistic reference scenario projects the highest migration levels. In South America, the more inclusive development scenario projects slightly higher numbers, although the relative share of climate migrants in the total population remains on par with the pessimistic scenario.

Table 4.2: Projected numbers and shares of internal climate migrants by 2050 for subregions in Sub-Saharan Africa and Latin America

	Scenario					
Region	**Pessimistic reference**		**More inclusive development**		**More climate-friendly**	
East Africa						
Average number of internal climate migrants by 2050 (million)	**10.1**		**9.2**		**6.9**	
Minimum (left) and Maximum (right) (million)	8.1	12.1	7.2	11.2	4.3	9.3
Internal climate migrants as percent of population	**1.28%**		**1.37%**		**0.87%**	
Minimum (left) and Maximum (right)	1.03%	1.54%	1.07%	1.66%	0.56%	1.19%
West Africa						
Average number of internal climate migrants by 2050 (million)	**54.4**		**38.5**		**17.9**	
Minimum (left) and Maximum (right) (million)	44.8	64.0	32.0	45.0	11.1	24.8
Internal climate migrants as percent of population	**6.87%**		**5.67%**		**2.27%**	
Minimum (left) and Maximum (right)	5.67%	8.08%	4.71%	6.63%	1.40%	3.13%
Central Africa						
Average number of internal climate migrants by 2050 (million)	**5.1**		**4.3**		**2.6**	
Minimum (left) and Maximum (right) (million)	3.1	7.1	2.9	5.7	1.7	3.5
Internal climate migrants as percent of population	**1.31%**		**1.31%**		**0.66%**	
Minimum (left) and Maximum (right)	0.80%	1.81%	0.83%	1.65%	0.43%	0.89%
Southern Africa						
Average number of internal climate migrants by 2050 (million)	**1.5**		**1.5**		**0.9**	
Minimum (left) and Maximum (right) (million)	0.6	2.5	0.07	2.8	0.2	1.6
Internal climate migrants as percent of population	**2.31%**		**1.98%**		**1.40%**	
Minimum (left) and Maximum (right)	0.85%	3.77%	0.09%	3.86%	0.85%	3.77%
Mexico and Central America						
Average number of internal climate migrants by 2050 (million)	**2.1**		**1.4**		**1.7**	
Minimum (left) and Maximum (right) (million)	0.3	3.9	0.5	2.4	0.2	3.3
Internal climate migrants as percent of population	**1.03%**		**0.68%**		**0.85%**	
Minimum (left) and Maximum (right)	0.17%	1.90%	0.22%	1.14%	0.09%	1.61%
South America						
Average number of internal climate migrants by 2050 (million)	**8.6**		**9.1**		**4.1**	
Minimum (left) and Maximum (right) (million)	3.9	13.2	4.4	13.2	2.0	6.2
Internal climate migrants as percent of population	**1.86%**		**1.86%**		**0.89%**	
Minimum (left) and Maximum (right)	0.86%	2.86%	0.90%	2.82%	0.44%	1.34%

Note: The scenarios are based on combinations of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). SSP2 =moderate development and SSP4 = unequal development; RCP 2.6 =low emissions; RCP 8.5 = high emissions.

Table 4.3 shows aggregate projections for total climate migration for the three regions of focus: Sub-Saharan Africa, South Asia and Latin America.

Common trends emerge regarding the scale, magnitude, and direction of climate migration:

- Internal climate migration will increase under all three scenarios across all three regions.
- Under the pessimistic reference scenario, which reflects high emissions coupled with unequal development, the number of climate migrants could reach more than 143 million by 2050; the average is 118 million; the minimum 92 million. Sub-Saharan Africa could see as many as 85.7 million climate migrants, South Asia 40.5 million, and Latin America 17.1 million.
- Under the more inclusive development scenario, the number of climate migrants is projected to be 38 million lower than under the pessimistic reference scenario, with the biggest decreases in Sub-Saharan Africa (down 21 million) and South Asia (down 16.4 million); while the number of climate migrants in Latin America drops slightly (down 0.9 million). The changes reflect the fact that climate migration is closely intertwined with a country's development context. The more moderate development trajectory in this scenario means slower population growth in low-income countries, as well as less economic inequality, slower urbanization, higher GDP, and more education.
- The fewest internal climate migrants are projected under the more climate-friendly scenario: 28.3 million in Sub-Saharan Africa, 16.9 million in South Asia, and 5.8 million in Latin America. In all regions, the average number is cut by at least half by 2050 from the pessimistic reference scenario. This means that large gains in sustaining rural livelihoods that help people stay in place may come from investing in stringent mitigation measures and commitments to reduce emissions globally.

Photo Credit: World Bank

Table 4.3: Projected numbers and shares of internal climate migrants by 2050 for the three regions of focus—Sub-Saharan Africa, South Asia and Latin America

	Scenario					
Region	Pessimistic reference		More inclusive development		More climate-friendly	
Sub-Saharan Africa						
Average number of internal climate migrants by 2050 (million)	**71.1 million**		**53.3 million**		**28.3 million**	
Minimum (left) and Maximum (right)	56.6 mn	85.7 mn	42.1 mn	64.7 mn	17.4 mn	39.9 mn
Internal climate migrants as percent of population	**3.49%**		**3.01%**		**1.39%**	
Minimum (left) and Maximum (right)	2.71%	4.03%	2.33%	3.58%	0.91%	2.04%
South Asia						
Average number of internal climate migrants by 2050 (million)	**35.7 million**		**21.1 million**		**16.9 million**	
Minimum (left) and Maximum (right)	30.9 mn	40.5 mn	18.1 mn	24.1 mn	11.4 mn	22.4 mn
Internal climate migrants as percent of population	**1.56%**		**0.89%**		**0.74%**	
Minimum (left) and Maximum (right)	1.35%	1.77%	0.76%	1.02%	0.50%	0.98%
Latin America						
Average number of internal climate migrants by 2050 (million)	**10.6 million**		**10.5 million**		**5.8 million**	
Minimum (left) and Maximum (right)	4.3 mn	17.1 mn	4.9 mn	16.2 mn	2.2 mn	9.4 mn
Internal climate migrants as percent of population	**1.61%**		**1.50%**		**0.88%**	
Minimum (left) and Maximum (right)	0.65%	2.56%	0.70%	2.31%	0.33%	1.42%
Total						
Average number of internal climate migrants by 2050 (million)	**117.5 million**		**85.1 million**		**51.1 million**	
Minimum (left) and Maximum (right)	91.8 mn	143.3 mn	65.1 mn	105.3 mn	31.2 mn	71.7 mn
Internal climate migrants as percent of population	**2.36%**		**1.75%**		**1.02%**	
Minimum (left) and Maximum (right)	1.81%	2.80%	1.33%	2.14%	0.64%	1.47%

Note: The scenarios are based on combinations of Shared Socioeconomic Pathways (SSP2—moderate development; SSP4—unequal development) and Representative Concentration Pathways (RCP 2.6—low emissions; RCP 8.5—high emissions) that drive climate impacts on crop productivity and water availability as well as sea level rise and storm surge.

CLIMATE IMPACT TRENDS 2050–2100

The climate migration trends projected through 2050 may be just a starting point for much greater flows in the second half of the century in some regions. According to results from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) water and crop sectoral models, maps that compare water runoff and crop productivity changes for 2050–2100 with the baseline values for 1970–2010 show that impacts will be more severe, further strengthening the conditions for increased climate migration. Just as with the results for 2010–50, the ISIMIP results vary spatially. The scenarios modeled in this study represent two climate models, two water models, and two crop sector models. They do not represent the full range of results possible. In some regions—East Africa in particular—climate projections are highly uncertain, in part because the projections of future precipitation appear to contradict evidence of current drying. Models were selected in part because their future precipitation trends differ substantially in magnitude, and partly even in sign, for the focus regions.

In general, however, the ISIMIP model runs to the end of the century suggest more extensive and extreme climate impacts on water availability and crop productivity, which will have significant ramifications for population movements. The model calibration using historical impacts and population distribution data demonstrated that populations are already sensitive to climate impacts in ways that will affect population distributions through 2050. Therefore, more accentuated impacts from 2050 onward would have the potential to drive more migration, particularly distress migration.

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For water availability in East Africa, the results are not markedly worse than for 2010–50 (Figure 4.32), although the literature suggests that there will be more variability and more extreme rainfall events, which long-term averages may not capture. The crop productivity projections are significantly worse (Figure 4.33), with large areas under RCP8.5 seeing steep declines.

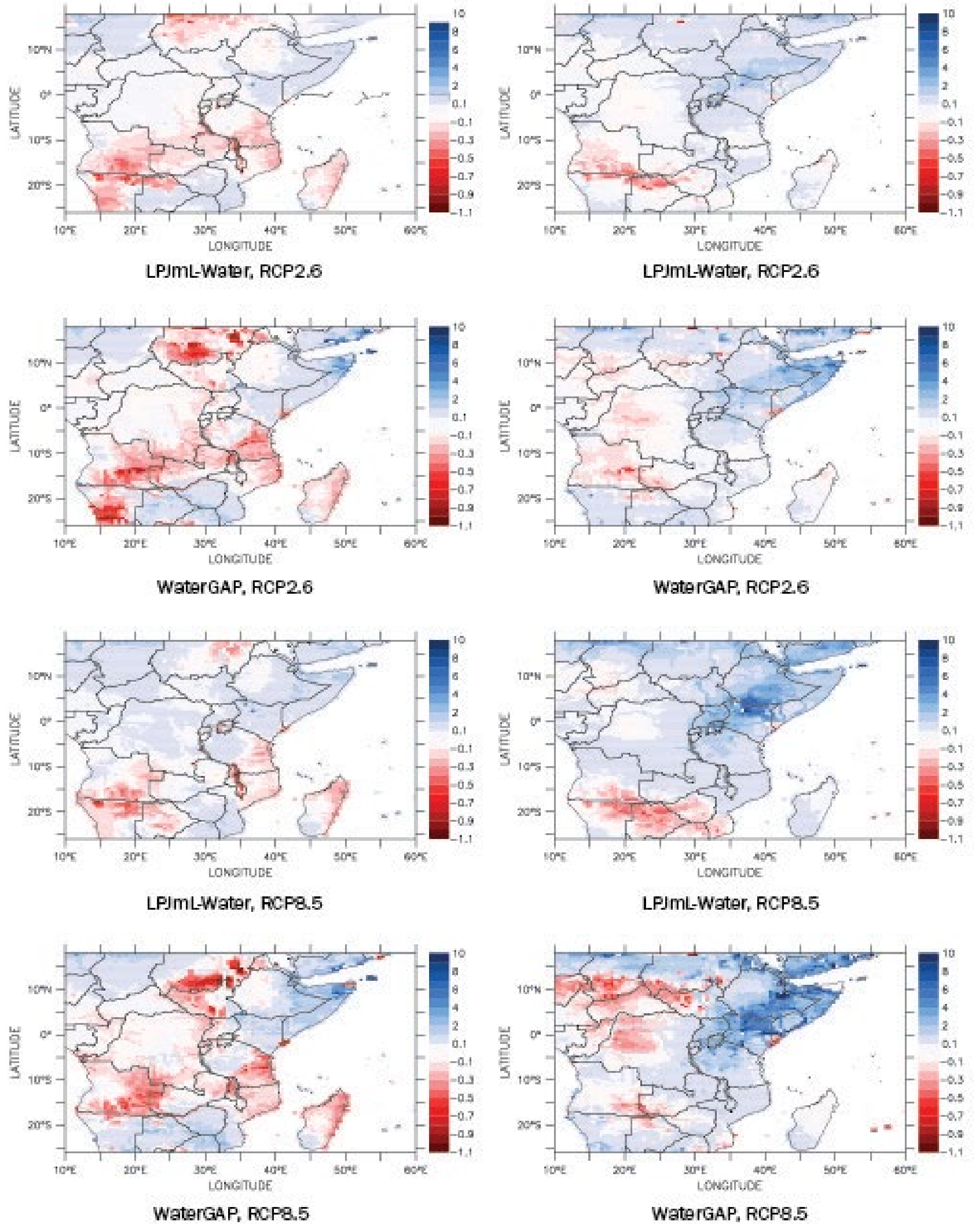
In South Asia, water availability is projected to increase over broad swaths of the continent through the end of the century but to decline in Afghanistan, northeastern Pakistan, and northwestern India under the IPSL-CM5A RCP8.5 scenario (Figure 4.34). However, even areas that may see stable or increasing water availability on average may see extremes of flooding (because of the trend toward increasingly intense rainfall events) or periodic drought. For crop production (Figure 4.35), the picture is more negative, particularly under the GEPIC crop model (see Chapter 3), according to which much of India will see sharp declines in crop productivity, especially under the high greenhouse gas concentration RCP8.5 scenarios, where the climate impacts toward the end of the century are severe for both water availability and crop productivity across most model runs.

In Mexico and Central America, results are generally more negative, especially for the high greenhouse gas concentration RCP8.5 scenarios, where the climate impacts toward the end of the century are severe for both water availability and crop productivity across most model runs. Water availability declines sharply relative to the historical baseline (Figure 4.36), and crop productivity follows a similar pattern (Figure 4.37). This region will see potentially dramatic impacts and consequences for climate migration toward the end of the century. Results are consistent with the extreme drought conditions projected by Dai (2012) by the end of the century under RCP8.5.

Figure 4.32: Projected change in water availability in East Africa between 1970–2010 and 2050–2100

a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A global climate model



LPJmL-Water, RCP2.6 | LPJmL-Water, RCP2.6

WaterGAP, RCP2.6 | WaterGAP, RCP2.6

LPJmL-Water, RCP8.5 | LPJmL-Water, RCP8.5

WaterGAP, RCP8.5 | WaterGAP, RCP8.5

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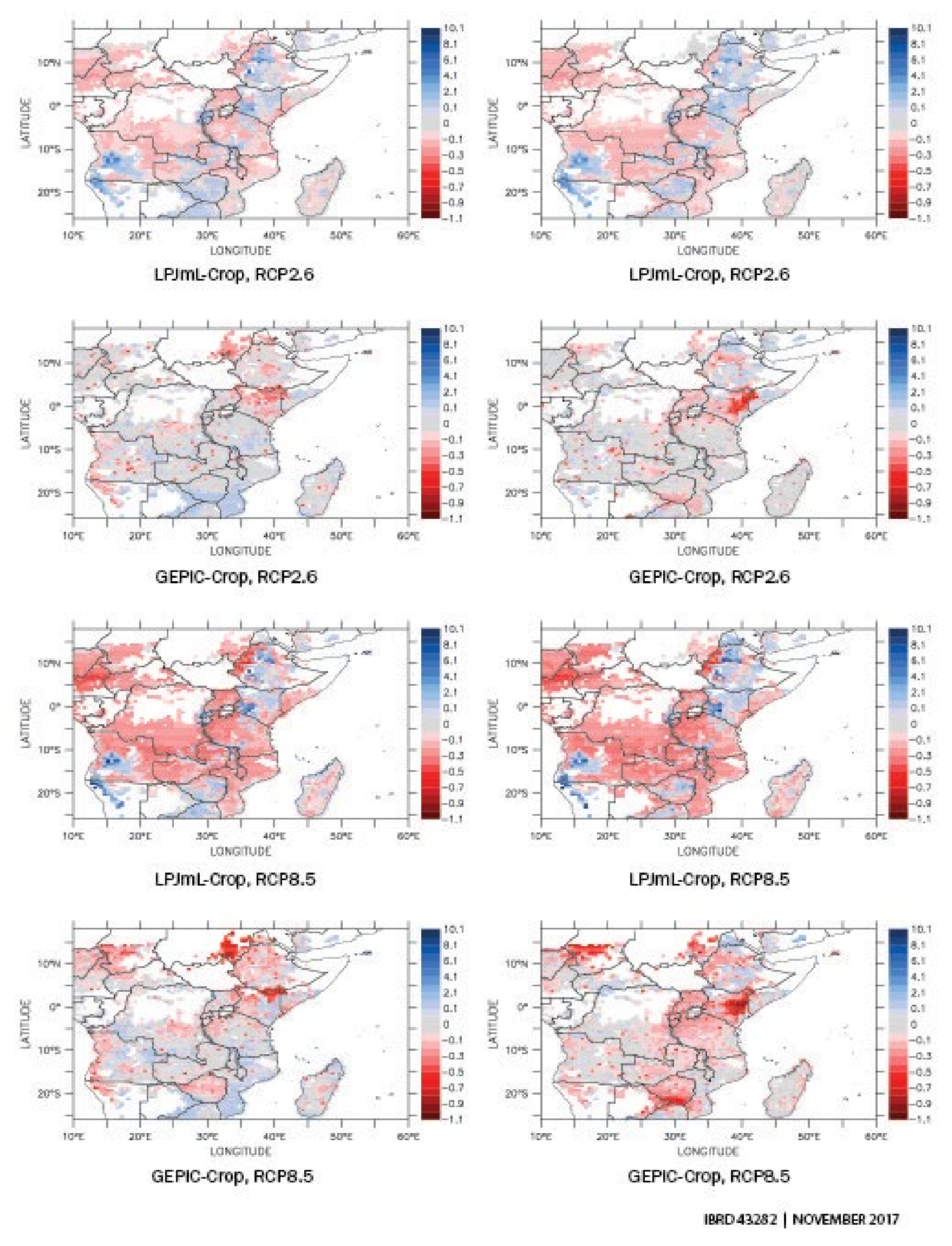
Note: Both global climate models are used in conjunction with the LPJmL and WaterGAP water models under low and high emissions pathways (RCP pathways 2.6 and 8.5, respectively). The maps represent indices of change in water availability for the 2050-2100 period relative to the long-term average for 1970-2010. Values such as 0.2 represent 20 percent above the baseline average, and -0.6 representing 60 percent below the baseline average. Positive and negative values are represented in blue scale and red scale, respectively, with increasing color saturation representing higher values (more positive or negative values, respectively) on both scales. See Chapter 3 for details on the HadGEM2-ES and IPSL-CM5A-LR global climate models.

Figure 4.33: Projected change in crop production in East Africa between 1970–2010 and 2050–2100



a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A global climate model

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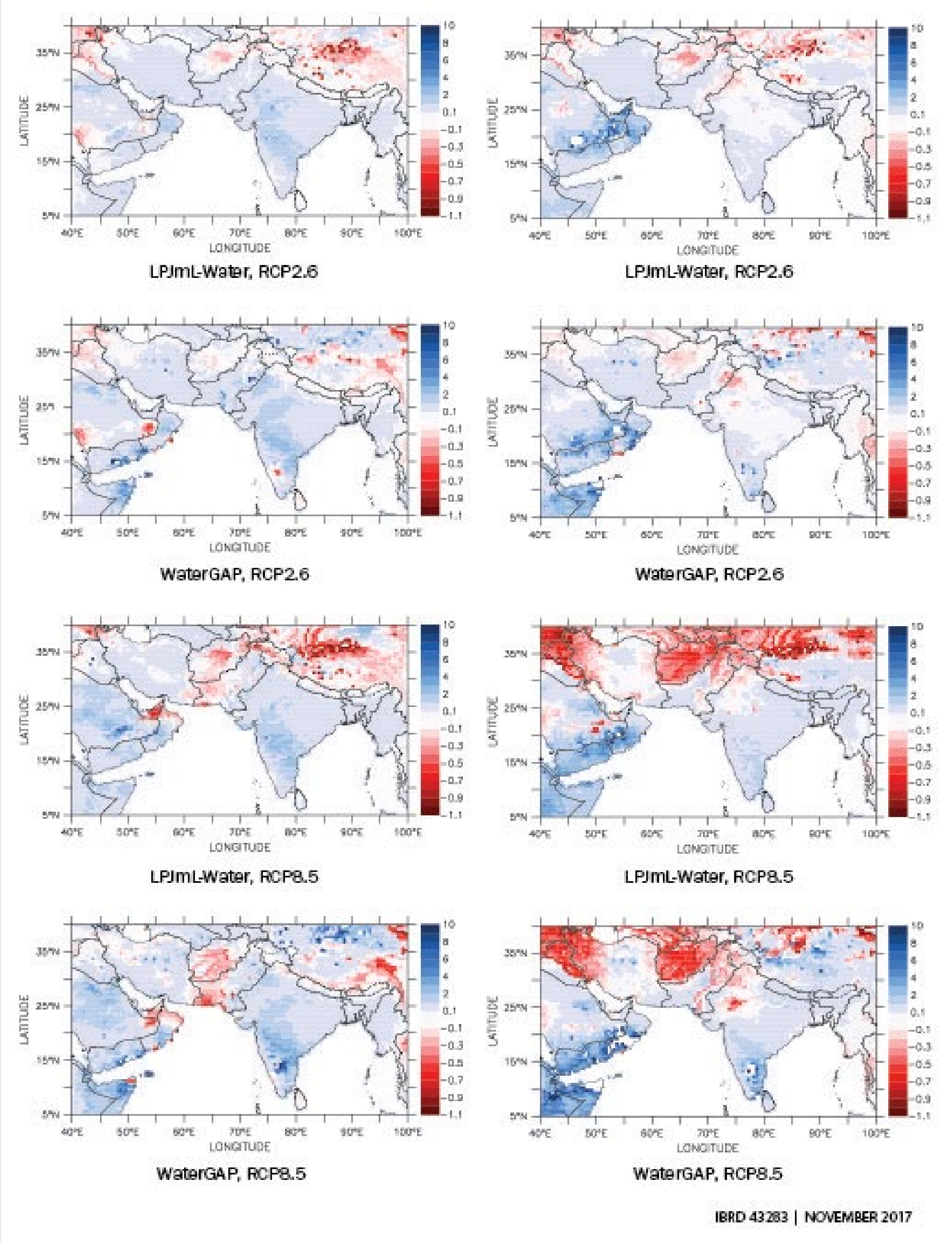
Note: Both global climate models are used in conjunction with the LPJmL and GEPIC crop models under low and high emissions pathways (RCP pathways 2.6 and 8.5, respectively). The maps represent indices of change in crop production for the 2050-2100 period relative to the long-term average for 1970-2010. Values such as 0.2 represent 20 percent above the baseline average, and -0.6 representing 60 percent below the baseline average. Positive and negative values are represented in blue scale and red scale, respectively, with increasing color saturation representing higher values (more positive or negative values, respectively) on both scales. See Chapter 3 for details on the HadGEM2-ES and IPSL-CM5A-LR global climate models.

Figure 4.34: Projected change in water availability in South Asia between 1970–2010 and 2050–2100



a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A global climate model

LPJmL-Water, RCP2.6

LPJmL-Water, RCP2.6

WaterGAP, RCP2.6

WaterGAP, RCP2.6

LPJmL-Water, RCP8.5

LPJmL-Water, RCP8.5

WaterGAP, RCP8.5

WaterGAP, RCP8.5

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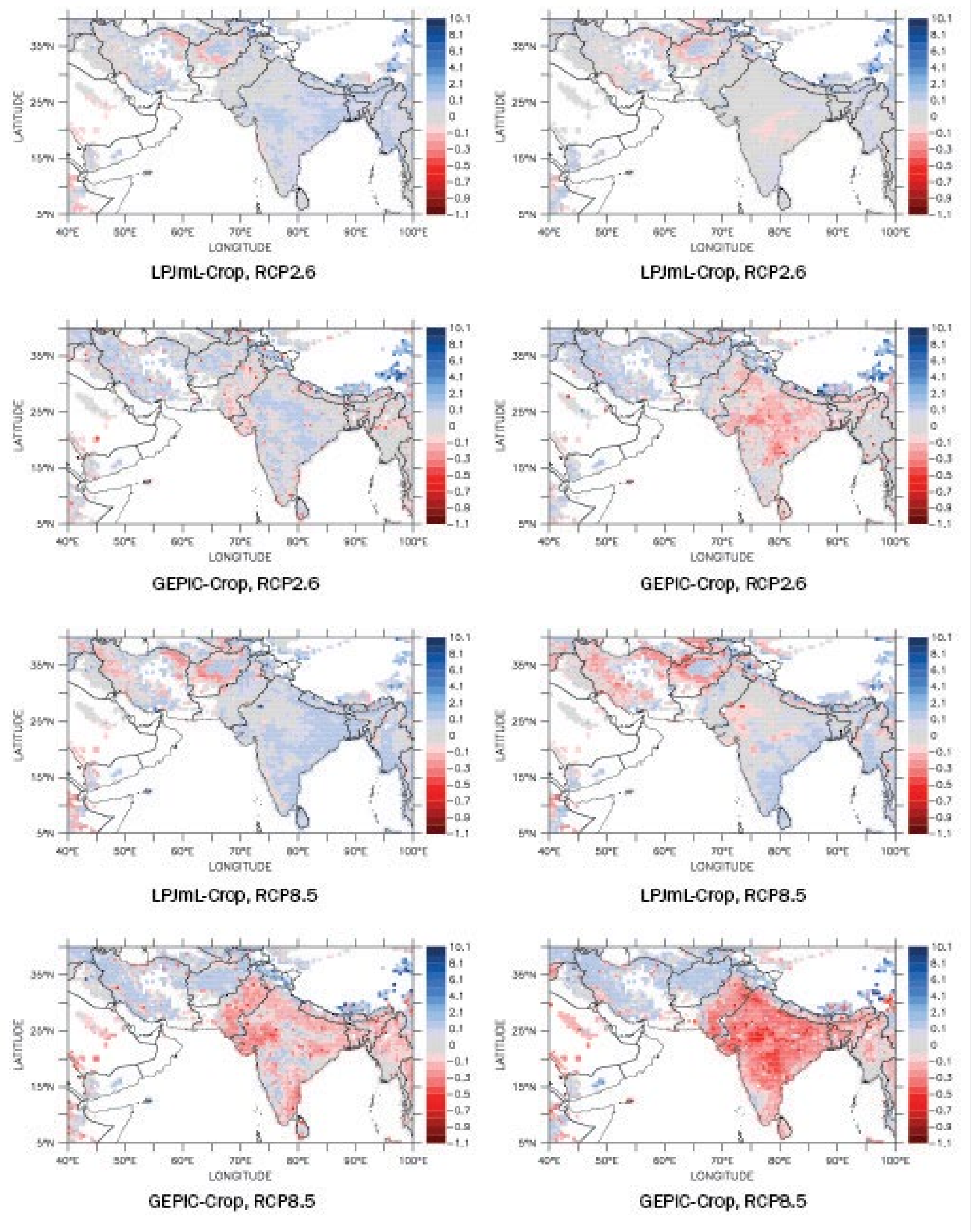
Note: Both global climate models are used in conjunction with the LPJmL and WaterGAP water models under low and high emissions pathways (RCP pathways 2.6 and 8.5, respectively). The maps represent indices of change in water availability for the 2050-2100 period relative to the long-term average for 1970-2010. Values such as 0.2 represent 20 percent above the baseline average, and -0.6 representing 60 percent below the baseline average. Positive and negative values are represented in blue scale and red scale, respectively, with increasing color saturation representing higher values (more positive or negative values, respectively) on both scales. See Chapter 3 for details on the HadGEM2-ES and IPSL-CM5A-LR global climate models.

Figure 4.35: Projected change in crop production in South Asia between 1970–2010 and 2050–2100



a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A global climate model

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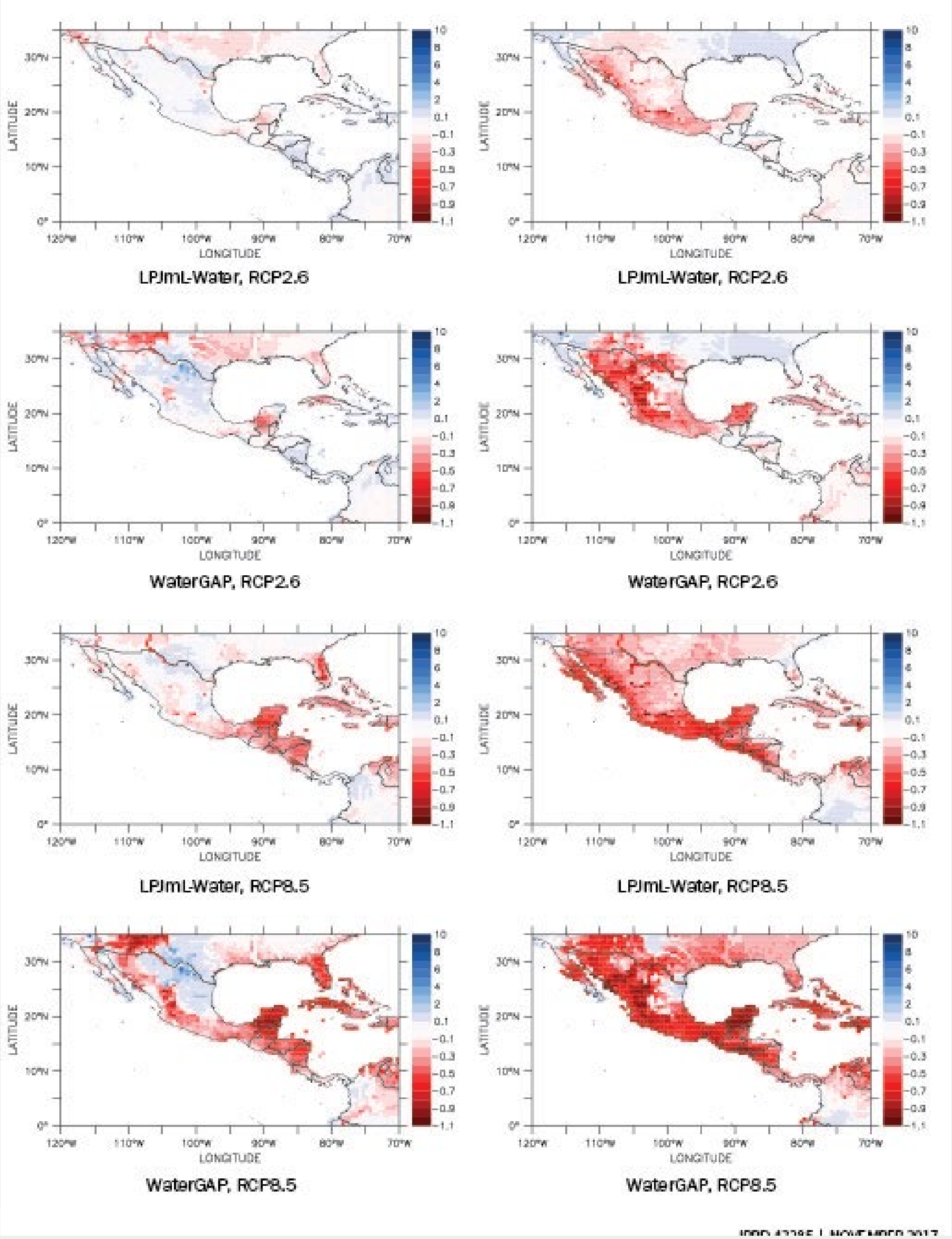
Note: Both global climate models are used in conjunction with the LPJmL and GEPIC crop models under low and high emissions pathways (RCP pathways 2.6 and 8.5, respectively). The maps represent indices of change in crop production for the 2050-2100 period relative to the long-term average for 1970-2010. Values such as 0.2 represent 20 percent above the baseline average, and -0.6 representing 60 percent below the baseline average. Positive and negative values are represented in blue scale and red scale, respectively, with increasing color saturation representing higher values (more positive or negative values, respectively) on both scales. See Chapter 3 for details on the HadGEM2-ES and IPSL-CM5A-LR global climate models.

Figure 4.36: Projected change in water availability in Mexico and Central America between 1970–2010 and 2050–2100

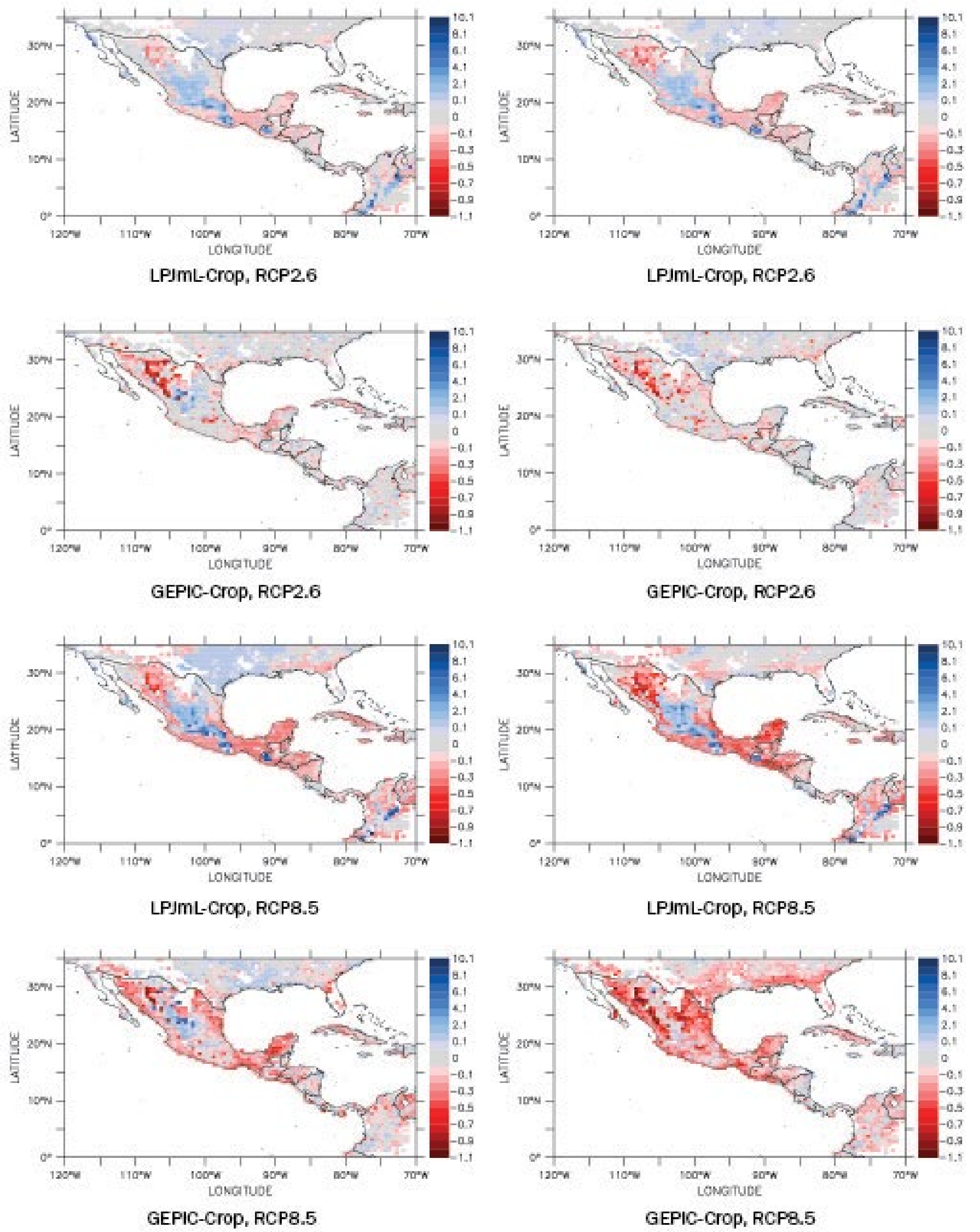


a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A global climate model

Note: Both global climate models are used in conjunction with the LPJmL and WaterGAP water models under low and high emissions pathways (RCP pathways 2.6 and 8.5, respectively). The maps represent indices of change in water availability for the 2050-2100 period relative to the long-term average for 1970-2010. Values such as 0.2 represent 20 percent above the baseline average, and -0.6 representing 60 percent below the baseline average. Positive and negative values are represented in blue scale and red scale, respectively, with increasing color saturation representing higher values (more positive or negative values, respectively) on both scales. See Chapter 3 for details on the HadGEM2-ES and IPSL-CM5A-LR global climate models.

Figure 4.37: Projected change in crop production in Mexico and Central America between 1970–2010 and 2050–2100


a. Impact models driven by the HADGEM2-ES global climate model

b. Impact models driven by the IPSL-CM5A global climate model

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Note: Both global climate models are used in conjunction with the LPJmL and GEPIC crop models under low and high emissions pathways (RCP pathways 2.6 and 8.5, respectively). The maps represent indices of change in crop production for the 2050-2100 period relative to the long-term average for 1970-2010. Values such as 0.2 represent 20 percent above the baseline average, and -0.6 representing 60 percent below the baseline average. Positive and negative values are represented in blue scale and red scale, respectively, with increasing color saturation representing higher values (more positive or negative values, respectively) on both scales. See Chapter 3 for details on the HadGEM2-ES and IPSL-CM5A-LR global climate models.

REFERENCES

Abel, G. J., and N. Sander. 2014. “Quantifying Global International Migration Flows.” *Science* 343 (6178): 1520–22. doi:10.1126/science.1248676.

Anyah, R.O., and W. Qiu. 2012. “Characteristic 20th and 21st Century Precipitation and Temperature Patterns and Changes over the Greater Horn of Africa.” *International Journal of Climatology* 32 (3): 347–63.

ADB (Asian Development Bank). 2012. “Addressing Climate Change and Migration in Asia and the Pacific.” Manila: Asian Development Bank. http://www.worldcat.org/oclc/780416971.

Christenson E., M. Elliot, O. Banerjee, L. Hamrick, and J.E. Bartram. 2014. “Climate-Related Hazards: A Method for Global Assessment of Urban and Rural Population Exposure to Cyclones, Droughts, and Floods.” *International Journal of Environmental Research and Public Health* 11 (2): 2169–92.

Cottier, F. 2017. “Environmental Change and Its Effect on Internal Migration.” Ph.D. diss., Department of Geography, University of Geneva.

Dai, A. 2012. “Increasing Drought under Global Warming in Observations and Models.” *Nature Climate Change* 3: 52–58. doi:10.1038/nclimate1633.

Dyson, T., R. Cassen, and L. Visaria, eds. 2005. *Twenty-First Century India: Population, Economy, Human Development and the Environment.* New York: Oxford University Press.

Eitzinger, A., P. Läderach, K. Sonder A. Schmidt, G. Sain, S. Beebe, B. Rodríguez, M. Fisher, P. Hicks, C. Navarrete-Frías, and A. Nowak. 2012. “Tortillas on the Roaster: Central America’s Maize–Bean Systems and the Changing Climate.” CIAT Policy Brief 6. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

FAO (Food and Agriculture Organization). 2011. *The State of the World’s Land and Water Resources for Food and Agriculture (SOLAW): Managing Systems at Risk*. Rome: Food and Agriculture Organization.

Feng, S., A.B. Krueger, and M. Oppenheimer. 2010. “Linkages among Climate Change, Crop Yields and Mexico–US Cross-Border Migration.” *Proceedings of the National Academy of Sciences* 107 (32): 14257–62.

Hijioka, Y., E. Lin, J.J. Pereira, R.T. Corlett, X. Cui, G.E. Insarov, R.D. Lasco, E. Lindgren, and A. Surjan. 2014. “Asia.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Hugo, G., and D.K. Bardlsey. 2014. “Migration and Environmental Change in Asia” In *People on the Move in a Changing Climate*, E. Piguet and F. Laczo, eds. New York: Springer.

IDMC (Internal Displacement Monitoring Center). 2017b. GRID 2017: *Global Report on Internal Displacement.* Geneva: Internal Displacement Monitoring Center and Norwegian Refugee Council. http://www.internal-displacement.org/global-report/grid2017/pdfs/2017-GRID.pdf.

ILO (International Labour Organization). 2017. Key Indicators of the Labour Market Database, ILOSTAT. Geneva. Accessed October 5, 2017.

IOM (International Organization for Migration). 2015. *Regional Migration Initiatives 2015*. Geneva.

———. 2017. “GMDAC Migfacts: International Migration.” Geneva. https://gmdac.iom.int/gmdac-migfacts-international-migration.

Jones, B., and B. C. O’Neill. 2016. “Spatially Explicit Global Population Scenarios Consistent with the Shared Socioeconomic Pathways.” *Environmental Research Letters* 11: 084003.

Kaenzig, R., and E. Piguet. 2014. “Migration and Climate Change in Latin America and the Caribbean.” In *People on the Move in a Changing Climate*, ed. E. Piguet and F. Laczo. New York: Springer.

Karmalkar, A.V., R.S. Bradley, and H.F. Diaz. 2011. “Climate Change in Central America and Mexico: Regional Climate Model Validation and Climate Change Projections.” *Climate Dynamics* 37: 605. https://doi.org/10.1007/s00382-011-1099-9.

Magrin, G.O., J.A. Marengo, J.-P. Boulanger, M.S. Buckeridge, E. Castellanos, G. Poveda, F.R. Scarano, and S. Vicuña. 2014. “Central and South America.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, 1499–566. Cambridge: Cambridge University Press.

Mason, S. J., and L. Goddard. 2001. “Probabilistic Precipitation Anomalies Associated with ENSO.” *Bulletin of the American Meteorological Society* 82 (4): 619–38. http://doi.org/10.1175/1520-0477(2001)082<0619:PPAAWE>2.3.CO;2

Menon, A., A. Levermann, and J. Schewe. 2013a. “Enhanced Future Variability during India’s Rainy Season.” *Geophysical Research Letters* 40 (12): 3242–47. http://doi.org/10.1002/grl.50583.

Menon, A., A. Levermann, J. Schewe, J. Lehmann, and K. Frieler. 2013b. “Consistent Increase in Indian Monsoon Rainfall and Its Variability across CMIP-5 models.” *Earth System Dynamics* 4 (2): 287–300. http://doi.org/10.5194/esd-4-287-2013.

Morrissey, J. 2014. “Environmental Change and Human Migration in Sub-Saharan Africa.” In *People on the Move in a Changing Climate,* ed. E. Piguet and F. Laczo. New York: Springer.

Nawrotzki, R.J., F. Riosmena, and L.M. Hunter. 2013. “Do Rainfall Deficits Predict U.S.-Bound Migration from Rural Mexico? Evidence from the Mexican Census.” *Population Research and Policy Review* 32 (1): 129–58. doi:10.1007/s11113-012-9251-8.

Nawrotzki, R.J., F. Riosmena, L.M. Hunter, and D.M. Runfola. 2015. “Amplification or Suppression: Social Networks and the Climate Change–Migration Association in Rural Mexico.” *Global Environmental Change* 35: 463–74. doi:http://dx.doi.org/10.1016/j.gloenvcha.2015.09.002.

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart. 2014. “Africa.” In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, 1199–265. Cambridge: Cambridge University Press.

Olson, D. M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D’amico, I. Itoua, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, T.H. Ricketts, Y. Kura, J.F. Lamoreux, W.W. Wettengel, P. Hedao, and K.R. Kassem. 2001. “Terrestrial Ecoregions of the World: A New Map of Life on Earth: A New Global Map of Terrestrial Ecoregions Provides an Innovative Tool for Conserving Biodiversity.” *BioScience* 51 (11): 933–38. https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2.

PRB (Population Reference Bureau). 2017. “2017 World Population Data Sheet.” Washington, DC.

Reyer, C.P., S. Adams, T. Albrecht, F. Baarsch, A. Boit, N.C. Trujillo, M. Cartsburg, D. Coumou, A. Eden, E. Fernandes, and F. Langerwisch. 2015. “Climate Change Impacts in Latin America and the Caribbean and Their Implications for Development.” *Regional Environmental Change* 17 (6): 1–21.

Singh, D., M. Tsiang, B. Rajaratnam, and N.S. Diffenbaugh. 2014. “Observed Changes in Extreme Wet and Dry Spells during the South Asian Summer Monsoon Season.” *Nature Climate Change* 4 (6) : 456–61. http://doi.org/10.1038/nclimate2208.

Tiwari, V.M., J. Wahr, and S. Swenson. 2009. “Dwindling Groundwater Resources in Northern India, from Satellite Gravity Observations.” *Geophysical Research Letters* 36 (18).

Tucker, C.M., H. Eakin, and E.J. Castellanos. 2010. “Perceptions of Risk and Adaptation: Coffee Producers, Market Shocks, and Extreme Weather in Central America and Mexico.” *Global Environmental Change* 20 (1): 23–32.

UNDP (United Nations Development Programme). 2016. *Human Development Report 2016*. New York: United Nations Development Programme. http://hdr.undp.org/en/composite/HDI.

UNEP (United Nations Environment Programme). 2011. *Climate Change, Conflict and Migration in the Sahel*. Geneva: United Nations Environment Programme. https://postconflict.unep.ch/publications/UNEP_Sahel_EN.pdf

Warner, K., C. Erhart, A. de Sherbinin, S.B. Adamo, and T.Chai-Onn. 2009. "In Search of Shelter: Mapping the Effects of Climate Change on Human Migration And Displacement." Bonn: United Nations University, CARE, and CIESIN-Columbia University.

Wenju, C., S. Borlace, M. Lengaigne, P. van Rensch, M. Collins, G, Vecchi, A. Timmerman, A. Santoso, M. McPhaden, L. Wu, M.H. England, G. Wang, E. Guilyardi, and F.-F. Jin. 2014. "Increasing Frequency of Extreme El Niño Events Due to greenhouse Warming." *Nature Climate Change* 5 (1): 1–6. http://doi.org/10.1038/nclimate2100.

WFP (World Food Programme), IABD (Inter-American Development Bank), and IFAD (International Fund for Agricultural Development). 2017. *Food Security and Emigration: Why People Flee and the Impact on Family Members Left behind in El Salvador, Guatemala and Hondura*s. Rome: World Food Programme.

Williams, A.P., and C. Funk. 2011. "A Westward Extension of the Warm Pool Leads to a Westward Extension of the Walker Circulation, Drying Eastern Africa." *Climate Dynamics* 37 (11–12): 2417–35. doi:10.1007/s00382-010-0984-y.

WRI (World Resources Institute). 2013. *Aqueduct Water Risk Atlas*. Washington, DC: World Resources Institute. http://www.wri.org/our-work/project/aqueduct.

Yang, W.C., R. Seager, M.A. Cane, and B. Lyon. 2015. "The Annual Cycle of East African Precipitation." *Journal of Climate* 28 (6): 2385–404. doi:10.1175/Jcli-D-14-00484.1.

Chapter 5

Placing Climate Migration in the Development Context for Ethiopia, Bangladesh, and Mexico

Slow-onset climate change will shape migration decisions and outcomes in different ways across different economic and livelihood systems. The findings in Chapter 4 are embedded in a deeper understanding of local development contexts and of issues addressed in the literature in this chapter. An emerging common theme across these countries is that decision makers should view internal climate migration as a cross-cutting issue to be integrated into policy and planning. Key differences on how to do so reflect each country's development context, institutional capacity, and climate vulnerabilities.

Ethiopia, Bangladesh, and Mexico were selected as illustrative examples for several reasons. All are populous countries with differing climatic conditions, ecosystems, indicators of development, and urbanization. They also differ in their vulnerability to climate risk, demographic profiles, past migration patterns, and institutional capacity. Data and previous studies on climate migration are available on all three countries.

Ethiopia is a low-income country, Bangladesh is lower-middle-income, and Mexico is an upper-middle-income country (Table 5.1). This pattern, from low to high, also holds for the share of urban population, secondary school enrollment, and literacy. Ethiopia is the most dependent on agriculture (37 percent of GDP), followed by Bangladesh (15 percent) and Mexico (4 percent). Population growth and the total dependency ratio are high for Ethiopia, indicating a larger youth bulge in its demographic profile. The youth bulge is smaller for Bangladesh and Mexico, where a larger part of the population has entered the workforce. In terms of vulnerability to climate and disaster risk, Mexico is less vulnerable and has greater readiness than both Ethiopia and Bangladesh, according to the ND-GAIN Index (ND-GAIN 2017). The World Risk Index, which captures mainly natural disaster risk, ranks Bangladesh 5th in the world, Ethiopia 75th, and Mexico 95th (United Nations University 2016).

Table 5.1: Demographic, socioeconomic, and climate risk indicators for Ethiopia, Bangladesh, and Mexico

Indicator	Ethiopia	Bangladesh	Mexico
Population			
Population (millions)	102	163	127
Annual population growth (percent)	2.5	1.1	1.3
Population in 2050 under SSP2 (millions)	159	199	145
Population in 2050 under SSP4 (millions)	184	177	136
Age dependency ratio (percent)	80.5	51.5	51.0
Population density (people per square kilometer of land)	102	1,252	66
Urban share of population (percent)	20.4	35.8	79.2
Share of population engaged in agriculture (percent)	73 (2013)	47 (2010)	13.4 (2011)
GDP			
World Bank Group income classification	Low	Lower-middle	Upper-middle
GDP (billions of current dollars)	72	221	1,046
Annual GDP growth (percent)	7.6	7.1	2.3
GDP per capita (current dollars)	707	1,359	8,201
Value added of agriculture (percent of GDP)	37	15	4
Value added of industry (percent of GDP)	21	29	33
Value added of services (percent of GDP)	41	56	63
Poverty			
Poverty headcount ratio at national poverty lines (percent of population)	29.6 (2010)	24.3 (2016)	50.6 (2016)
Poverty headcount ratio at $1.90 a day (2011 purchasing power parity, percent of population, 2010)	33.5	18.5	3.8
Education			
Gross secondary school enrollment (percent)	35 (2015)	64 (2015)	91 (2014)
Literacy rate (percent of people 15 and older)	49.1*	72.8 (2011)	94.5 (2015)
Climate and disaster risk indexes			
ND GAIN Index (2015)			
Rank	146	142	68
Score	40.0	41.0	56.7
World Risk Index			
Rank	70	5	95
Score	7.0	19.2	6.0

Source: World Bank (2017a, 2017b); ND-GAIN (2017); United Nations University (2016)
Note: All figures are for 2016, except where otherwise indicated.
* of total population (2007)

This chapter presents the modeling results for each country. It reviews potential policy and development implications of climate migration and considers the broader development and mobility trends in each country.

OVERALL FINDINGS

In all three countries, the scale of climate migration is projected to increase by 2050 in all three scenarios—pessimistic reference, more inclusive development, and more climate-friendly. The distribution of climate migrants between hotspots of climate in- and out-migration and livelihood zones depends on each country's climate vulnerability and development context.

Table 5.2 presents the key climate migration findings for the three countries.

Key takeaways include the following:

- Climate migration occurs against a backdrop of overall population growth through 2050 in all three countries. In Ethiopia the population is expected to grow 60–85 percent by 2050, driven mainly by a youth bulge that will result in population growth for several decades to come. In Bangladesh population growth rates are half those of Ethiopia, but population density is among the highest in the world, particularly in low-lying urban and coastal areas. In both countries, increases in the number of climate migrants are thus likely to exert additional pressures on land, natural resources, infrastructure, and institutions. In contrast, as an upper-middle-income country with a diversified economy that has already experienced a demographic transition, Mexico could anticipate and cope with climate change-induced population redistribution.

- Climate migration will occur in a context of already high internal mobility in all three countries. In Ethiopia most migrants have historically been internal, as a result of resettlement policies and rural to rural and rural to urban migration. Rural to rural and rural to urban migration is also significant in Bangladesh. The internal migration pattern in Mexico is somewhat different. Given the country's already high level of urbanization, intra-metropolitan mobility and mobility from central downtown areas to surrounding suburban and peri-urban areas is replacing the rural to urban flows. Policy makers need to understand how climate will interact with other factors to induce future climate migration in countries at different development stages.

- While there is an overall increase in climate migrants across the scenarios, locality matters in the context of climate change. In Bangladesh and Mexico, the pessimistic reference scenario projects the largest number of climate migrants by 2050. In Ethiopia, the more climate-friendly scenario has the largest number of climate migrants by 2050. The higher number of climate migrants under this scenario is in part driven by the regional climate models which project lower water availability by 2050 in general compared to the other two scenarios (pessimistic reference and more inclusive development scenarios) which are coupled with higher emissions.

- Similarly, baseline development context and development trajectories influence the trajectory of climate migrants. In Ethiopia and Mexico, the more inclusive development scenario yields the lowest numbers of climate migrants by 2050. These results show that sustained development gains are imperative to reduce the scale of climate migration, though for different reasons depending on country context. In a low-income country with high population growth like Ethiopia, inclusive development can help absorb a growing young labor force into less climate sensitive sectors. In an upper-middle-income country like Mexico, a stronger economy means higher adaptive capacity and financial resources to target the most vulnerable areas and groups. In a highly climate vulnerable country like Bangladesh, the more climate-friendly scenario yields the lowest numbers of climate migrants by 2050, indicating that global low emissions pathways can help reduce pressures on livelihoods from climate impacts and thus the scale of climate migration.

- The share of climate migrants in total internal migrants is projected to increase in all scenarios by 2050 in all three countries, although there are differences. In Bangladesh, where past population distributions have been highly sensitive and responsive to climate impacts, climate migration outpaces other internal migrations by 2050 under the pessimistic reference scenario. In Ethiopia climate migrants are projected to constitute a smaller portion of all internal migrants (about 12 percent in the more climate-friendly scenario) by 2050. In Mexico, climate migrants could constitute about 11 percent of all internal migrants in the pessimistic reference scenario by 2050 suggesting that broader development will continue to drive other internal migration. Internal climate migration must therefore be addressed as an important part of the broader adaptive opportunities and challenges associated with internal migration.

- While urban areas will generally see population increases, this growth could be dampened in some cases by climate out-migration. Urban areas will be out-migration hotspots in Ethiopia and Bangladesh but not in Mexico. Addis Ababa located in the heart of the rainfed agricultural region is projected to be affected by declines in crop productivity. Bangladesh's major urban centers (Dhaka and Chittagong) are in deltaic and coastal areas, leaving them vulnerable to rising seas combined with storm surge. In contrast, the central plateau around Mexico City offers more favorable conditions for livelihoods and settlements than the arid north and low-lying states along the coast are Mexico's south and southeast. Anticipatory diagnostics to understand these trends and planning are needed to avert mass distress migration in and out of urban areas. Efforts are also needed to accommodate people who cannot adapt in place because of the impacts of climate and natural hazards or deteriorating livelihood conditions.

- Changes in water availability and crop productivity by 2050 will drive population redistribution across agricultural livelihood zones in the three countries. In Ethiopia, climate out-migration hotspots will occur in the increasingly desiccated rainfed cropland areas of the northern highlands; in-migration hotspots will develop in the pastoral/rangelands and semi-natural and wild areas (mostly semi-arid to arid areas) of the southern highlands and Ahmar Mountains in the east. In Bangladesh out-migration hotspots will occur in the rice-growing areas of the northeast; in-migration hotspots will develop in the irrigated and rainfed cropland areas of the Ganges River basin in the west. In Mexico, declining water availability and crop productivity in low-lying and hotter regions, and impacts in coastal Mexico (especially the Yucatan), will drive climate migrants out of rainfed cropland-based rural livelihoods into peri-urban or urban locations. This pattern reflects Mexico's advanced urbanization, the declining relevance of farming-only livelihoods, and continuing depopulation of rural areas. In contrast to Mexico, significant proportions of the populations of Ethiopia and Bangladesh still depend on agriculture. Understanding local vulnerabilities and constraints is key to designing adaptive agricultural practices for people to stay where they are if possible, and to facilitate movement when needed.

- Climate induced migration can be a positive adaptation choice, but may further reduce the availability of, or access to, already stretched land resources in productive areas with burgeoning populations and intensifying climate impacts. If the viability of rural ecosystems deteriorates despite adaptive practices, opportunities for livelihood diversification out of climate-sensitive areas and sectors will need to be identified and pursued, so that climate migrants can be absorbed into the national economy. In Ethiopia, labor migration in pursuit of non-agrarian livelihoods is becoming increasingly prominent. In Bangladesh, employment in manufacturing, particularly textiles, and services is growing.

Table 5.2: Key climate migration results for Ethiopia, Bangladesh, and Mexico in 2050

Result	Ethiopia	Bangladesh	Mexico
Population in 2050 compared to 2020	Increases to 159 million from 103 million (in SSP2) or 184 million from 105 million (in SSP4)*	Increases to 196 million from 166 million (in SSP2) or 177 million from 164 million (in SSP4)*	Increases to 149 million from 126 million (in SSP2) or 136 million from 125 million (in SSP4)*
Number of climate migrants by 2050	Highest in more climate-friendly scenario, with average projection of 1.5 million**	Highest in pessimistic reference scenario, with average projection of 13.3 million	Highest in pessimistic reference scenario, with average projection of 1.7 million
Climate in-migration hotspots	Southern highlands Ahmar Mountains in the east	Main stem of the Ganges River basin in the west	Central plateau near Mexico City and east of Puebla Smaller hotspots farther south in Oaxaca State and on the northern coast of Baja California south of Tijuana
Climate out-migration hotspots	Northern highlands Addis Ababa	Dhaka and river delta south of the city Eastern coast near Chittagong Northeast	Along Gulf of Mexico, especially Veracruz and Tabasco States; in southern state of Chiapas; and on Pacific coast, especially Guerrero State Scattered in the arid north
Climate migration in/out of rural livelihood zones	In-migration: Pastoral and rangelands, semi-natural and wild areas Out-migration: Rainfed croplands	In-migration: Rainfed croplands Out-migration: Rice-growing areas	In-migration: Pastoral and rangelands Out-migration: Rainfed croplands

Note: SSP2= moderate development; SSP4 = unequal development.
*The moderate development SSP2 scenario for Bangladesh and Mexico yield larger populations than the unequal development SSP4 scenario because both are middle-income countries. Only low-income countries show marked increases in population under SPP4.
**The higher number of climate migrants under the more climate-friendly scenario in Ethiopia is in part driven by the regional climate models which project lower water availability by 2050 in general compared to the other two scenarios (pessimistic reference and more inclusive development scenarios) which are coupled with higher emissions.

ETHIOPIA

The 8th of 16 children, he fled his father's small farm in a drought-stricken part of Ethiopia and walked to the small but bustling city of Hawassa.

> *"My name is Wolde Danse, I am from Wolayita zone, Damosorey district, Ethiopia. I am 28 years old. My father was a small-scale farmer and the farm was not sufficient for farming. Sometimes it would rain and other times it wouldn't. Because of this, many people had to migrate, and as a result I left and came to Hawassa."*

Life was hard for Wolde in Hawassa. He knew no one and was often homeless—and starving. But now enrolled in Ethiopia's extensive Urban Safety Net Programme, he receives a small salary for supervising street cleaners.

"I thought I could work and change my life by leaving and coming to the city. I got into a food security program and it helped change my life. Before I could either pay rent or buy food. But now my wife works and I work and from the assistance the program gives me I am ok. The program is for three years."

BANGLADESH

23-year-old Monoara Khatun fled the flooding in her home village. She moved to the capital Dhaka to join a program that teaches young rural women life skills. She's learned how to navigate the city, how to handle money and to take care of herself.

> *"The floods come every year but this year the situation is worse. Every house in my village was affected. Now all my family is living in one of my relatives house."*

MEXICO

26 year old Javier Martinez of the little village of Trinidad in Oaxaca, Mexico counts himself as lucky. He and his family have been able to thrive in their little village without having to migrate to create a new life. They are carpenters who sustainably use the nearby forest for their livelihood.

> *"It's really important to have the wood at hand because there are communities that don't have that. We've learned how to manage the forest. We manage it and we work in it."*

Wolde must demonstrate his commitment by working a few more months. Then he can go to this polytechnic university. It offers skills training and computer courses. Wolde can attend classes for three years without paying tuition. Then he hopes to find a good job in the private sector.

The hope I have for my daughter is for her to enroll in a good school and get a better education, so she can grow and have a better life than I had. That is all that I want.

After a few days I started to like this place a lot. I got life skill training, to learn to be self-dependent; At the same time we got technical skills training, taught to operate machines, sew dresses.

I have a dream to study and have a good job and look after my family. Now after this training, I have a job. I think I will be able to send money to my mother to help with her expenses.

There are many jobs here. There's no need to migrate like before. Maybe 5 to 10 percent of the population migrates. In the community we have carpenters, and masons and plumbers, stores. There's employment of all kinds.

My goal is to grow my business, have better equipment and a bigger market. One day I would like to participate in the furniture expo in Guadalajara.

KEY FINDINGS ON ETHIOPIA

Main findings on Ethiopia include the following:

- The scale of climate migration is projected to increase in all scenarios by 2050, set against a backdrop of rapid population growth. Ethiopia's population is projected to grow 60–85 percent by 2050, from about 100 million in 2016 to 159 million (in SSP2) or 184 million (in SSP4). This growth is driven mainly by a youth bulge that will drive continued population growth for several decades.

- The more climate-friendly scenario has the largest number of climate migrants by 2050. The number of climate migrants could almost triple, to as many as 1.5 million by 2050 under this scenario compared to 2020. The higher number of climate migrants under this scenario is in part driven by the regional climate models which project lower water availability by 2050 in general compared to higher precipitation under the two scenarios (pessimistic reference and more inclusive development scenarios) which are coupled with higher emissions. The more inclusive development scenario yields the lowest numbers of climate migrants by 2050, showing that sustained development gains can drive reductions in the scale of climate migration for a low-income country with high population growth like Ethiopia.

- Climate migrants will increase steadily as a share of total internal migrants through 2050 across all scenarios albeit at a slower pace than other development factors. This finding suggests that slow-onset climate change remains a consistent and non-negligible driver of internal migration in a country that already has high internal mobility. It also reinforces the implication that climate migration should be managed in an integrated manner with other types and drivers of internal migration.

- Addis Ababa is projected to be a climate out-migration hotspot by 2050 and would thus see slower population growth. It is located in the heart of the rainfed agricultural region that is projected to be hit by crop productivity declines. Continued attention to adaptive capacity is needed to avert distress migration out of this area as a result of deteriorating livelihood conditions.

- Changes in water availability and crop productivity by 2050 will drive population redistribution across agricultural livelihood zones. Climate out-migration hotspots will occur in the increasingly desiccated rainfed cropland areas of the northern highlands. Climate in-migration hotspots will occur in the pastoral areas, rangelands, and semi-natural and wild areas (mostly semi-arid to arid areas) of the southern highlands and Ahmar Mountains in the east, where better water availability and crop productivity are projected. Nationally, 73 percent of the population depends on agriculture (World Bank 2017c). A better understanding of regional differences and vulnerabilities in rural livelihoods is therefore critical to provide a stronger basis for adaptive agricultural practices that would enable people to stay and identify viable livelihood systems in host areas for people to transition into.

Country context

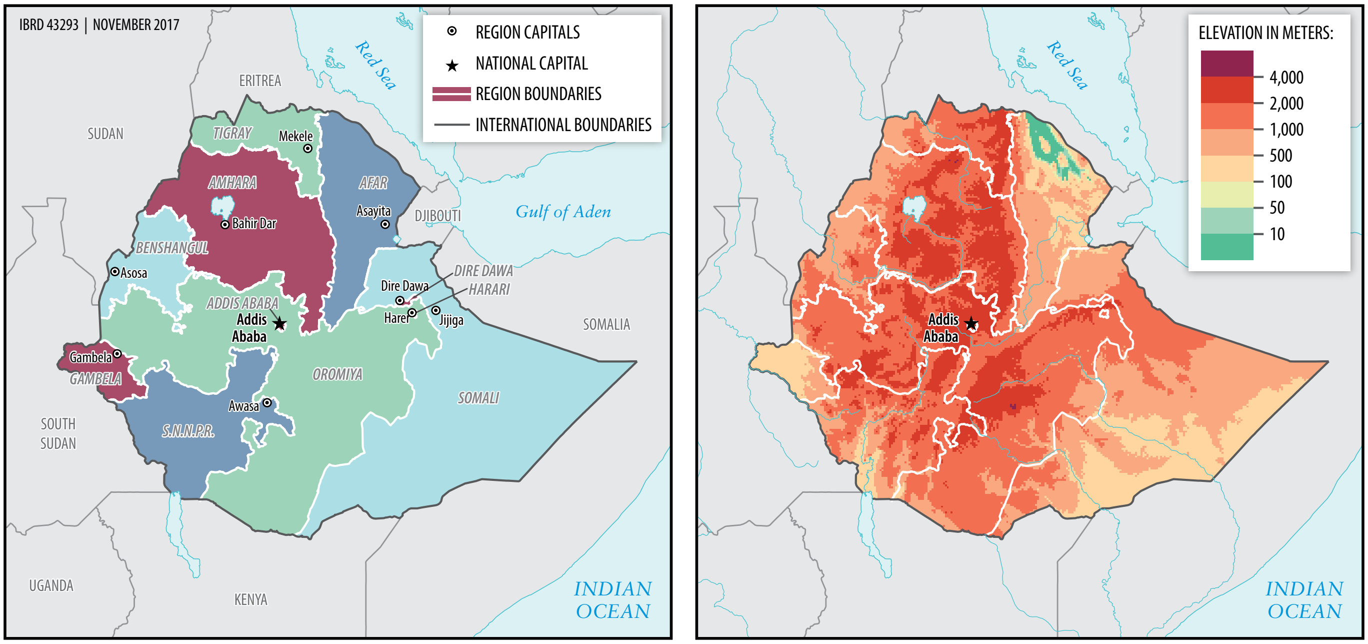
Recent economic growth in Ethiopia has been impressive, though poverty challenges remain. GDP grew from $12.4 billion ($162 per capita) in 2005 to $72.4 billion ($707 per capita) in 2016 (World Bank 2017c). During these 10 years, Ethiopia achieved marked gains across most sectors of the economy. The poverty headcount ratio at national poverty lines declined from 44 percent in 1999 to 30 percent in 2010 (World Bank 2017c).

Concurrent with recent economic growth, Ethiopia made progress in education. The gross enrollment ratio for primary school rose from 79 percent in 2005 to 95 percent in 2015 (World Bank 2017c). Secondary school enrollment was 35 percent in 2015 (World Bank 2017b).

Some health outcomes also improved. Stunting among children under five has fallen since 2000, and access to water, sanitation, and hygiene has increased (WHO 2017). Access to improved sanitation is at 28 percent up from 3 percent in 1996 (World Bank 2017c).

Despite excellent economic performance, Ethiopia remains a low-income country, with about a third of its population classified as poor (living on less than $1.90 a day) in 2010 (World Bank 2017c). Map 5.1 shows the political boundaries and elevation of Ethiopia.

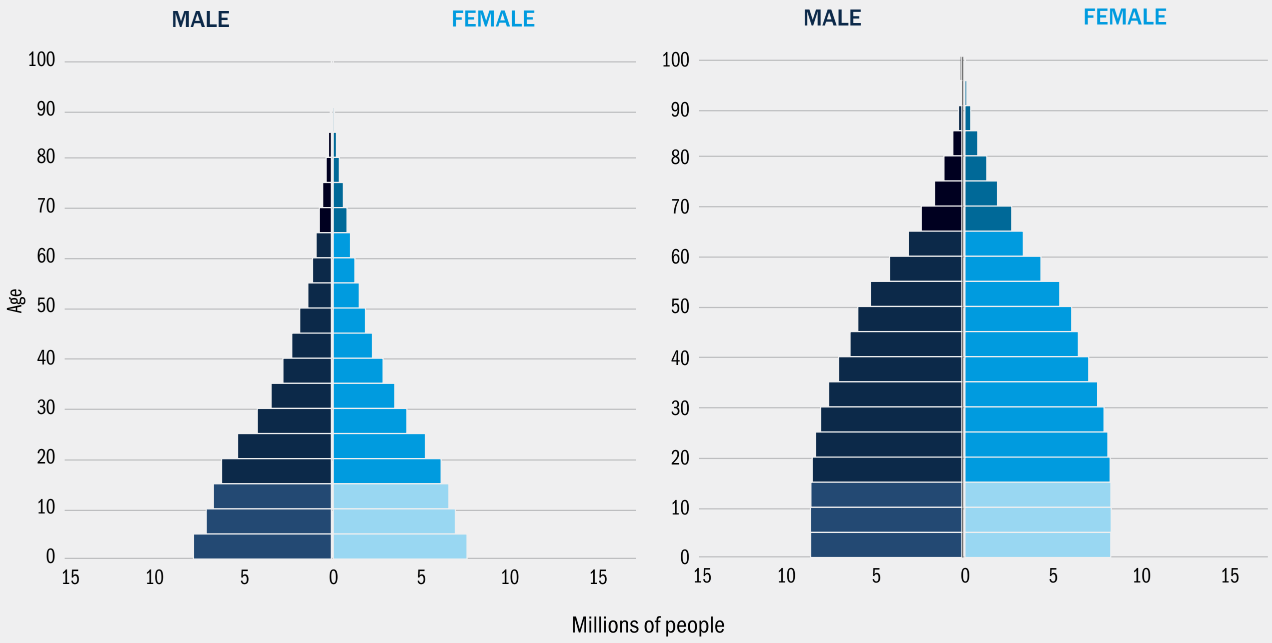
Map 5.1: Political boundaries and elevation in Ethiopia



a. Political boundaries

b. Elevation

Figure 5.1: Population pyramids for Ethiopia, 2017 and 2050



Source: UNDESA (2017).

Ethiopia's population more than doubled between 1990 and 2016, rising from 48 million to more than 100 million (World Bank 2017c). Population growth rates remain high by world standards, but they have fallen in recent years, from 2.7 percent a year in 2007 to 2.5 percent in 2015. The adolescent birth rate fell from 84 births per 1,000 in 2007 to 57 in 2015. Life expectancy rose from 59 in 2007 to 65 in 2015, as the mortality rate of children under five fell from 97 per 1,000 in 2007 to 58 per 1,000 in 2016 (World Bank 2017b).

Even if the fertility rate were to drop to replacement levels immediately, Ethiopia's population would grow for several decades because of the large share of young people (Figure 5.1). The high proportion of people under 18 creates future challenges for labor markets and economic stability, particularly if continued population growth cannot be absorbed in nonagricultural sectors. Given existing pressure on land resources, it is unlikely that future productivity gains in agriculture will be able to absorb such a rapidly growing population. Population growth is likely to exert enormous pressure on the country's natural resources and institutions (UNDESA 2016). Massive investments in services are necessary to boost climate-smart and inclusive economic growth, including infrastructure, housing, and food production.

Climate trends

Ethiopia is one of the most vulnerable countries in Africa to climate and environmental change (Kassie and others 2014). Its climate is highly variable and its population highly vulnerable to droughts. Comenetz and Caviedes (2002) link drought to 18 El Niño Southern Oscillations (ENSOs) since 1500, including the latest events, in 1991–93 and 1997–98. These droughts have often caused food shortages or famines. The north, northeast, and east of Ethiopia tend to experience more frequent and severe droughts than the rest of the country. Severe floods associated with heavy rainfall in the highlands have affected vulnerable communities in the northwest (Bewket and Conway 2007).

Ethiopia's reliance on rainfed agriculture as the dominant livelihood strategy makes the country particularly vulnerable to climate change impacts. Agriculture accounts for 37 percent of GDP, and 73 percent of the population depends on agriculture (World Bank 2017b). Agriculture in Ethiopia is largely subsistence smallholder agriculture with low levels of mechanization. Mixed farming dominates the northern and central highlands, and pastoralism and agro-pastoralism dominate the lowlands, which are arid and semi-arid lands, particularly in the east, northeast, and extreme south (Headey, Taffesse, and You 2014). Land degradation threatens the country's smallholder farmers, pushing down yields and putting stress on already shrinking farming areas (Haileslassie and others 2005). Deforestation is also widespread, particularly in the south central Rift Valley, which constitutes a core region for economic activity, population, urbanization, and road transport (Dessie and Kleman 2007).

Large changes in water availability and crop productivity drive the population distribution models through 2050.[31] The water sector models consistently show small increases in water availability throughout the country, except under the models driven by the Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model, in which the northern highlands experience either no change or slight declines (see Appendix B). The population distribution model tends to be more sensitive to changes in water availability, in part because it projects results for the whole country whereas the crop model results are limited to areas with cropping. Modeling details used in this report are provided in Chapter 3 and Appendix B.

Cropping in Ethiopia is dominated by teff (a species of lovegrass), wheat, barley, corn, sorghum, and millet. The crop models include only wheat and corn. The LPJmL crop model shows increases in productivity—in a few areas up to 40–50 percent—in the northern highlands. The GIS-based Environmental Policy Integrated Climate (GEPIC) crop model shows decreases across the northern highlands and small increases elsewhere.

During the second half of the 21st century, the trends in crop productivity for the two models become more accentuated (see Chapter 4 for ISIMIP water and crop model outputs for 2050–2100). In the highlands, the LPJmL crop model projects increases in yields of 40–60 percent; just to the west, in the lowlands, it projects declines of 60–80 percent. The GEPIC model projects yield declines in the northern highlands of 30–60 percent. In both models, impacts are worse under the high emissions RCP8.5 than under RCP2.6. Water availability increases in the southern and southeastern areas of the country (relative to a baseline of very dry conditions) and remains stable in the northern highlands.

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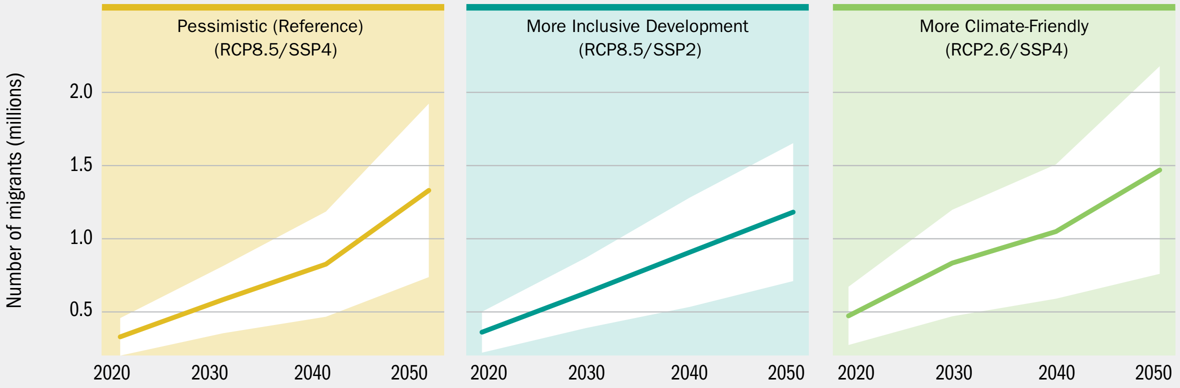
[31] There is significant uncertainty in future climate projections in the Horn of Africa (see Appendix B). Together with the different characteristics of the water and crop sectoral models, it explains the somewhat divergent results for the water availability and crop productivity projections for Ethiopia.

Figure 5.2: Projected number of internal climate migrants in Ethiopia under three scenarios, 2020-50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
%	0.31	0.45	0.53	0.72	0.35	0.51	0.64	0.74	0.45	0.64	0.67	0.80

Note: Dark lines represent the average runs for each scenario. White unshaded areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

Projected climate migration trends

Climate migration is projected to increase by 2050, showing similar upward trends across scenarios (Figure 5.2), though differences in numbers between the scenarios are small. Across scenarios, climate migrants represent 0.4 to 1.2 percent of the total population by 2050.

The more climate-friendly scenario with 1.5 million climate migrants by 2050 (with a range of 0.8–2.2 million) has marginally higher numbers than the pessimistic reference scenario (Table 5.3). This is in part driven by the climate models, which project lower water availability by 2050 in the lower emissions scenario in general, hence increasing climate migration numbers. Numbers are thus lower under the pessimistic reference scenario, with 1.3 million climate migrants by 2050 (with a range of 0.7–1.9 million). The lowest numbers of climate migrants are under the more inclusive development scenario, driven by both the higher water availability projected in the higher emissions scenarios in general coupled with stronger development policies. This scenario projects 1.2 million climate migrants (with a range of 0.7–1.7 million) by 2050. These findings indicate that for a low income country with high population growth like Ethiopia, sustained development gains are an imperative to reduce the scale of climate migration.

Climate migration will not occur in isolation; other types of internal migration will occur simultaneously and will need to be managed in an integrated manner in a country with already high internal mobility. The number of other internal migrants will continue to outstrip the number of climate migrants through 2050 across all scenarios, owing to the large population growth projected for Ethiopia by 2050 (Figure 5.3). However, climate migrants will increase steadily as a share of total internal migrants through 2050 across all scenarios.

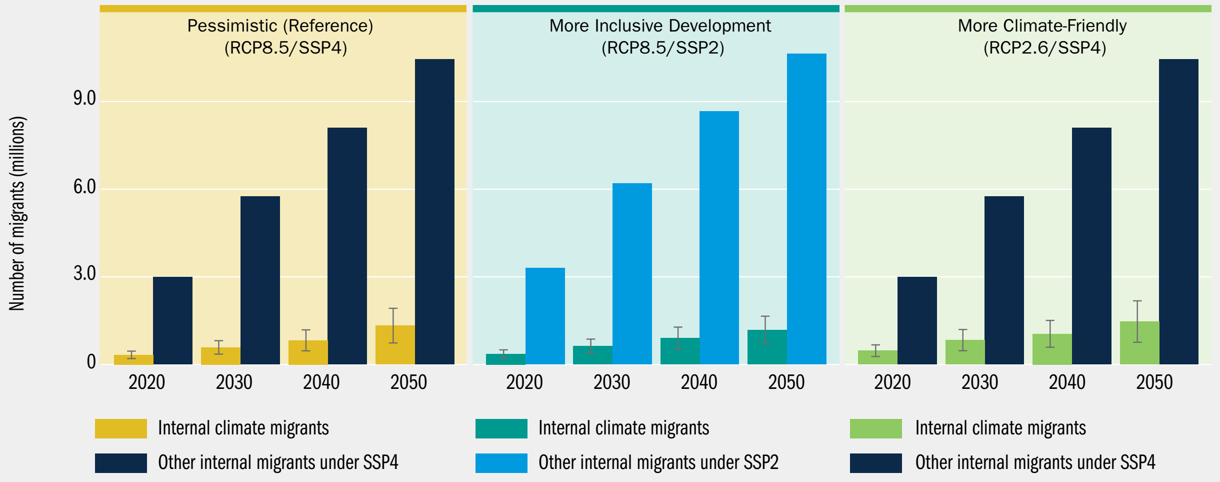
The example of Ethiopia demonstrates how regional climate impact variations and their uncertainty can have implications on climate migration trajectories. This also emphasizes the need to better understand and contextualize the scale, nature, and magnitude of climate change-induced migration at the country-level.

Table 5.3: Projected number and share of internal climate migrants in Ethiopia under three scenarios, 2050

	Scenario					
Result	**Pessimistic/ Reference**		**More inclusive development**		**More climate-friendly**	
Number of internal climate migrants by 2050 (million)	**1.3**		**1.2**		**1.5**	
Minimum (left) and maximum (right) (million)	0.7	1.9	0.7	1.7	0.8	2.2
Internal climate migrants as percent of population	0.72%		0.74%		0.80%	
Minimum (left) and maximum (right)	0.40%	1.05%	0.45%	1.04%	0.41%	1.18%

Note: The scenarios are based on combinations of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). SSP2 = moderate development; SSP4 = unequal development; RCP2.6 = low emissions; RCP8.5 = high emissions.

Figure 5.3: Projected number of climate and other internal migrants in Ethiopia under three scenarios, 2020-50



Note: The whiskers on the climate migrant bars represent the 95th percentile confidence interval for the four model runs that comprise each scenario. There are no confidence intervals for other migrants, because only a single development trajectory is used in each scenario (SSP2 or SSP4).

Projected spatial patterns of climate migration

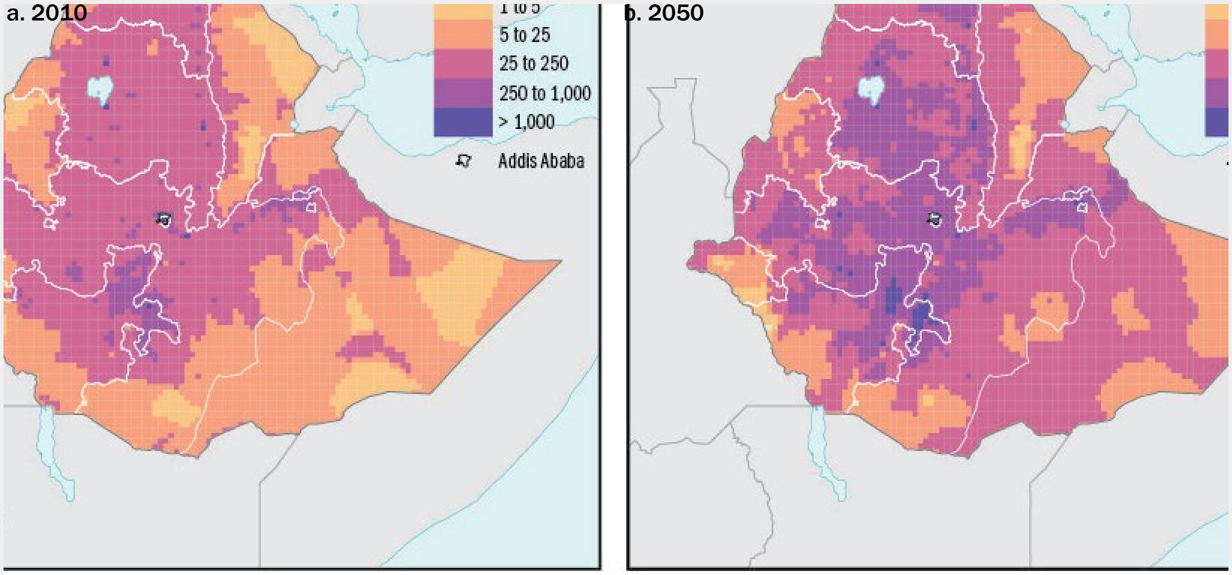
Ethiopia’s population is likely to grow by 60–85 percent by 2050, to 159 million (in SSP2) or 184 million (in SSP4). This huge increase will exert immense pressure on the country’s natural resources and institutions.

Population densities will increase across most of the country. Figure 5.4 displays the baseline (2010) population density and 2050 projected population density under the pessimistic reference scenario. It shows that urban areas will continue to grow and to retain the highest population densities. Population densities will also increase in the highlands and the Ahmar Mountains. Historically, Ethiopia’s population has been highly concentrated in the highlands, with only sparse populations in the lowlands, because of a harsh climate and the presence of malaria and other diseases in the western lowlands and extremely arid conditions in the southeast and northeast. Consequently, some 80 percent of the population inhabits only 37 percent of the country’s land area. All results on climate migration for Ethiopia should be interpreted against this backdrop of total population growth and distribution. Modeling suggests that climate change will increase movement out of some areas and livelihood zones and dampen movement into others.

Figure 5.5 displays the change in population density between the baseline (2010) population and the 2050 projected population under the pessimistic reference scenario. It shows that most areas of the country will see 100–300 percent increases in population density. Only isolated pockets of the country—namely, areas with very low baseline populations—will see stable or declining population densities.

Climate in-migration hotspots are expected in the southern highlands and the Ahmar Mountains, with a smaller in-migration hotspot in the far north in the Tigray region, amplifying the projected population growth trends in these areas (Figure 5.6).[32] Recent population increases in these regions may be driven by greatly improving water availability and crop productivity, as projected by the ISIMIP model. These regions are predominantly pastoral areas, rangelands, and semi-natural and wild areas. The distribution of livelihood zones in accordance with anthropogenic biomes is presented in Figure 5.7 for the baseline year of 2015. Across Ethiopia these livelihood zones will see population growth in all scenarios. Increasing population densities in these marginal semi-arid to arid areas will require strong adaptation interventions in rangeland management to ensure sustainability.

Figure 5.4: Baseline population density 2010, and projected population density under the pessimistic reference scenario 2050, Ethiopia


a. 2010

b. 2050

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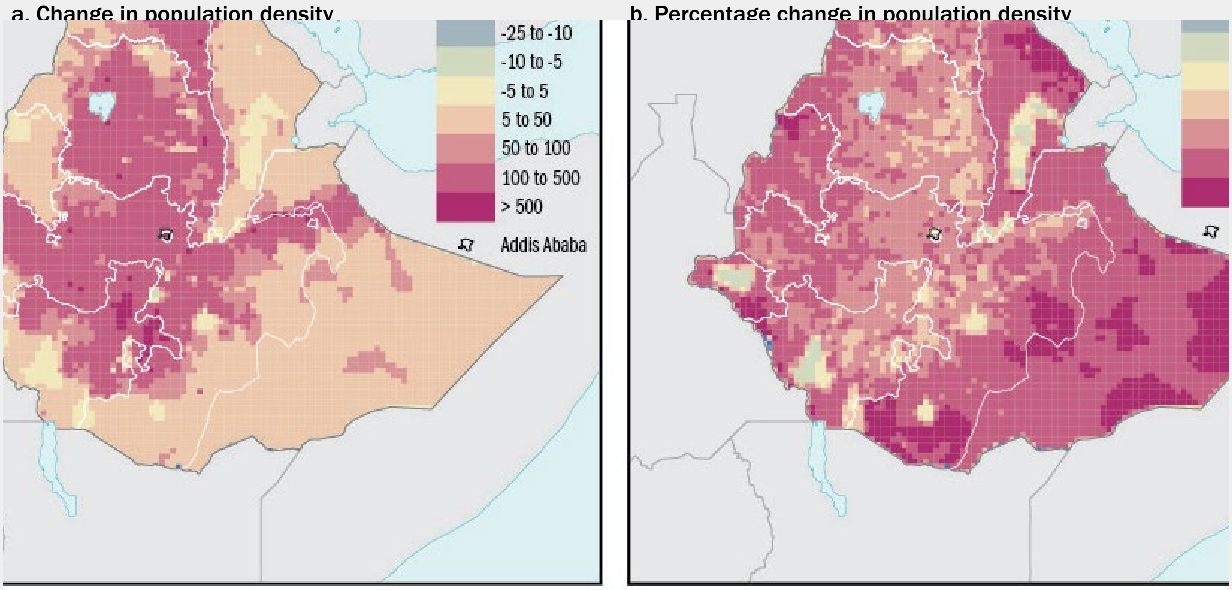
[32] The modeling does not take into account limits to agricultural carrying capacity; no limit was placed on population densities based on theoretical or observed maximums.

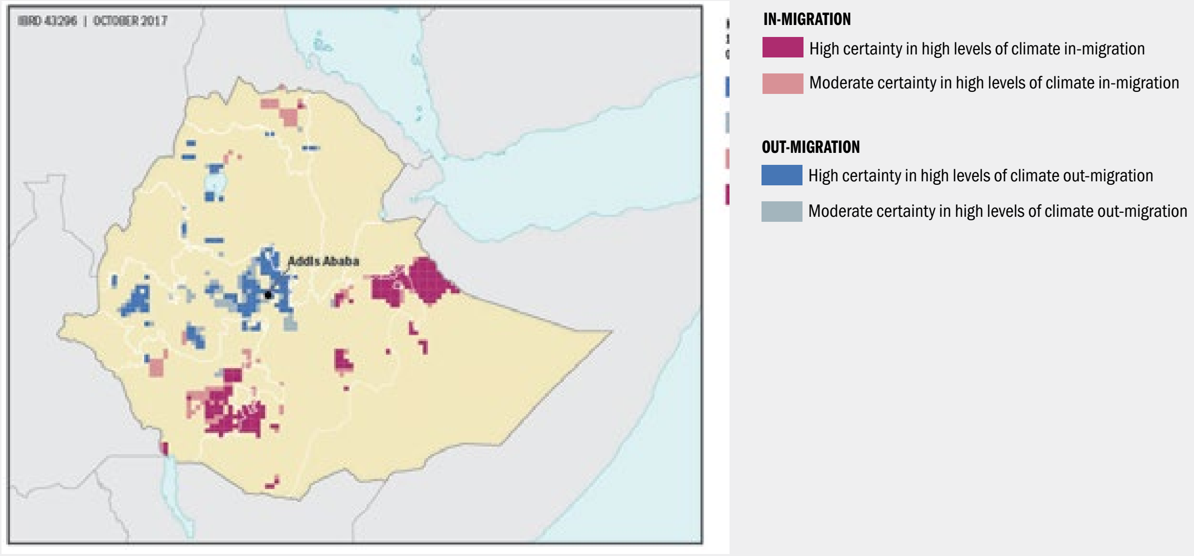
Figure 5.5: Absolute and percentage change in population density in Ethiopia under the pessimistic reference scenario, 2010-50



a. Change in population density

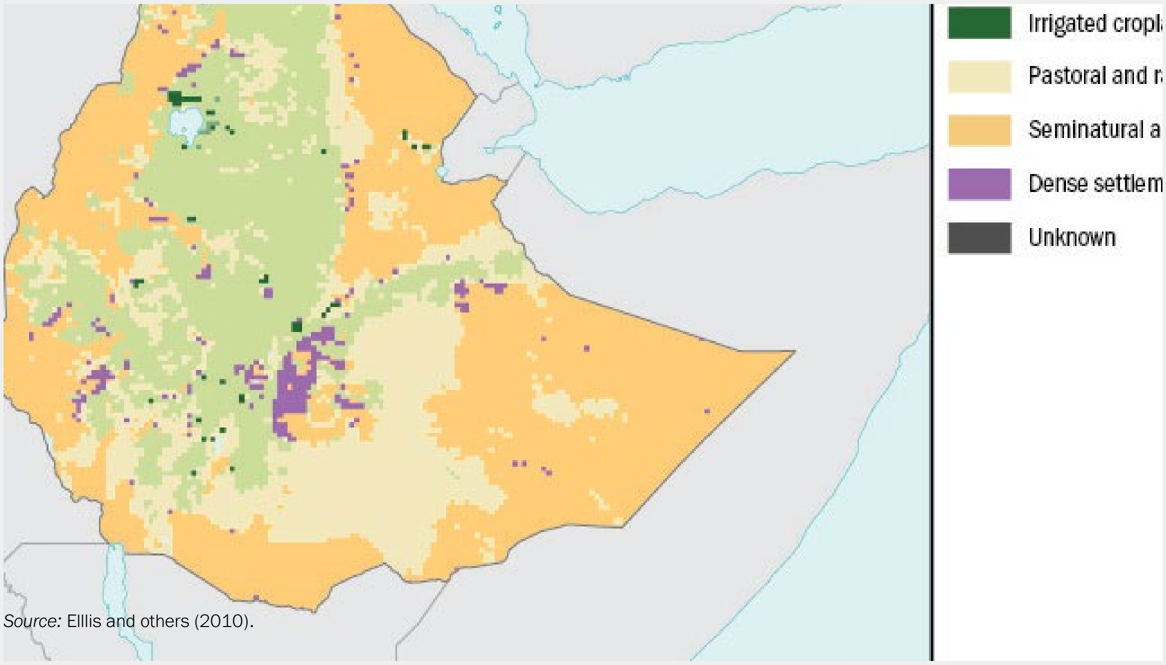
b. Percentage change in population density

Figure 5.6: Hotspots projected to have high levels of climate in-migration and climate out-migration in Ethiopia, 2050



Note: High certainty reflects agreement across all three scenarios modeled, and moderate certainty reflects agreement across two scenarios. In- and out-migration hotspots are thus areas in which at least two scenarios concur on density changes in the top 10th percentile of the density distribution, which in East Africa represents an increased population density in 2050 of about 4.2 to 4.8 people per square kilometer, depending on the scenario. For decreased population density, it is about minus 3.6 to minus 5.5 people per square kilometer.

Figure 5.7: Livelihood zones in Ethiopia, by anthropogenic biome, 2015

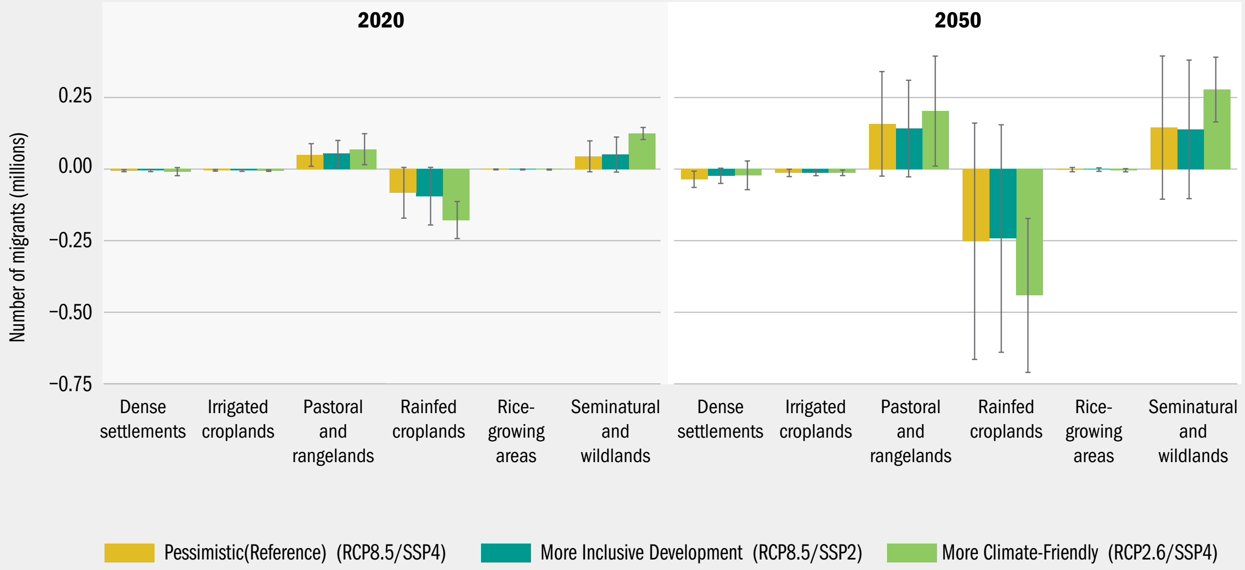


Source: Elllis and others (2010).

An out-migration hotspot is expected in the northern highlands, dampening projected population growth trends in this area. This region is predominantly rainfed cropland, which will see population declines across Ethiopia in all scenarios (Figure 5.8), driven by declines in crop productivity in the rainfed agricultural heartland of the highlands. This region already suffers from soil erosion and land degradation as a result of high population densities. Given migration history in Ethiopia, it is likely that migrants will continue moving from the increasingly desiccated northeastern and southeastern parts of the country into the southern highlands and secondary cities in the dryland parts of the east.

Addis Ababa is projected to become an out-migration hotspot. Climate impacts are expected to reduce population densities, thus dampening the projected population growth trends for the capital. Although the population is projected to urbanize heavily through 2050, population will also be drawn to secondary cities. The capital is in the heart of the rainfed agricultural region that will be affected by declines in crop productivity. The large declines in water availability projected for 2030–50 will reduce the attractiveness of the capital region relative to other urban destinations.

Figure 5.8: Projected net climate migration in and out of livelihood zones in Ethiopia under three scenarios, 2020–50



Note: Whiskers show 95th percent confidence intervals for climate migrants.

In-country consultations on modeling results

Consultations were undertaken with stakeholders in Ethiopia on the modeling results and to collect input on the case study narratives in June 2017. They were conducted with national, regional, and district (*woreda)* level government officials, civil society, cooperative associations, and academia. The national workshop was held in Addis Ababa, the regional workshop in Jigjiga, and the *woreda* level workshop in Shinile Town, outside Dire Dawa. Sixty-two people participated in the consultation sessions. For the national workshop, small groups of participants were asked about their experiences and knowledge of current observations of climate change and their expectations of climate change through 2030 and 2050, existing climate change-induced migration patterns (if any) and future climate migration, and vulnerability and livelihood impacts. Break-out sessions and consultations at the local level were conducted in local languages.

Participants found the 2050 modeling scenarios reasonable. Many noted that they had already observed mobility changes and indicated that the scenarios were in line with their expectations. They validated the spatial patterns of population movement, noting that secondary cities in the far east of the country have already begun growing rapidly.

Participants suggested that the modeling and case study should include more research on pastoral movement; that the local institutional context (the ability of the government to plan and act, for instance) be included; and that the larger regional (East African) context be considered, given the history of cross-border migration.

What do these results mean for Ethiopia's development future?

Ethiopia's reliance on rainfed agriculture makes rural livelihoods especially vulnerable to climate change in the face of high population growth and already high internal mobility. This suggests a need to diversify into less climate-sensitive sectors and pursue climate-smart and inclusive growth to secure recent development gains and sustained growth in the future.

Historically, most migrants in Ethiopia have been internal (Ezra and Kiros 2001; Ezra 2003; Jónsson 2010; Afifi and others 2012). Ethiopia has had large rural to urban and rural to rural movements, both voluntary and involuntary. The Internal Displacement Monitoring Centre (IDMC) estimates that in 2015, 450,000 people in Ethiopia were displaced by conflict and 104,000 were displaced by disasters (IDMC 2015).

International mobility is less common than internal mobility, but it will likely represent a significant portion of mobility in Ethiopia. International outflows accounted for just 0.6 percent of the population in 2005, with the bulk of these migrants headed to Asia and North America (Fransen and Kuschminder 2009). Ethiopia also hosts large numbers of immigrants and refugees. Regional conflicts in Sudan and Somalia from the 1980s and 1990s have led to disruptions in the south, southeast, and southwest of the country. In 2017 Ethiopia hosted about 245,000 Somali refugees displaced by food stress and conflict (Diaz 2017). Recent conflict in South Sudan has led to large movements of pastoralists in the south and southeast of that country into Ethiopia. Drought in northern Kenya has exacerbated the situation.

It is difficult to untangle climate- or environment-induced mobility in Ethiopia from mobility induced by political, social, or economic upheaval, as suggested in Chapter 2. The mere perception of climate change, through temperature and precipitation changes, has been shown to spur action by households (Gebrehiwot and van der Veen 2013; Kassie and others 2014). In other cases, households perceive change but do not act for reasons that include lack of access to credit or markets (Bryan and others 2009; Ringler 2010).

Individual and family motivations for migration are often strongly tied to weather events. Gray and Mueller (2012) find that among men, labor-related movements and migration out of their study's rural highland district more than doubled under severe drought, with total mobility reaching 10 percent of adult men per year. They also find that women's short-distance and marriage-related mobility was reduced by half under moderate drought, reflecting a decreased ability to finance wedding expenses and new household formation (Gray and Mueller 2012). Morrissey (2013) finds that several factors, including access to food aid, access to land, and age, can keep people from moving. He categorizes effects on decisions to move as "additive" or "non-environmental factors which create an imperative to move that is in addition to stress generated by the biophysical environment"; "enabling" or "non-environmental factors which make mobility a particularly suitable response to the livelihood insecurity generated by environmental stress, thereby increasing the likelihood of moving"; "vulnerability" or "non-environmental factors which exacerbate the negative impacts of changes in the physical environment on livelihood security;" and "barrier" or "non-environmental factors which retard the imperative to move" (Morrissey 2013, 1507).

With population burgeoning throughout the country, climate migrants may exacerbate existing stresses on resources in receiving areas. Rapid economic growth is necessary to support widespread adaptation programs and policies such as the Productive Safety Net Programme (Box 5.1) and a forward-looking resilience strategy (Moller 2015) for addressing climate migration. Investments in infrastructure, housing, and food production are necessary. Accommodating climate migrants in host communities will require financial resources if they are not to be absorbed into slum areas. Climate migrants also have the potential to upset delicate land use arrangements. Rapid population growth will make it increasingly difficult for urban areas to provide infrastructure, housing, health services, and education.

Box 5.1: How well did Ethiopia's Productive Safety Net Programme work?

In order to prevent food insecurity and reduce rural vulnerability, in 2005 the government of Ethiopia, with support from multiple donors, launched the Productive Safety Net Programme (PSNP). The program provides cash transfers to vulnerable households through public works projects that build community productive assets (Wiseman, Domelen, and Coll-Black 2010).

Evaluations of the PSNP suggest that the effects have been positive but modest. Berhane and others (2014) find that the program may decrease food insecurity by 1.3 months. Other studies find that the program works best when coupled with the Ethiopia's Food Security Programme, which provides households with access to credit, agricultural extension services, technology transfer, and irrigation and water harvesting schemes (Gilligan, Hoddinott, and Taffesse 2009). Andersson, Mekonnen, and Stage (2011) find no evidence that household participation in the PSNP prompted disinvestment in either livestock or trees. Sabates-Wheeler and Devereaux (2010) find that PSNP beneficiaries were better off than nonbeneficiaries but that the transfer had some inflationary effects. Debela, Shively, and Holden (2015) find that participation in the PSNP had positive effects on children's health and nutrition.

Climate migration is not uniform across the country. Movement from rainfed croplands will increase pressure on semi-natural and rangeland areas by 2050. Projections also suggest migration out of the northern highlands and into the southern highlands and Ahmar Mountains.

Ethiopia's diverse environments—from highland-montane to arid drylands—leave some parts of the country more vulnerable to climate change than others.

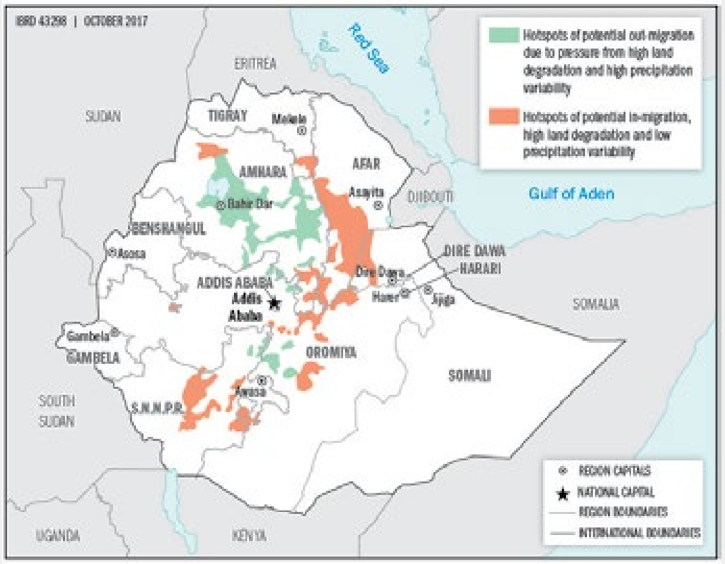
The findings of this study are broadly consistent with the results of earlier work on future pathways of climate-related mobility in Ethiopia, which have coalesced largely around hotspot detection. The hotspots identified by Hermans-Neumann, Priess, and Herold (2017)—by combining data on climate variability, net primary productivity, and population density (Figure 5.9)—are largely coincident with the ones identified in this report. One area of divergence is in the east of the country. The scenarios in this report indicate increased concentration of population in Dire Dawa, Harar, and Jigjiga in the Ahmar Mountains. Hermans-Neumann, Priess, and Herold suggest concentrations farther north in Afar.

Given past migration patterns in Ethiopia, it is likely that migrants will continue moving from the increasingly desiccated northeastern and southeastern parts of the country into the southern highlands as well as urban areas and secondary cities in the dryland parts of the east. There is considerable uncertainty in climate projections for the Horn of Africa. However, climate models suggest the possibility of increased rainfall in the Rift Valley and southern highlands, but these could be offset by increases in temperature. Should farming practices remain unchanged, however, soil erosion and land degradation would be expected in areas of high in-migration in the highlands.

Given historical patterns, modest cross-border migration from neighboring states is also expected. The refugee crisis in Somalia illustrates a possible climate migration future, as drylands continue to see warmer temperatures and lower rainfall and political and economic instability continue. An alternate scenario—one that includes proactive planning—might include the growth of secondary cities, strong environmental remediation and adaptation development activities to support the local population.

Understanding future climate migration requires examination of the different dimensions of vulnerability, particularly for rural livelihoods. Much of the literature identifies climate and environmental stress as a key driver of displacement, though one intricately tied to social, economic, and political forces, for farmers, agro-pastoralists, and pastoralists alike (Ginnetti and Franck 2014).

Figure 5.9: Potential migration hotspots in Ethiopia as identified in Hermans-Neumann, Priess, and Herold (2017)



Source: Hermans-Neumann, Priess, and Herold (2017).

Migration is but one of many possible outcomes of the combined impact of weather and socioeconomic stress (Morrissey 2013). It is a strategy for coping with and adapting to a changing climate, but it is not practiced in isolation from other strategies. Understanding how people cope and adapt can provide insight into responses to climate and environmental change.

Agrarian households first cope with environmental stress, such as lack of precipitation or high temperature, by replanting crops or switching crop mixes, whereas, pastoralists sell small livestock (Adimassu, Kessler, and Stroosnijder 2014). Other coping mechanisms include migration to relatives, accessing relief programs, reducing seed density, accessing credit, and using the existing social security system. In addition to these on-farm coping mechanisms, households use off-farm coping mechanisms (Demeke and Zeller 2012), which can be viewed as a first step from localized agriculture and pastoral livelihood activities toward labor migration.

Labor migration—migration prompted by the pursuit of other, often nonagrarian, livelihoods elsewhere—has increased in recent years (Demeke and Zeller 2012). As Adimassu, Kessler, and Stroosnijder (2014) note, it has disparate effects on environmental conditions in rural areas, making a causal pathway difficult to establish. In the case of climate change-induced migration, the push to resort to such strategies could be deferred by enrolling households in social safety net programs such as the Productive Safety Net Programme. Even marginal improvement in livelihoods from participation in such programs may delay the onset of migration-as-coping during stress events.

While urban areas will continue to expand as a result of rural to urban migration and population growth, climate change will dampen population growth in Addis Ababa by 2050 implying a role for secondary cities.

Long-term rural to urban migration will continue in Ethiopia: projections indicate a near-doubling of the population of cities, from 15 million in 2010 to 37 million in 2030 (UNDESA 2014). Ezra and Kiros (2001) attribute rural to urban migration to poverty and food insecurity. Households in poor and food-insecure areas are compelled to send a family member to urban areas to secure a job and remit cash to the rural household. Mberu (2006) finds that out-migration did not significantly improve the living conditions of most migrants. Only migrants with higher levels of education and nonagrarian jobs appeared to benefit.

Gibson and Gurmu (2012) find that higher levels of out-migration from rural areas were associated with development interventions. The provision of clean water promoted an increase in family size, which in turn compelled out-migration as a result of competition for scarce resources.

With the relative attractiveness of the capital region declining as a result of climate change, secondary cities may become growth poles. A network of secondary cities could help reinforce Addis Ababa for continued economic growth and development by providing a large, active domestic market and focus areas for tertiary manufacturing (New Climate Economy 2015). These can also help strengthen rural to urban linkages by providing access to markets.

Migration can be a positive adaptation strategy but must be addressed holistically and embedded into development policies and planning through inclusive and participatory approaches.

Migration can be an effective adaptation strategy in Ethiopia, yielding gains to individuals, households, and the state. As population grows rapidly through 2050, mobility will be critical to resolving land pressure in areas of high demand. Migration out of degraded and deforested areas can also help the country reach its commitment to restoring one-sixth of its deforested and degraded land area (Minnick and others 2014). At the same time, inclusive development can help absorb a growing young labor force into less climate sensitive sectors.

The government should consider taking proactive steps now to facilitate climate migration by preparing for movement into more climatically favorable areas, acting while the window of opportunity is still open. In the past, resettlement, either forced or incentivized, has occurred frequently in Ethiopia, in the 1970s and 1980s and as recently as 2003. The National Food Security Strategy sought to move some two million people from food-insecure areas in the north to more fertile lowlands in the south (Fransen and Kuschminder 2009). The National Population Policy of 1993 sought to “ensure a spatially balanced population distribution pattern” (Ezra 2003, 63). A key consideration will be how to integrate climate migration into development policy and planning through participatory and inclusive approaches.

Ethiopia has no specific government body to oversee planning or data collection on climate migration, enable the sharing of data with line ministries, or incorporate migration into national planning. At the regional and local levels, registration of migrants by municipality, city administration, and labor agencies needs to be fully implemented. Further support for migrants could also include providing information on destinations (especially information about jobs), vocational training, and access to microfinance.

Such an anticipatory approach should be coupled with the application and scaling up of tested and successful on-the-ground programs. The Productive Safety Net Programme (PSNP) provides some important lessons of proactive planning (see Box 5.1). Other areas of intervention that could be scaled up include multi-village water systems to provide small-scale irrigation to households in drought-prone areas, land use policy to support pastoralists, feed banks for livestock during droughts, a better system of food supply to help buffer short-term food shortages during droughts, and robust disaster risk management and early warning systems.

KEY FINDINGS ON BANGLADESH

Main findings on Bangladesh include the following:

- The number of climate migrants is projected to increase in all scenarios by 2050, in a highly climate vulnerable country. Large-scale internal movement is projected in a country that has been sensitive to environmental change, is already very densely populated, and will continue to experience population increases through 2050.

- The number of climate migrants by 2050 is largest in the pessimistic reference scenario, reaching 13.3 million on average. Climate migration levels show similar but lower trends in the more inclusive development and more climate-friendly scenarios. Both of these scenarios suggest that development pathways targeting lower inequality and lower global emission trajectories will help reduce pressures on people's livelihoods and the associated scale of climate migration.

- The share of climate migrants in total internal migrants is projected to increase in all scenarios by 2050. In the pessimistic reference scenario, the number of climate migrants outpaces the number of other internal migrants. In this scenario, climate impacts may become one of the dominant forces driving internal migration in Bangladesh by 2050. In the other scenarios, climate migrants still represent a significant share of all internal migrants.

- Climate change will dampen population growth in urban and coastal areas, as Dhaka, the river delta south of the city, and the eastern coast near Chittagong become out-migration hotspots. These major urban centers are in deltaic and coastal areas, which are particularly vulnerable to climate change because of rising seas combined with storm surges. Estimates show that a one meter combined sea level rise and storm surge leads to a loss of more than 4,800 square kilometers of land (roughly 3.2 percent of the country); a two meter combined sea level rise and storm surge leads to the inundation of nearly 12,150 square kilometers (roughly eight percent of the country). The impacts of sea level rise are concentrated in coastal areas[33], but they extend inland along the banks of the Brahmaputra, Meghna, and Ganges rivers. Continued attention to adaptive capacity is needed to avert distress migration out of these areas, but also local maladaptation. Efforts are also needed to accommodate people who cannot adapt in place because of the impacts of climate or natural hazards.

- Changes in water availability and crop productivity will drive population redistribution in agricultural livelihood zones. Climate out-migration hotspots will occur in the rice-growing areas of the northeast. In-migration hotspots will be seen in the irrigated and rainfed cropland areas along the main stem of the Ganges River basin, which is already densely settled but where better water availability and crop productivity are projected. Nationally, 47 percent of Bangladesh's population depends on agriculture. A better understanding of regional differences and vulnerabilities in rural livelihoods is therefore critical to provide a stronger basis for adaptive agricultural practices that would enable people to stay where they are and to identify viable livelihood systems in host areas if people move.

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[33] This report defines coastal areas as map grid cells for which more than half their area lies within 10 kilometers of the coastline.

Country context

Bangladesh is developing rapidly. In 2015 it achieved lower-middle-income status, following a decade of annual GDP growth of more than five percent (World Bank 2017b). The poverty rate fell to 24.3 percent in 2016, down from 48.9 percent in 2000 (World Bank 2017c).

Educational performance soared on several measures. The primary school completion rate rose from 57.3 percent in 2008 to 98.5 percent in 2015 (World Bank 2017c). The percentage of girls repeating primary school fell from 12.9 percent in 2008 to 5.3 percent in 2015, and the rate for boys fell from 13.4 percent to 5.4 percent. Secondary school enrollment rose to 64 percent in 2015 (World Bank 2017c).

Although the extreme poverty rate is declining, broad-based gains are more pronounced in cities (World Bank 2016). Growth has also seen some challenges, such as infrastructure (including power) deficits, lack of access to improved water supply and sanitation, and declines in remittances (World Bank 2016).

Map 5.2 shows the political boundaries and elevation of Bangladesh.

Bangladesh has a growing population and one of the highest population densities in the world, particularly in urban areas. The 2016 population of 163 million people is projected to increase to 177 million (under SSP4) or 196 million (under SSP2) by 2050. The national population density was estimated at 1,252 people per square kilometer in 2016 (World Bank 2017c); density in Dhaka was 20,000 people per square kilometer in 2015 (Walter 2015).

Bangladesh also has one of the highest urban population growth rates in the world, estimated at 4 percent in 2015 (Walter 2015). Population growth of 1.1 percent (World Bank 2017b), coupled with a continued pace of fertility decline, could lead to changes in the country's age structure, yielding a lower dependency ratio and a larger working population by 2050 (Figure 5.10). Bangladesh could benefit from this "demographic dividend" if it creates a labor market that can absorb the working population into productive and climate-resilient labor markets—and ensure that they have good access to health care, employment, and education (Bloom and others 2003; IMF 2006; El-Saharty, Ahsan, and May 2014; UNDESA 2015).

Map 5.2: Political boundaries and elevation in Bangladesh

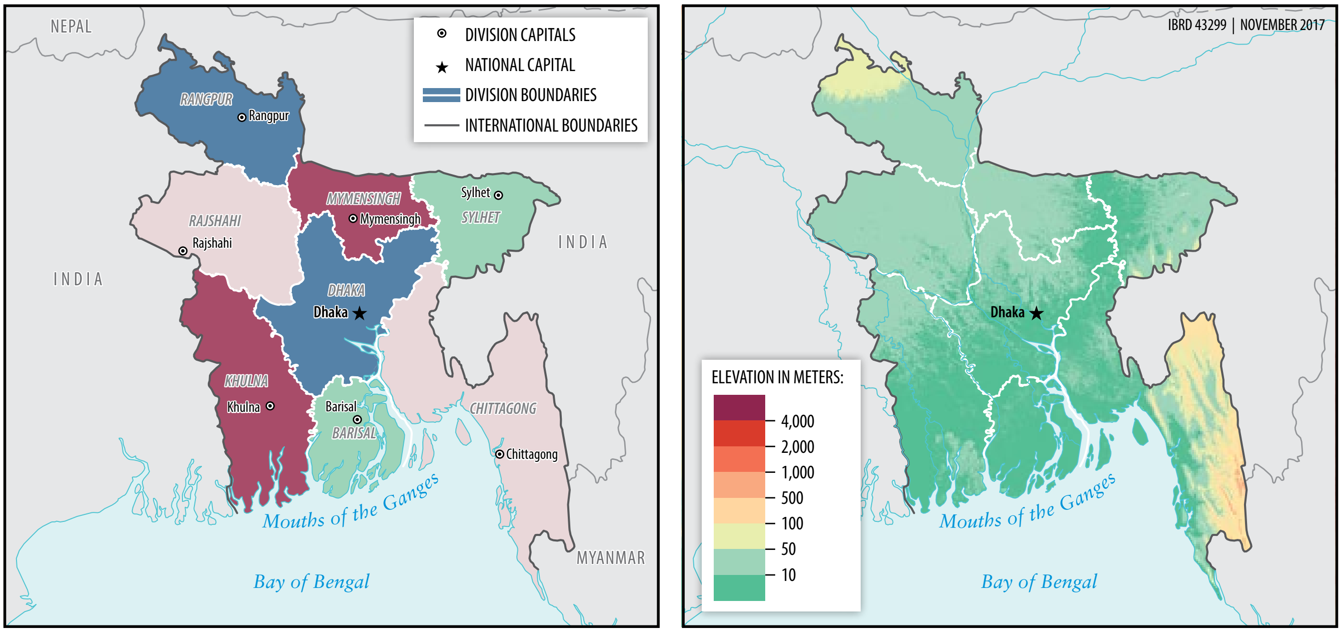
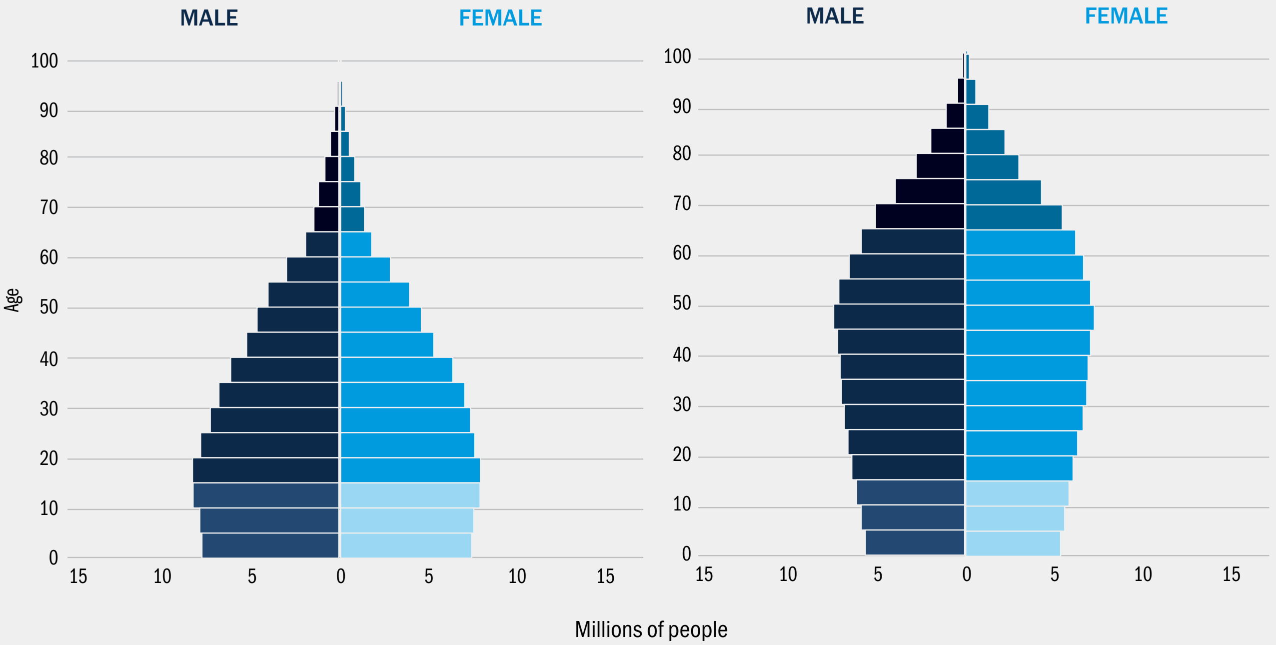


Figure 5.10: Population pyramids for Bangladesh, 2017 and 2050



Source: UNDESA 2017.

Climate trends

As a deltaic and coastal country, Bangladesh is particularly exposed to compounding climate risks, resulting from the interacting effects of increased temperature, growing risks of river flooding, rising sea level, and increasingly intense tropical cyclones (World Bank 2013b). The IPCC reports that mean annual temperature in Asia has "very likely" increased (Hijioka and others 2014). The consensus on climate scenarios for Bangladesh is that the temperatures will rise by 2.6°–4.8°C by 2100 (Caesar and others 2015). Sea surface temperature changes and sea level rise, both caused by temperature changes, will directly affect Bangladesh, perhaps more than any other non-island nation. These changes will increase the frequency and/or severity of tropical cyclones; cause unanticipated shifts in the timing and intensity of the South Asian seasonal monsoon; inundate the Ganges-Brahmaputra-Meghna delta as a result of sea level rise and increased glacial melt; and change river flow in the Ganges and Brahmaputra rivers (Immerzeel, Van Beek, and Bierkins 2010; Whitehead and other 2015; Dasgupta and others 2016; Yang and others 2016). Changes in precipitation are projected to increase the peak discharges of the Ganges, Brahmaputra, and Meghna rivers, with the flooded area increasing by as much as 29 percent if global temperatures rise by 2.5 °C above preindustrial levels. Human activity (dams, barrages, river embankments, and diversions of the inland basins of rivers) can also significantly increase the risk of flooding downstream from extreme rainfall events higher up in river catchments (World Bank 2013b). Drought can exacerbate seasonal food insecurity (*monga*) in the ecologically and economically vulnerable areas of the northwest (Sarker and Mian 2012), which can result in seasonal displacements. The greatest effects from climate impacts will be felt on food production, livelihoods, urban areas, and infrastructure (World Bank 2013b).

Bangladesh has a monsoonal tropical climate, with one main rainy season, beginning in June, which is subject to interannual variability. Annual precipitation ranges from an average of 1,500 millimeters in the center-west to 4,500 millimeters in the far northeast. Tropical cyclone activity in the Indian Ocean is the main driver of interannual variability. Shifts in the timing or intensity of the South Asian seasonal monsoon are also factors of interannual variability. A late-onset or weak monsoon leading to lower than average precipitation can cause as much disruption as a very strong monsoon leading to flooding. Because Bangladesh is at the confluence of three major rivers, heavy monsoons upstream can induce flooding, even if precipitation in the country is average.

The modeling takes into account impacts on water availability and crop productivity (largely rice followed by wheat production), as well as sea level rise (combined with storm surge) of one meter under RCP2.6 and two meters under RCP8.5. The ISIMIP projections for 2010–50 suggest modest increases in water availability over the entire country for all models under all scenarios (except for a single map grid cell in the northwestern corner, which experiences a 10–30 percent decline).

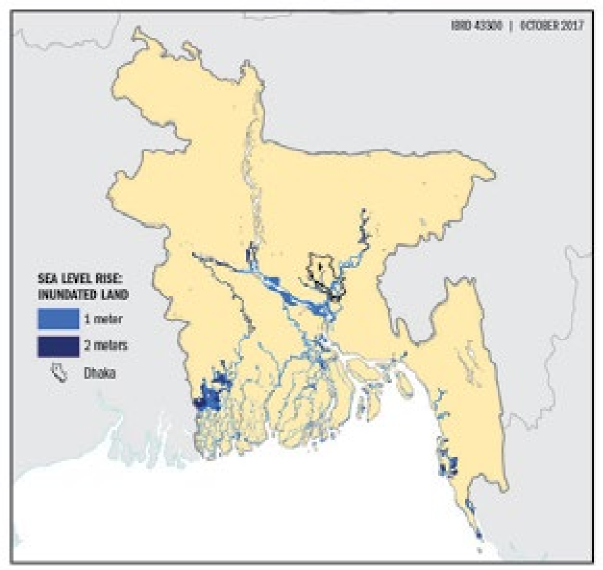
By contrast, the two crop models yield different results—which is not surprising given that the choice of models was guided in part by capturing the widest spread in outputs (see Appendix A). The LPJmL model shows modest increases in crop productivity by 2050 over the entire country; the GEPIC model shows declines in more than half the country. The GEPIC model driven by the IPSL-CM5A-LR climate model in particular shows that between 10 percent (under RCP2.6) and 18 percent (under RCP8.5) of the territory could experience 10–50 percent declines in crop productivity. Two pockets, around Dhaka and northeastern Bangladesh, may experience >50 percent declines under RCP2.6.

Toward the end of the century, crop productivity is likely to trend downward, especially under the GEPIC model, with widespread declines of 50–80 percent under RCP8.5 (see Chapter 4 for ISIMIP water and crop model outputs for 2050–2100). The LPJmL crop model projects fewer declines. Water availability increases slightly, but even areas that may see stable or increasing water availability may see extremes of flooding (as a result of the trend toward increasingly intense rainfall events) or periodic drought. The model does not fully capture these effects, because it looks at long-term averages.

The modeling has shown that Bangladesh's population distribution is more sensitive to water availability and crop productivity than the distributions of Ethiopia and Mexico; relatively small deviations from the baseline water availability and crop productivity during 2020–50 are projected to produce a large population response relative to similar deviations in other countries. Changes in crop yields and potential changes in the pattern of the annual monsoon may drive fairly large population redistribution from the northeast to the western portions of the country, as discussed below.

Bangladesh is a low-lying country with sizable areas just above sea level near the Bay of Bengal, leaving it highly exposed to storm surge and sea level rise. A one meter rise in sea level is projected to lead to a loss of more than 4,800 square kilometers of land area (roughly 3.2 percent of the country); a two meter rise, augmented for storm surge impacts, would lead to the inundation of nearly 12,150 square kilometers (eight percent of the country's land area). The impacts of sea level rise are concentrated in coastal areas, but they are projected to extend inland along the banks of the Brahmaputra, Meghna, and Ganges rivers (Figure 5.11).

Figure 5.11: Land area inundated by 1-meter and 2-meter combined sea level rise and storm surge in Bangladesh



Projected climate migration trends

The number of climate migrants and their share in the population grows across all scenarios from 2020 to 2050 (Figure 5.12). The number of climate migrants is highest under the pessimistic reference scenario and lowest under the more climate-friendly scenario with large differences between these two scenarios.

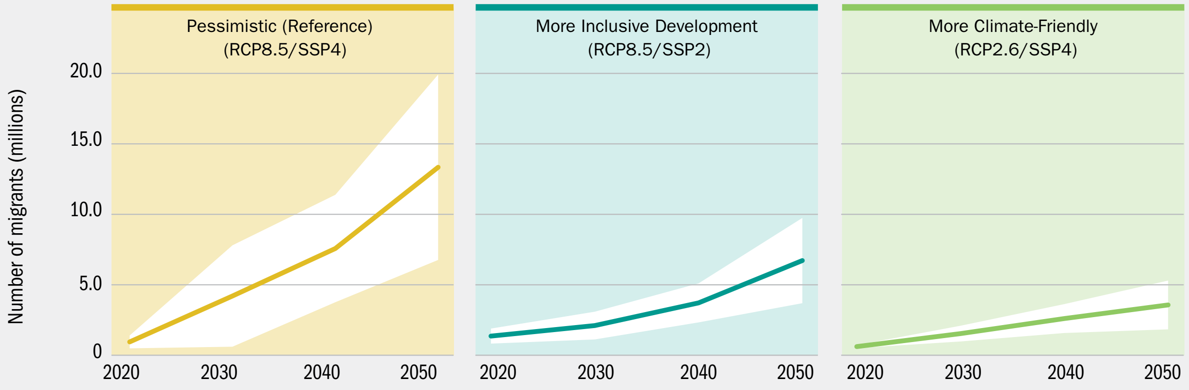
In the pessimistic reference scenario, there will be 13.3 million climate migrants by 2050 (with a range of 6.8 –19.9 million), which translates into 7.5 percent of the total population (with a range of 3.8–11.3 percent) (Table 5.4). The numbers are reduced by about half under the more inclusive development scenario to 6.7 million (with a range of 3.7–9.7 million) and further halved to 3.6 million (with a range of 1.8–5.3 million) under the more climate-friendly scenario. Under these last two scenarios, climate migrants average about 2–3 percent of the population by 2050. This suggests that development pathways with more inclusive development policies together with lower global emission trajectories will help reduce the scale of climate migration.

Table 5.4: Projected number and share of internal climate migrants in Bangladesh under three scenarios, 2050

	Scenario					
Result	**Pessimistic/Reference**		**More inclusive development**		**More climate-friendly**	
Number of iinternal climate migrants by 2050 (million)	**13.3**		**6.7**		**3.6**	
Minimum (left) and maximum (right) (million)	6.8	19.9	3.7	9.7	1.8	5.3
Internal climate migrants as percent of population	7.53%		3.43%		2.02%	
Minimum (left) and maximum (right)	3.82%	11.25%	1.89%	4.98%	1.04%	2.99%

Note: The scenarios are based on combinations of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). SSP2 = moderate development; SSP4 =unequal development; RCP2.6 = low emissions; RCP2.6 = high emissions.

Figure 5.12: Projected number of internal climate migrants in Bangladesh under three scenarios, 2020-50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
%	0.58	2.41	4.24	7.53	0.82	1.16	1.94	3.43	0.37	0.88	1.46	2.02

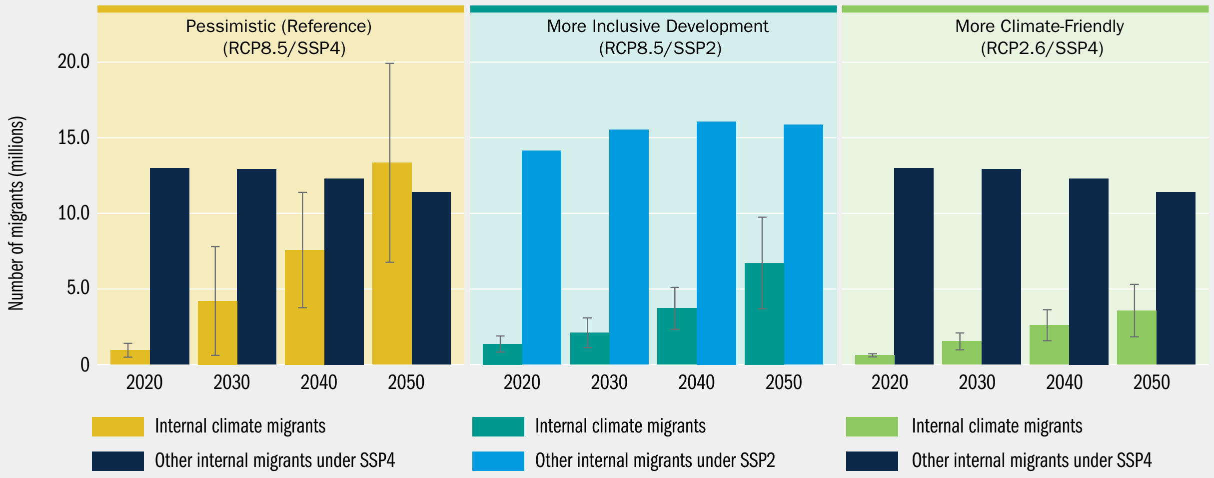
Note: Dark lines represent the average runs for each scenario. White unshaded areas represent the 95th percentile confidence intervals. The wide intervals are in part a reflection of the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

The number of climate migrants trends upward in the last decade of the modeling period in the pessimistic reference and more inclusive development scenarios, which share the high emissions pathway (Figure 5.12). In contrast, in the more climate-friendly scenario, the number of climate migrants increase at a slower pace. The uptick, particularly in the pessimistic reference scenario, may reflect the more pronounced climate impacts expected in the second half of the century, as shown in the ISIMIP water availability and crop productivity projections.

These findings indicate an opportunity to prepare for and address the potential scale and magnitude of climate migrants, particularly for a climate-vulnerable country like Bangladesh. It also reinforces the idea that a low-emissions development pathway may help stabilize or at least slow increases in pressures on people's livelihoods and the ensuing rate of climate migration.

The vulnerability of Bangladesh to climate impacts is highlighted when examining climate migrants as a share of other internal migrants. While climate migrants will represent an increasing share of other internal migrants across all scenarios (Figure 5.13), the shares are largest under the pessimistic reference scenario, with climate migrants outpacing other internal migrants. Numbers are somewhat lower for the other two scenarios, but still represent a third to a half of other internal migrants.

Figure 5.13: Projected number of climate and other internal migrants in Bangladesh under three scenarios, 2020–50



Note: The whiskers on the climate migrant bars represent the 95th percentile confidence interval for the four model runs that comprise each scenario. There are no confidence intervals for other migrants, because only a single development trajectory is used in each scenario (SSP2 or SSP4).

Projected spatial patterns of climate migration

Bangladesh's population is likely to grow to 177 million (under SSP4) or 196 million (under SSP2) by 2050.[34] Figure 5.14 displays the baseline 2010 population density and 2050 projected population density under the pessimistic reference scenario. It shows that Dhaka and Chittagong will continue to grow and retain the highest population density levels. All results pertaining to climate migration should be interpreted against this backdrop of overall population growth in the country.

Modeling suggests that climate change will increase movement out of some areas and livelihood zones and dampen movement into others. But even in these cases, the population will still grow, though less quickly than in the absence of climate change.

Figure 5.15 displays the change in population density between the baseline 2010 population and the 2050 projected population under the pessimistic reference scenario. It shows that in the pessimistic reference scenario, population density increases throughout most of Bangladesh, except in coastal areas and along the Brahmaputra River. Specifially:

- Population density grows fastest in the west, particularly the Ganges River basin, where it will more than double.
- Population density increases by 5–25 percent in Dhaka and by 25–50 percent in Chittagong.
- Population density increases by 5–25 percent in the eastern part of the country.
- Population density decreases by 40 percent along the coasts, except in the southwestern corner of the coastline.
- Population density also decreases along the Brahmaputra River, an area that is still largely rural. Rural–urban migration out of the region is expected to outpace local urban growth. The region therefore experiences population density declines of 40 percent or more.

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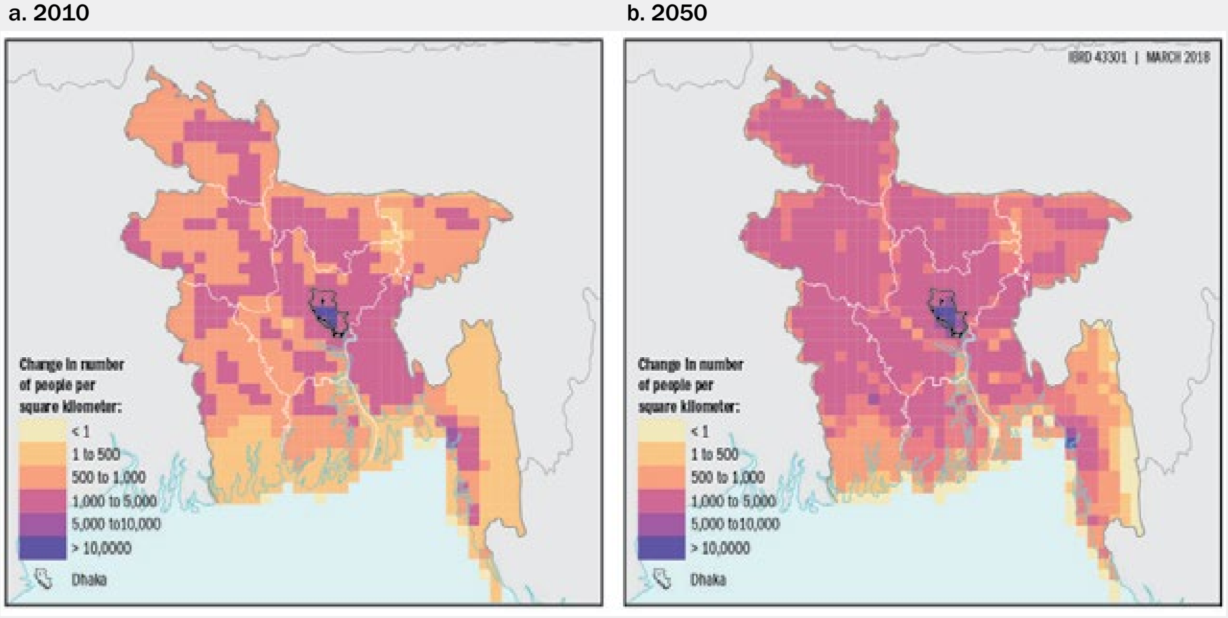
[34] The moderate development pathway for Bangladesh yields larger populations than the SSP4 pathway, because it is a lower-middle-income country. Only low-income countries show marked increases in population under SSP4 (see Chapter 3).

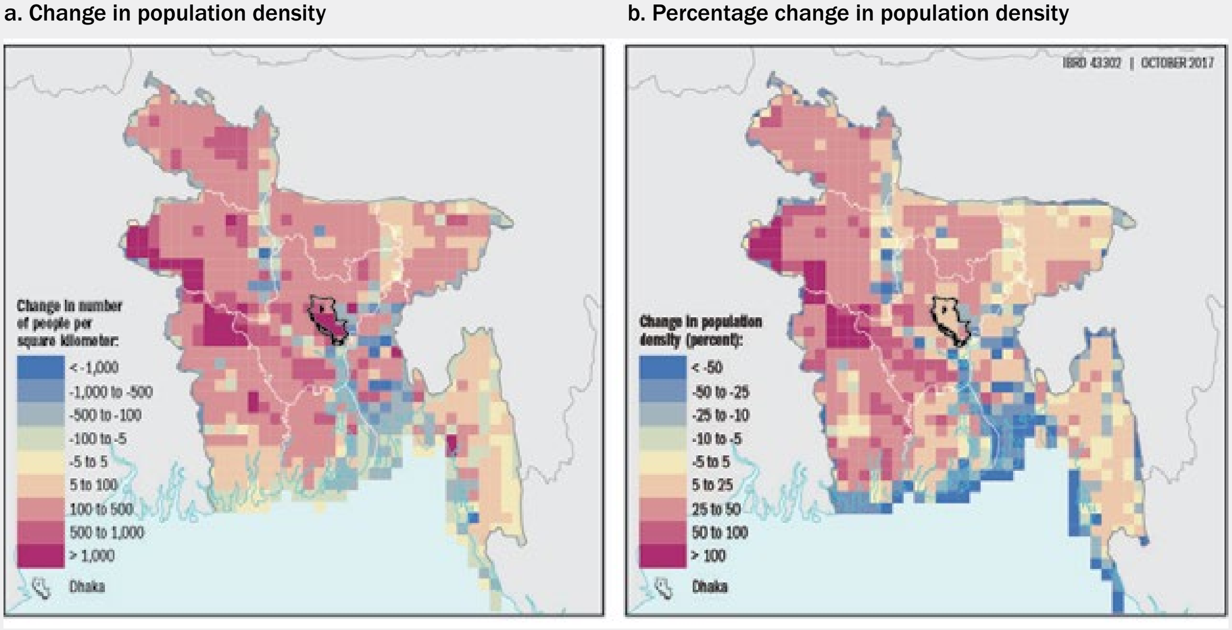
Figure 5.14: Baseline population density 2010, and projected population density under the pessimistic reference scenario 2050, Bangladesh



a. 2010

b. 2050

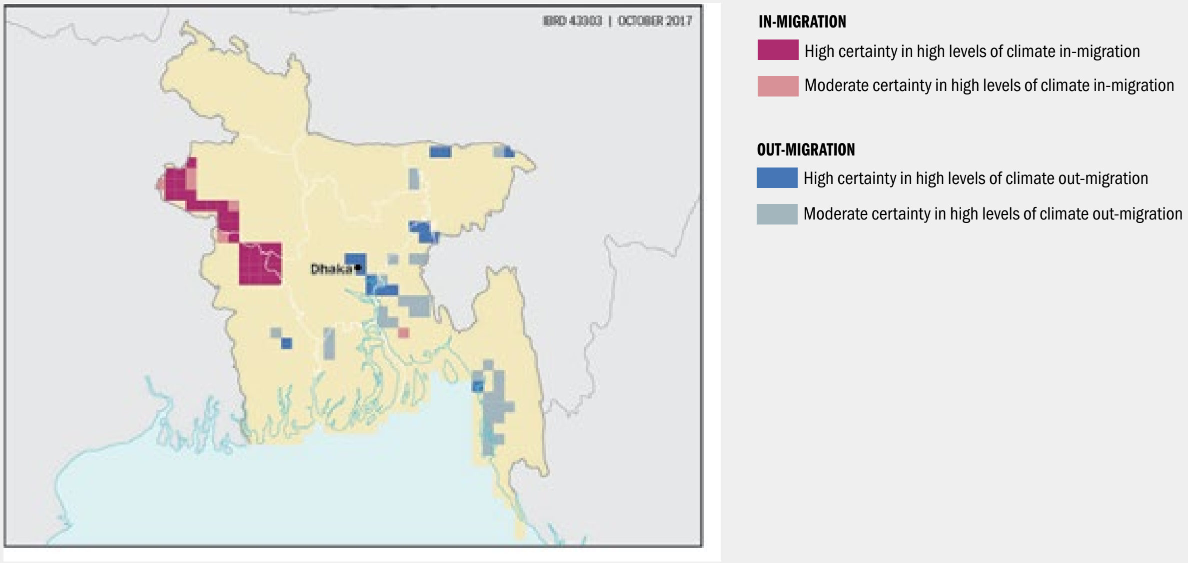
Figure 5.15: Absolute and percentage change in population density in Bangladesh under the pessimistic reference scenario, 2010-50



a. Change in population density

b. Percentage change in population density

Figure 5.16: Hotspots projected to have high levels of climate in-migration and climate out-migration in Bangladesh, 2050



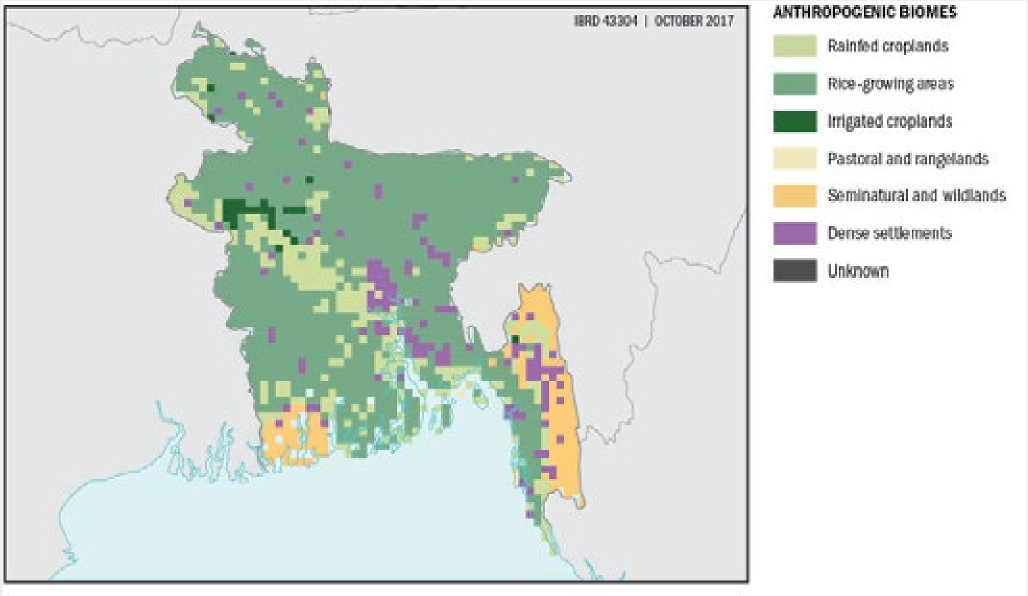
Note: High certainty reflects agreement across all three scenarios modeled, and moderate certainty reflects agreement across two scenarios. In- and out-migration hotspots are thus areas in which at least two scenarios concur on density changes in the top 10th percentile of the density distribution, which in South Asia represents an increased population density in 2050 of about 8 to 14 people per square kilometer, depending on the scenario. For decreased population density, it is about minus 10 to minus 25 people per square kilometer.

A climate in-migration hotspot is projected in the Ganges River basin in the west (Figure 5.16). This area is a rainfed agriculture livelihood zone, amplifying projected population growth trends in this region. Higher crop productivity partly drives these increases, but they probably also reflect declining productivity in the northeast and the impact of sea level rise in coastal settlements, which drives people inland.

The Ganges River basin is predominantly rainfed cropland, with some irrigated cropland areas (Figure 5.17). Across Bangladesh rainfed croplands will see strong population growth under all scenarios. Growth will be particularly strong in the pessimistic reference scenario, in which rainfed croplands see average climate in-migration of 1.3 million people by 2050 (with a range of 0.3–2.3 million) (Figure 5.18). As much as 10 percent of the population in rainfed areas could be climate migrants. It bears reiterating that the model does not place limits on rural densities that reflect the land's "carrying capacity." Results need to be validated in light of current land tenure and productivity potential.

In contrast, out-migration hotspots are projected in the northeast (see Figure 5.16), dampening the small projected population growth trends in this region. Projected reductions in crop productivity of 10–50 percent in isolated pockets, largely in rice-production areas, drive these declines. Rice-growing areas may see declines in population in the pessimistic reference scenario of about 0.2 million by 2050 (Figure 5.18). The more inclusive development scenario sees projected population growth in such areas of 0.1 million; the more climate-friendly scenario projects virtually no difference from the no climate impact scenario. In no case does the change exceed 0.2 percent of the population in these zones.

Figure 5.17: Livelihood zones in Bangladesh, by anthropogenic biome, 2015

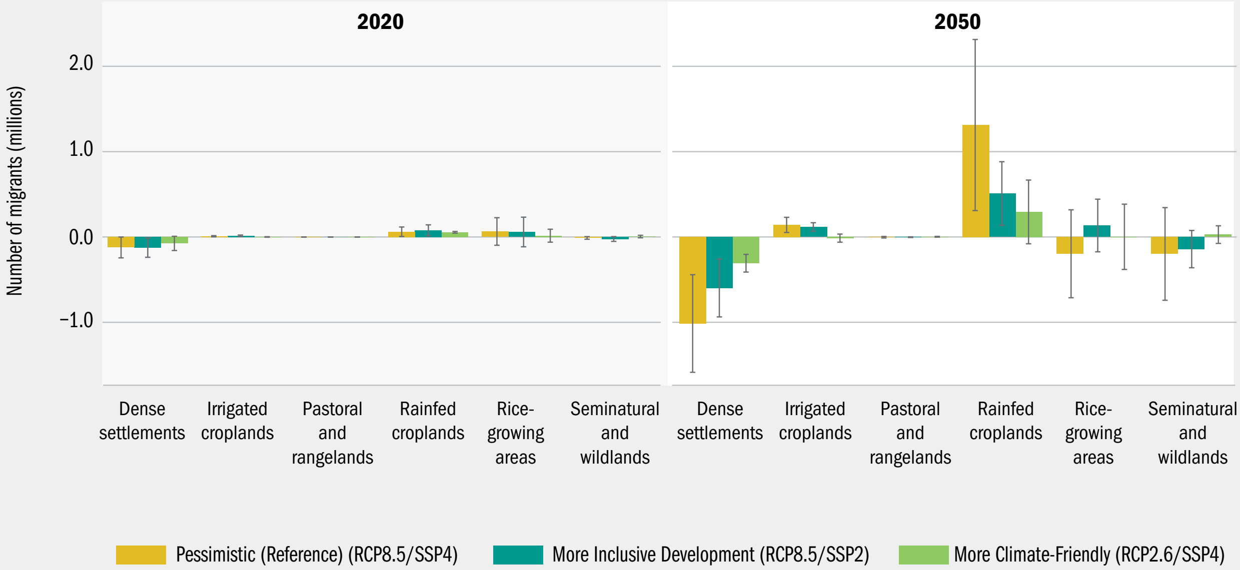


Source: Ellis and others (2010).

Other out-migration hotspots are projected around Dhaka and the river delta south of the city and along the eastern coast near Chittagong (see Figure 5.16), dampening the projected population growth trends for these major urban areas. The dampening effect in coastal areas, along the Meghna and Ganges rivers near Dhaka and to the south of Chittagong along the Karnaphuli River, is a result of land losses associated with the modeled sea level rise and storm surge bands (see Figure 5.11). In the pessimistic reference scenario, roughly eight percent of the country's total area is lost. Inland migration of households and economic activity has already been observed in Bangladesh, where exposed coastal areas are characterized by lower population growth rates than the rest of the country (World Bank 2013b). Other effects of climate change on cities, such as heat stress and flooding, could discourage people from moving to urban areas. The infrastructure of Dhaka is already overstretched, and flooding is a perennial problem. Deltaic and coastal urban areas are highly vulnerable and are rendered less livable when climate change is considered.

These hotspot patterns imply movement in a country that is already highly densely populated and expected to become even more so by 2050. Past changes in population distribution in Bangladesh showed high sensitivity and responsiveness to changes in ISIMIP water and crop model outputs, which is understandable given the country's riverine and coastal geography as well as history of natural disasters. Relatively modest changes in temperature and precipitation conditions may drive fairly large population redistribution. Given the strengthening of the climate signal after 2050—as shown by the water and crop model (ISIMIP) results and the increasing exposure of deltaic and coastal urban areas to climate hazards—the scale, magnitude, and patterns of climate migration may be amplified in the second half of the century, underscoring the need to act before 2050.

Figure 5.18: Projected net migration in and out of livelihood zones in Bangladesh under three scenarios, 2020–50



Note: Whiskers show 95th percent confidence intervals for climate migrants.

In-country consultations on modeling results

National consultations were held in Dhaka on July 23 and 24, 2017. They involved 40 participants from more than 25 organizations, including the Ministry of Agriculture, the Ministry of Food, the Department of Haor and Wetland Development, the Bangladesh Institute of Development Studies, the Rural Reconstruction Foundation, the Palli Karma-Sahayak Foundation, the Ashrai Foundation, the Sajida Foundation, the WAVE Foundation, East-West University, the Asian Development Bank, USAID, the UN Development Programme, the European Union, and some bilateral development partners. Participants were divided into small groups and addressed questions about their experiences and knowledge of current climate change, anticipated climate change to 2030 and 2050, existing climate change-induced migration patterns (if any), anticipated (future) climate change-induced migration, and vulnerability and livelihood impacts. Break-out sessions were conducted in local languages.

Many experts agreed that climate migration would affect the country's population distribution and that the issues raised by the modeling were relevant. While there was some difference in opinion on some of the spatial configurations relating to climate in- and out-migration hotspots, others noted their plausibility in view of current mobility patterns. In terms of model projections of population growth and in-migration to the Ganges River basin, some participants argued that the country's adaptation planning was well placed to counter these spatial reconfigurations. Participants noted that Bangladesh does not have a central ministerial focus on internal migration and that these issues need more attention. Participants mentioned the Bangladesh's Perspective Plan for 2041, which would consider issues related to climate and migration.

What do these results mean for Bangladesh's development future?

Climate migrants could reach almost 20 million by 2050 under the worst-case pessimistic reference scenario. Climate migration would occur in a country with already high internal mobility and where sudden extreme events already have important impacts.

Bangladesh has large numbers of people engaged in all four of the main migration types: rural to rural, rural to urban, immediate cross-border, and long-distance international (Box 5.2). Much of the country's rural to urban migration is to Dhaka (Marshall and Rahmann 2013). Immediate cross-border migration is primarily to West Bengal, in India (Banerjee and others 1999; Datta 2004; Rahaman and Sheikh 2016) and international is to more distant areas, including the Gulf States and Europe. Recent economic growth, particularly in the garment industry, has driven much of the internal mobility.

Box 5.2: International migration trends and gender dimensions of migration in Bangladesh

Many Bangladeshis migrate overseas. Most go to the Gulf States and Europe. International migration to the Middle East is primarily labor migration (Farid and others 2009). Bangladesh was the top sending country for migrants to Europe in the first three months of 2017 (Dearden 2017).

Most international migrants are men, because men often use sociocultural norms to prevent women from migrating (Danneker 2005). Women's dependence on remittances from men involves sensitive intrahousehold power relations. Women face increased vulnerability and workload as a result of the loss or inconsistency of the household male's income, despite remittances, and female migrants can be victims of human trafficking. Women are particularly vulnerable to being trapped or left behind in Bangladesh with no possibility of migrating themselves (Nguyen, Yeoh, and Toyota 2006; Debnath and Selim 2009). In some cases, changes in the household decision-making structure, with the absence of the male head, can lead to at least temporary empowerment of women (Debnath and Selim 2009).

Migration in Bangladesh is also strongly tied to gender relations and women may be particularly vulnerable to climate change impacts. As Bhatta and others (2015, 4) note, "unequal gender relations and access to resources may make women more vulnerable to climate change than men. Climatic events may not only directly impact women and vulnerable populations, but also make them more vulnerable because of their interaction with sociocultural factors." They find that migrating increases the risk of sexual violence against women. In addition, women face livelihood and subsistence burdens when men migrate, their ability to cope with and adapt to stressors and shocks is reduced, they face increased mortality during a shock, and their food security becomes more precarious (Chindakar 2012).

Extreme events may be an additional driver of internal migration. In a study of migration in the wake of cyclone Aila, in 2009, Saha (2016) finds that households in central Bangladesh were reluctant to migrate but had no other livelihood options and felt compelled to move to the secondary city of Khulna. The coastal and deltaic areas that are vulnerable to impacts from tropical cyclones coincide with the out-migration hotspots resulting from slow-onset climate impacts identified in this report.

Slow-onset changes and rapid-onset events may have compounding effects on internal migration patterns and should be considered together. Though not modeled in this study, sudden-onset and extreme events, particularly tropical cyclones, present major risks to some population groups in Bangladesh. Cyclone Sidr in 2007 exposed 3.5 million Bangladeshis to flooding (World Bank 2013b). It also caused production losses of 800,000 tons of rice, or about two percent of total annual production that year (FAO 2013) and resulted in $1.7 billion in economic damages. Major damage occurred in the housing sector, followed by agriculture and infrastructure (Wassmann and others 2009; Mearns and Norton 2010). Increased river flooding combined with tropical cyclone surges poses a high risk of inundation in areas with the largest shares of poor people. Approaches such as risk mapping, which combines hazard and vulnerability maps, can help better understand the sensitivities of different adaptation measures for future planning (DECCMA 2017).

Migration directly affects the vulnerability of household livelihoods in Bangladesh (Rahman and Rana 2016). Food price and health shocks are significant components of household vulnerability. Like people elsewhere, Bangladeshis' coping and adaptation strategies include "doing nothing, sharing losses, modifying the threat [mitigation], changing [land] use, moving and ecosystem restoration" (Pender 2008, 54–55). In response to floods in northern and northeastern Bangladesh in 2014, households took out loans, changed livelihood strategies, received support from relatives, exchanged labor, drew down savings, and sold productive assets (Walter 2015).

Climate change will interact with other factors to induce migration for different groups. In a case study on rural to urban migrants in the Barind Tract in the northern highland region of Bangladesh, Kabir and others (2017) examine how affected individuals and families make decisions to either stay or migrate internally in response to seasonal drought and other socioeconomic vulnerabilities. Their results suggest that migration decisions are consolidated by a variety of stressors, including both environmental and nonenvironmental components. Stojanov and others (2016) find that local experts in Bangladesh consider migration a viable adaptation strategy to climate change, although it is not exclusively an adaptation strategy.

Large coastal urban cities like Dhaka and Chittagong will need to balance climate out-migration against broader trends of population growth through longer term planning and investments in adaptive capacity to ensure resilience in the face of climate impacts.

Bangladesh has a long history of rural to urban migration to cities such as Dhaka, Chittagong, and Khulna. Economic growth in urban areas is a strong pull factor for the poorest. Islam and others (2006) find that 35 percent of the population of six major cities live in informal settlements, highlighting the importance of understanding internal rural to urban migration processes. Chowdhury and others (2012) find a similar pull factor in Sylhet, a city roughly one-fifth the size of Dhaka. Haider (2010) documents migration to Rajshahi City.

Low-lying coastal areas, particularly coastal cities, and the Ganges–Brahmaputra–Meghna Delta region, are especially vulnerable to climate impacts. Coastal populations must cope with progressive inundation from sea level rise and fluvio-tidal floods, heightened storm damage, loss of wetlands, river bank erosion, salinity intrusion as a result of seasonal low flow levels in rivers and upstream water diversion, and high levels of salinity in groundwater and arsenic contamination of shallow aquifers (Dasgupta and others 2014; DECCMA 2017). A sea level rise of one meter is expected to affect 13 million people in Bangladesh (Mearns and Norton 2010); it would not necessarily permanently displace all people affected (Gemenne 2011). By 2070 some 1.5 million people are projected to be affected by floods in the coastal cities of Bangladesh (Brecht and others 2012). About 20 million people in the coastal areas of Bangladesh are already affected by salinity in their drinking water (World Bank 2013b). Contamination of drinking water by saltwater intrusion may cause an increasing number of cases of diarrhea and more frequent outbreaks of cholera, among other health effects (World Bank 2013b).

Given its already high population, population density, and vulnerability to climate change, particularly in coastal and urban areas, Bangladesh must prepare for future shifts in population centers. Model results show that in all scenarios, urban and coastal areas may see dampened growth as they become less livable as a result of climate change impacts. Out-migration levels will be highest under the pessimistic reference scenario, followed by the more inclusive development and then the more climate-friendly scenario.

These findings have several policy and development implications. First, even if the most optimistic scenario materializes, internal migration will be a pressing issue in places like Dhaka, where climate out-migration only dampens the general increase in population and infrastructure and transport sectors are already overwhelmed. Increasing the adaptive capacity of urban areas, including the adequate provision of infrastructure and services, will take significant advanced preparation and resources. Second, the vulnerability implications of immobility, for those who choose to stay or are unable to move away, should also be considered.

Rural to rural climate migration will be driven by shifts in water availability and crop productivity, as in the northeast and the Ganges River basin in the west. This will require a combination of targeted and strategic policy responses, such as livelihood diversification and shifts to less climate sensitive sectors.

Large parts of Bangladesh's population (about 47 percent) still depends on agriculture and therefore remains vulnerable to climate impacts (World Bank 2017c). Rice production in the Ganges–Brahmaputra–Meghna Delta region, for example, accounts for 34 percent of national production and is used for domestic consumption only (World Bank 2013b]). Large parts of the area are less than five meters above sea level and therefore at high risk of sea level rise (World Bank 2013b). Yu and others (2010) estimate the discounted total losses in agricultural GDP as a result of the combined impacts of climate change at about \$25.8 billion, or \$600 million a year between 2005 and 2050. Destruction of ecosystems and livelihoods may occur as rivers and coastal marshes become increasingly saline, groundwater salinizes, riverbanks erode, and tropical cyclone activity intensifies.

Given the importance of rice for rural livelihoods, particularly in the northeast, where crop conditions are projected to deteriorate, adaptation to climate change is vital. Higher flood risk poses a severe threat to Aman rice, one of Bangladesh's three main rice crops, which grows in the monsoon season and accounts for more than half the national crop (Wassmann and others 2009). Increased flood risk to the Aman and Aus (pre-monsoon) rice crops is likely to interact with other climate change impacts on Boro (post-monsoon) rice crop production, leading to enormous economic damage (Yu and others 2010). Moniruzzaman (2015) finds that farmers change the variety of rice they grow in response to temperature. Farmers chose to switch to Aus as summer temperatures increased. Other practices include the use of hydroponics (Ayers and Forsyth 2009), the conservation of water, the use of wells and irrigation, crop switching, and automation or technological innovation (Selvaraju and others 2006). Increasingly, households are also seeking off-farm employment (Thomas and others 2013).

Given regional differences in climate vulnerability, rural to rural migration levels are likely to increase, especially over short distances. The uneven distribution of climate change impacts can have differential effects on food prices, agricultural yields, and production, which affect poverty reduction and well-being. Climate change may induce migration out of the mainly rice-growing areas of the northeast, where declines in crop productivity are projected, toward the mainly rainfed and irrigated cropland areas of the Ganges River basin in the west, where improving water availability and crop productivity conditions are expected. More understanding of regional differences and vulnerabilities in rural livelihoods is therefore critical to provide a stronger basis for adaptive agricultural practices that would enable people to stay where they are and to identify potential viable host areas if people choose to move.

Opportunities will also need to be identified and pursued for livelihood diversification out of climate change–sensitive areas and sectors so that climate migrants can be absorbed into the national economy. Agriculture's share of GDP declined (from 24 percent in 2000 to 15 percent in 2016), and industry's share rose (from 23 percent in 2000 to 29 percent in 2016) (World Bank 2017b). Given the increase in manufacturing, particularly in textiles, and services employment, this trend is likely to continue. Absent major policy shifts or marked global economic changes, agriculture will continue to slowly decline in relative importance and propel livelihood diversification in rural areas, likely increasing labor out-migration.

Given the acceleration of climate migration trends, priority and urgency should be given to embedding climate migration into development policy and planning. Some of these efforts are currently underway in Bangladesh.

Bangladesh has the institutional capacity to adapt to climate change. According to its Nationally Determined Contribution, climate change adaptation is a key priority. The country has already undertaken initiatives in the water, health, forestry, agriculture, and infrastructure sectors to mainstream adaptation into national development. Several adaptation programs are underway—such as a program to enhance food security in the northwest and another to encourage labor migration out of the northwest during the dry season that could help shield the population from the worst effects of climate change. The Cyclone

Preparedness Programme is central to the country's early warning systems. It uses more than 42,000 volunteers along with a transceiver telecommunications network to ensure rapid delivery of warnings to the population at risk (Habib, Shahidullah, and Ahmed 2012).

Bangladesh's National Sustainable Development Strategy recognizes that absent adaptation efforts, by 2050, sea level rise, river bank erosion, and saline water intrusion in coastal areas may displace large numbers of people, who will have to migrate or be resettled (Government of Bangladesh 2013). The government identified "a clear gap in the broader strategic policy framework, specific legal mandate and dedicated institutional arrangements to deal with the issue" of disaster and climate induced internal displacement (Government of Bangladesh 2015). The National Strategy on the Management of Disaster and Climate Induced Internal Displacement aims to address this gap (Box 5.3). Further integration of climate migration could align with the adaptation priorities set out in the Nationally Determined Contribution, including climate-resilient infrastructure, housing, and communications; urban resilience; options for agriculture; and better early warning systems and disaster preparedness. Bangladesh's Vision 2021, which lays out development targets to that year, could incorporate good management of climate migration as an important factor in achieving inclusive development and adaptation. Bangladesh's Perspective Plan for 2041 provides a longer term planning horizon.

Box 5.3: Bangladesh's national strategy for managing disaster- and climate-induced internal displacement

Bangladesh's vision for the National Strategy on the Management of Disaster and Climate Induced Internal Displacement is to "set out a comprehensive and realistic rights-based framework that respects, protects and ensures the rights of climate-induced internally displaced persons in different stages of displacement and during the search for durable solutions." It includes:

- creation of a common and coherent basis for policy directions and action plans at the national and local levels;
- adoption of both preventive and adaptive measures to minimize the internal displacement caused by climate-related disasters;
- development of guides for sectoral programs for the creation of conducive environments for safe, voluntary and dignified return/integration or relocation/resettlement;
- effective and efficient management and access to entitlements; and
- promotion of livelihood opportunities and overall human development as part of inclusive development programs.

Targeted actions under the pre-displacement phase aim at prevention and preparedness. They include:

- promoting activities related to understanding risk;
- investing in disaster risk reduction and climate change adaptation;
- strengthening disaster risk governance;
- creating employment and decent livelihood options, by promoting and encouraging the decentralization of urban growth centers; and
- engaging land use planning that is responsive to climate disaster risk, by identifying highly vulnerable zones and restricting human settlement in unprotected or highly vulnerable areas.

Actions under the displacement phase would include strengthening humanitarian and disaster relief assistance and protecting fundamental human rights of people during displacement. Actions under the post-displacement phase would ensure that displaced people have the option to choose durable solutions, including return to their original place, local integration, or resettlement in a manner that is voluntary and safe and protects their dignity.

A National Task Force on Displacement would constitute the highest decision-making body with regard to internal displacement caused by climatic hazards. This interministerial and interagency body would be responsible for implementing the strategy and ensuring coordination with line ministries and government departments.

Source: Government of Bangladesh (2015).

KEY FINDINGS ON MEXICO

Main findings on Mexico include the following:

- The scale of internal climate migration is projected to increase in all scenarios by 2050, against a backdrop of overall population growth. Mexico's population is projected to grow from 125 million in 2015 to between 135 million (in SSP4) and 148 million (in SSP2) by 2050.[35] As an upper middle income country with a diversified economy that has already experienced a demographic transition, Mexico could be in a good position to anticipate and cope with climate change-induced population redistribution.

- The number of climate migrants by 2050 is largest in the pessimistic reference scenario. The figure could be as high as 3.1 million. Numbers are lower in the more climate-friendly scenario and lowest in the more inclusive development scenario, suggesting that development pathways targeting both lower global emission trajectories alongside reduced poverty and inequality will help reduce the scale of climate migration. Sustained development gains and a stronger economy mean higher adaptive capacity and financial resources to target the most vulnerable areas and groups.

- The share of climate migrants in total internal migrants is projected to increase in all scenarios. Climate migrants could constitute about 11 percent of all internal migrants in the pessimistic reference scenario by 2050, suggesting that slow-onset climate change may become an increasingly important driver of internal migration in a country that already has high internal mobility.

- The central plateau, where Mexico City and other major cities are located, will be a hotspot of future climate in-migration; the arid north as well as rainfed croplands and low-lying southern coastal areas will be out-migration hotspots. The central plateau may offer more favorable conditions for livelihoods and settlements than the arid north and the low-lying southern coastal states, which will be affected by sea level rise. This pattern aligns with Mexico's advanced levels of urbanization, declining relevance of farming-only livelihoods, and continuing depopulation of rural areas. Rural to urban flows are being replaced by intra-metropolitan mobility and mobility from the central downtown areas to surrounding suburban and peri-urban areas.

Country context

Mexico is a large and diverse country in terms of physical geography, climate, biodiversity, demographic and social composition, economic development, and culture. With a territory of 1.9 million square kilometers and a 2016 population of more than 125 million, it is the 10th most populous and 13th largest country in the world (World Bank 2017c). It is also highly urbanized, with 79 percent of its population living in urban areas (World Bank 2017c). Almost half of the population resides in cities of 100,000 people or more (CONAPO 2015; INEGI 2016). Map 5.3 shows the country's political boundaries and elevation.

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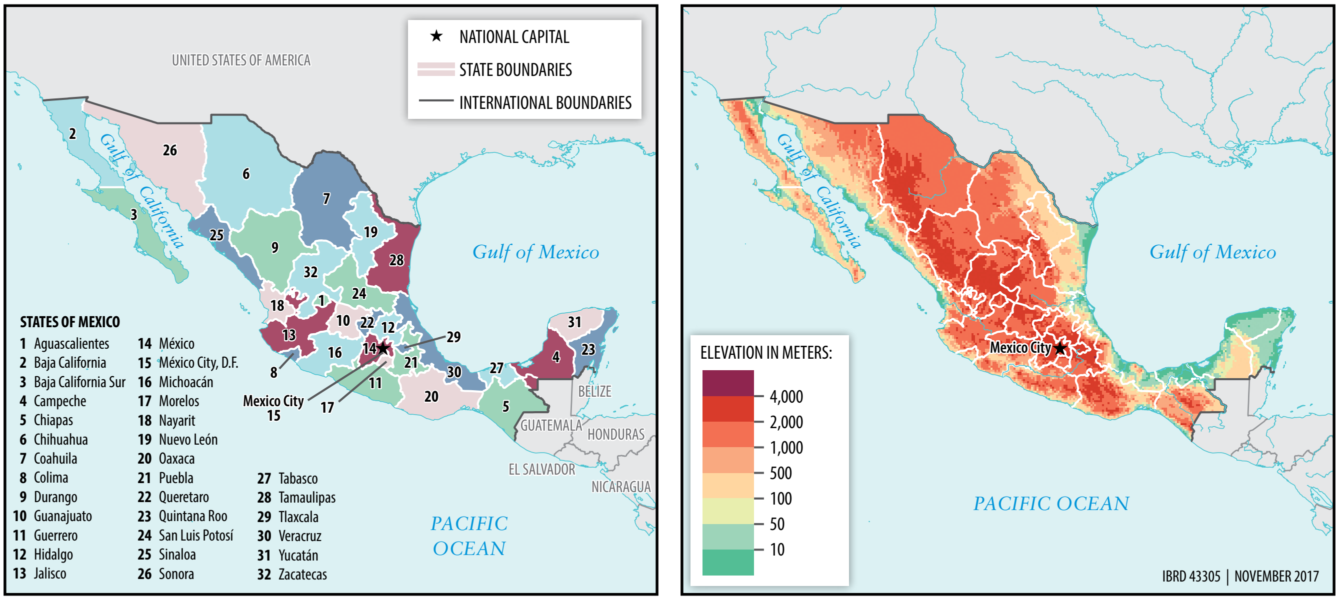
[35] The moderate development pathway (SSP2) for Mexico yields larger populations than the unequal development pathway (SSP4), because it is a middle-income country. Only low-income countries show marked increases in population under SSP4 (see Chapter 3).

Map 5.3: Political boundaries and elevation of Mexico

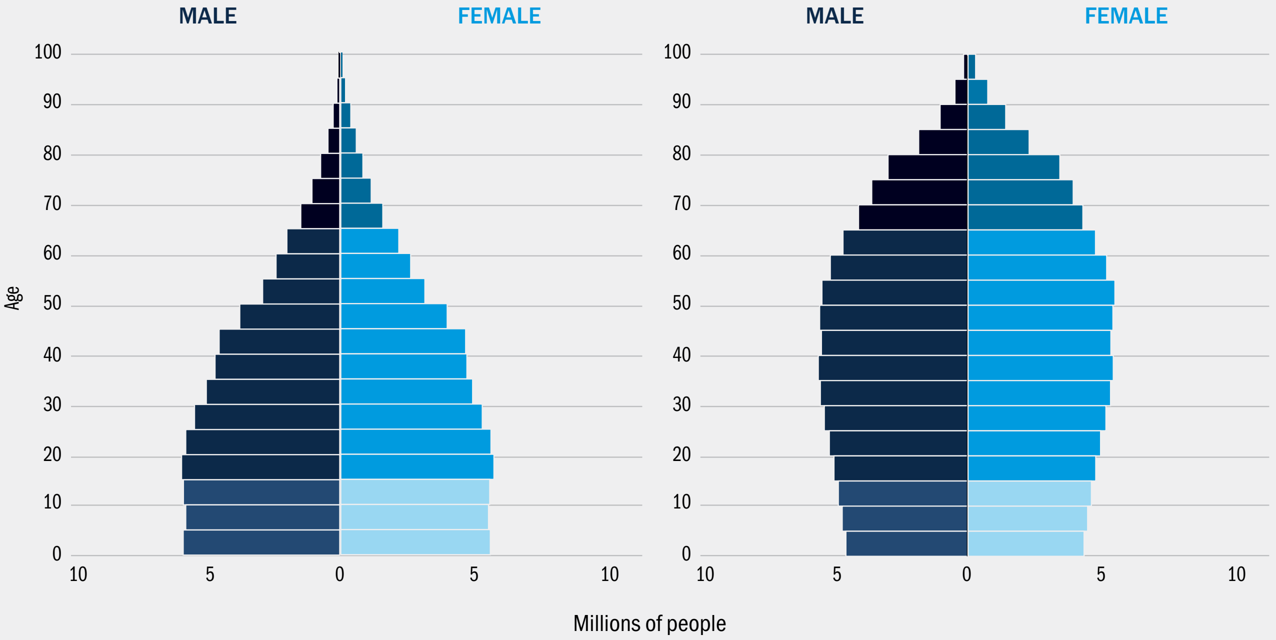


Mexico has already completed a demographic transition, which began in the 1970s. The national population growth rate is now declining, although there are regional differences. Baja California Sur, in the north, had the fastest growth, at 3.5 percent in 2010, while Mexico City contracted by 0.2 percent.

Mexico's age structure had a typical pyramid shape in 1950. By 2017 it had a more mature structure, with smaller cohorts supporting an older population (Figure 5.19). These changes have resulted in a reduction of the age dependency ratio, which reached 104.3 in 1970 before falling to 51 percent in 2016, leading to a working population that represents a larger proportion of the total population (World Bank 2017c). This demographic dividend is assumed to have a positive impact on economic development—but reaping that dividend requires coordinated policies that must be implemented within a narrow time window. Current population projections indicate that after 2024 the demographic dividend may end (Nava-Bolaños and Ham-Chande 2016). By 2050, the age structure is expected to adopt the classical urn shape of aging populations, with a sharp increase in the proportion of older adults.

Educational attainment is also paramount for decreasing climate vulnerability (Cuaresma, Lutz, and Sanderson 2014). Education can directly influence risk perception, skills and knowledge, while also having indirect effects on poverty reduction, health improvement, and access to information and resources, which in turn confers greater adaptive capacity (Muttarak and Lutz 2014). Secondary school enrollment was 91 percent in 2014 (World Bank 2017c). Disparities in educational attainment are wide, however, with lower levels in Chiapas, Michoacán, Guerrero, Oaxaca, and Veracruz and much higher levels in Mexico City, Nuevo Leon, Sonora, and Aguascalientes.

Figure 5.19: Population pyramids for Mexico, 2017 and 2050



Source: UNDESA (2017).

Climate trends

Mexico has large areas of semi-arid to arid lands in the north and pockets of semi-arid areas in the south (Oaxaca State for example) and in the northern Yucatan, making the country very susceptible to rainfall deficits. According to the IPCC, warming of 0.7°–1°C has been detected in Mexico over the past 40 years, and precipitation has declined since the 1950s by about 365 millimeters (Magrin and others 2014). Changes in streamflow and water availability have been observed and are projected to continue.

Mexico has historically been exposed to extreme events such as hurricanes, floods, and droughts. According to the Emergency Events Database (EM-DAT), between 1900 and 2016 tropical cyclones were the most frequent climate-related disaster in Mexico, followed by floods and droughts.

Results of the two ISIMIP models for water availability are highly varied through 2050 (see Appendix B). The WaterGAP model driven by the IPSL-CM5A-LR model shows the greatest declines in water availability, especially under the high emissions scenario, which projects declines of 70–90 percent through 2050 over large portions of Mexico. The WaterGAP model driven by the HadGEM2 model shows declining water availability only in the northwestern parts of Mexico, and in the Yucatan. The LPJmL water model driven by HadGEM2-ES shows only modest, mostly positive changes in water availability. The model runs driven by IPSL-CM5A-LR are similar to the WaterGAP results, with milder decreases. The general picture is one of declining water availability, with some individual runs showing modest increases over relatively large areas.

The crop model outputs do not generally see the same extreme proportional declines as the water models, except for the northwestern parts of Mexico under the GEPIC model. The LPJmL crop model projects slight increases in crop productivity (up to 20 percent) on the central plateau and marked increases in Oaxaca (up to 40–60 percent). In coastal areas, the LPJmL crop model projects crop productivity declines of 10–30 percent.

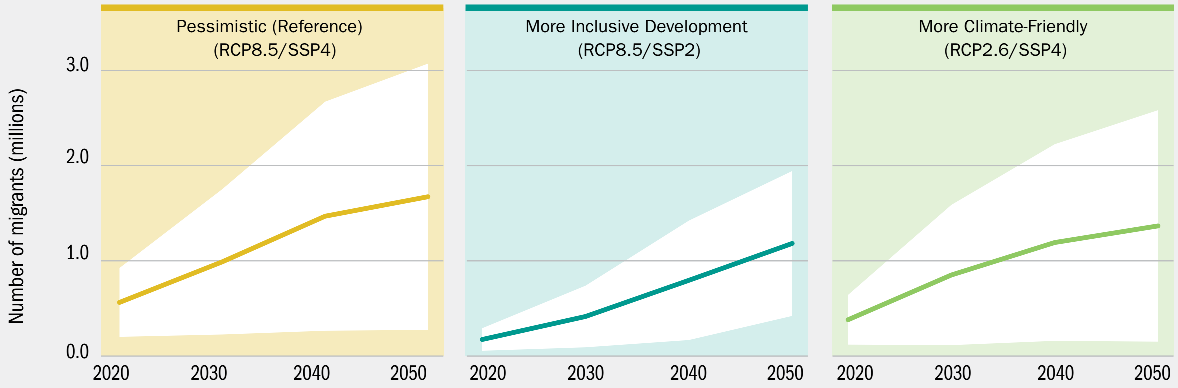
Sea level rise in 2010–50 will have impacts on low-lying areas of the Yucatan and other areas of the Gulf Coast, but the impacts are generally localized. The cities of Villahermosa and Campeche, on the southern Gulf Coast and western Yucatan, respectively, are particularly vulnerable, as are many smaller tourist-oriented cities and towns of the Yucatan. Farther north along the Gulf Coast, Tampico, a city of nearly one million, is also projected to suffer from significant inundation under the pessimistic reference scenario. Nationally, Mexico stands to lose some 19,390 square kilometers of land area to sea level rise, or just over one percent of its total (Romero-Lankao and others 2014; SEMARNAT 2016).

Climate change projections for 2050–2100 using the ISIMIP water and crop model outputs suggest extreme water stress for all of Mexico's regions, except the northeast under the more extreme RCP8.5 pathway (see Chapter 4 for ISIMIP water and crop model outputs for 2050–2100). The same models project increased temperatures, which will negatively affect crop yields and rural livelihoods. The IPCC (Christensen and others 2013) concurs with these results, stating that much of Mexico will likely see decreases in mean annual precipitation through the end of the century.

Projected climate migration trends

The number of climate migrants is projected to increase by 2050 regardless of the emissions and socioeconomic development pathway (Figure 5.20). Although the percentage of climate migrants will increase, they will not make up more than 2.3 percent of the population by 2050. (Table 5.5)

Figure 5.20: Projected numbers of internal climate migrants in Mexico under three scenarios, 2020-50



Climate migrants as a percentage of the total population

Year	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
%	0.45	0.45	1.08	1.23	0.14	0.30	0.55	0.80	0.31	0.64	0.88	1.01

Note: Dark lines represent the average of all model runs for each scenario. White unshaded areas represent the highest and lowest model runs for that scenario. The large intervals partly reflect the fact that climate and sectoral models were selected to represent the widest possible range of outcomes.

Table 5.5: Projected number and share of internal climate migrants in Mexico under three scenarios, 2050

	Scenario					
Result	Pessimistic/ Reference		More inclusive development		More climate-friendly	
Number of internal climate migrants by 2050 (million)	**1.7**		**1.2**		**1.4**	
Minimum (left) and maximum (right) (million)	0.3	3.1	0.4	1.9	0.2	2.5
Internal climate migrants as percent of population	1.23%		0.80%		1.01%	
Minimum (left) and maximum (right)	0.20%	2.27%	0.28%	1.31%	0.11%	1.90%

Note: The scenarios are based on combinations of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). SSP2 = moderate development; SSP4 = unequal development; RCP2.6 = low emissions; RCP8.5 = high emissions.

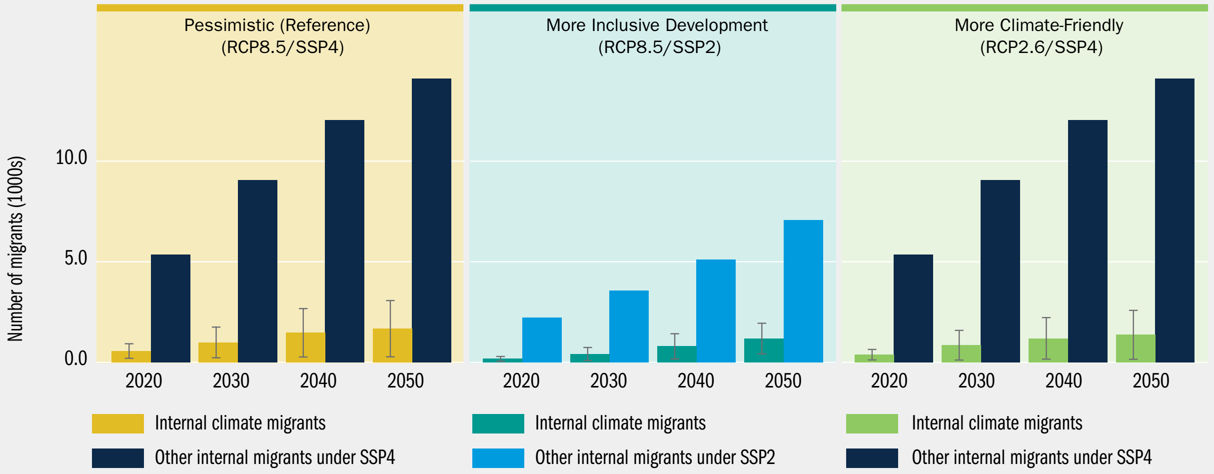
The largest numbers of climate migrants are in the pessimistic reference scenario, which projects that 1.7 million people (with a range of 0.3 million–3.1 million) are likely to move as a result of climate impacts (Table 5.5). This is followed by the more climate-friendly scenario which projects 1.4 million climate migrants (with a range of 0.2–2.5 million). The more inclusive development scenario with 1.2 million climate migrants (with a range of 0.4–1.9 million) has the lowest numbers.

Comparing the higher numbers of climate migrants in the pessimistic reference scenario with the lower numbers in the more inclusive development scenario, results suggest that in a middle-to-high income country like Mexico, development policies and targeted interventions that strengthen adaptive capacity play an important role in reducing climate migration. This is despite the higher population projections under the more inclusive development scenario.

The number of climate migrants under the more inclusive development scenario begins to trend upward, however, towards 2040, when more pronounced climate impacts start to set in. This suggests that development policy must also be accompanied by action on emissions reductions by Mexico and actors worldwide. This is particularly important given that the ISIMIP water and crop models project more widespread climate impacts in the second half of century.

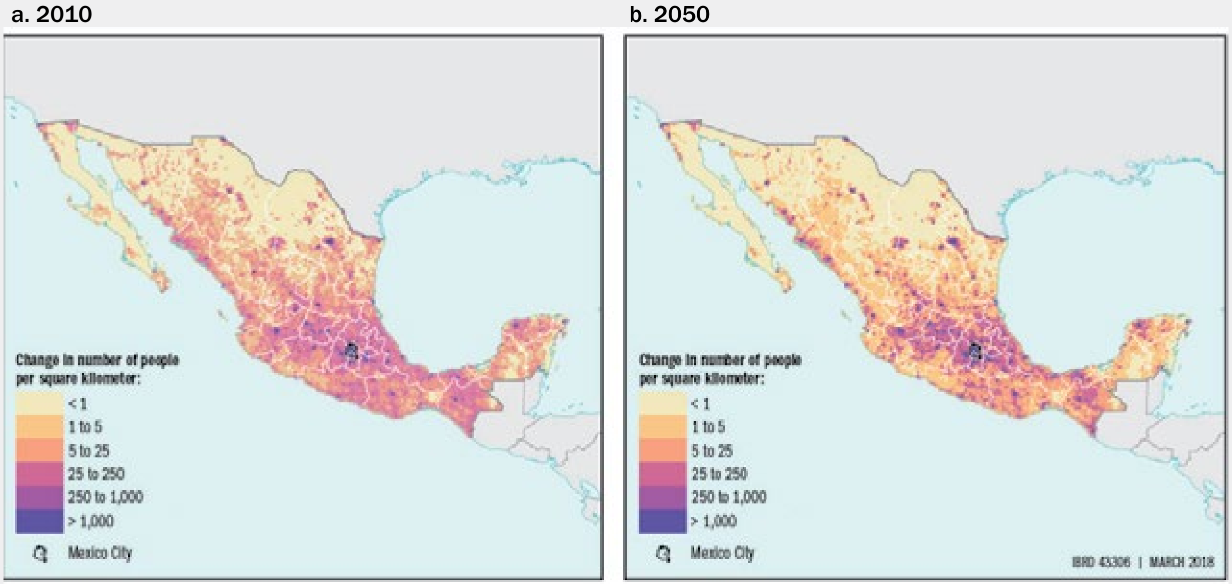
Climate migrants will represent an increasing share of internal migrants across all scenarios (Figure 5.21). This share will increase slightly in the pessimistic reference and more climate-friendly scenarios. These two scenarios share an unequal development pathway (SSP4), which drives a higher number of other internal migrants and results in a smaller share of climate migrants by 2050. In comparison, under the more inclusive development scenario, where the number of other internal migrants are lower, climate migrants represent a larger share of other internal migrants by 2050.

Figure 5.21: Projected number of climate and other internal migrants in Mexico under three scenarios, 2020–50



Note: The whiskers on the climate migrant bars represent the 95th percentile confidence interval for the four model runs that comprise each scenario. There are no confidence intervals for other migrants, because only a single development trajectory is used in each scenario (SSP2 or SSP4).

Figure 5.22: Baseline population density 2010, and projected population density under the pessimistic reference scenario 2050, Mexico

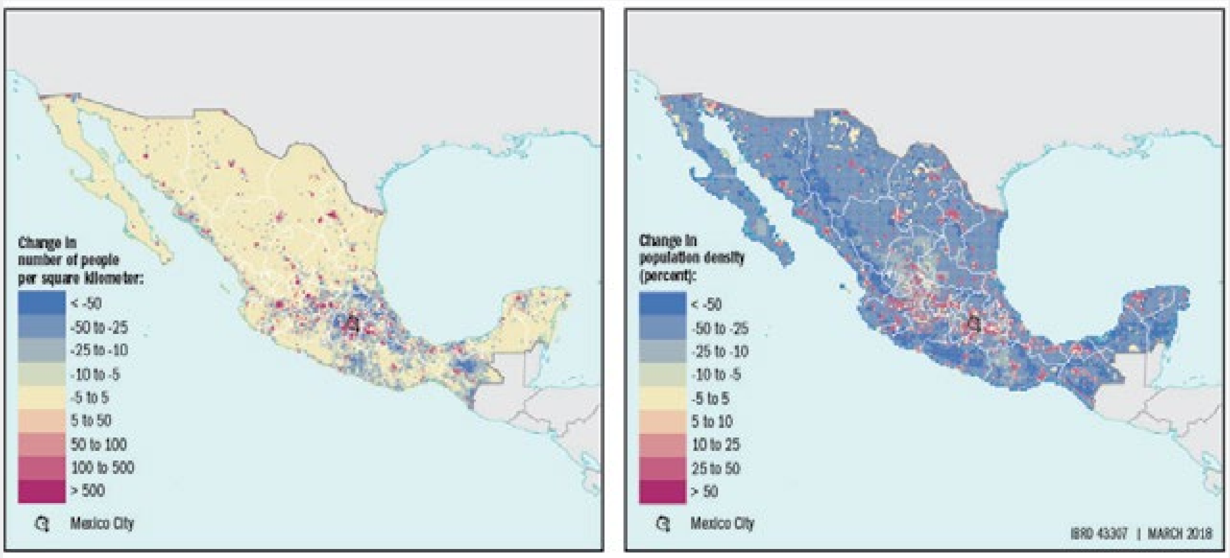


Projected spatial patterns of climate migration

The spatial distribution of population growth will vary widely across Mexico. Figure 5.22 displays the baseline (2010) population density and 2050 projected population density under the pessimistic reference scenario, while Figure 5.23 displays the change in population density over that time frame. These maps show highest growth and population densities in urban areas and widespread declines in population density in rural areas (the percentage changes appear high because of low baseline populations in many rural areas). The maps also underscore Mexico's ongoing urbanization story by showing urban growth in secondary or new urban areas around Mexico City. As people move from central cities to the surrounding suburban and peri-urban areas, they create new demand for housing, transportation, social services, and jobs. Depending on policies, they may also create new vulnerabilities (if, for example, settlement occurs on floodplains or on steep hills).

Projections show large climate in-migration hotspots in the central plateau near Mexico City and to the east of Puebla and scattered out-migration hotspots in the arid north and along the Gulf of Mexico (Figure 5.24). In-migration hotspots occur in the central plateau, where several of Mexico's largest cities are. Smaller hotspots are visible farther south, in Oaxaca State, and along the northern coast of Baja California just south of Tijuana. The map also shows some small out-migration hotspots scattered across the arid north of the country; the largest ones are concentrated on the coasts of the Gulf of Mexico, especially Veracruz and Tabasco States; in the southern state of Chiapas; and on the Pacific coast, especially in Guerrero State.

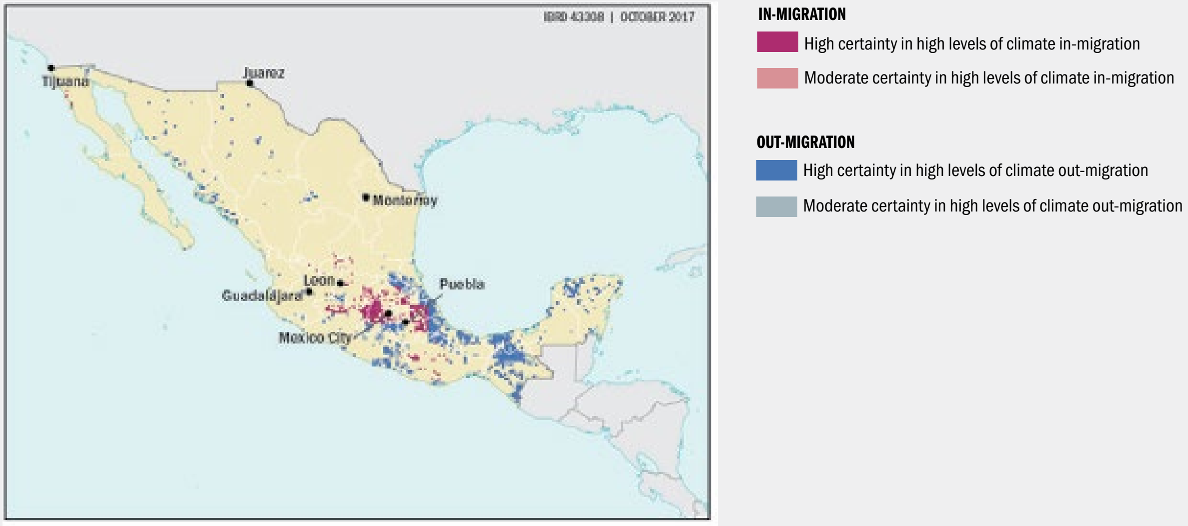
Figure 5.23: Absolute and percentage change in population density in Mexico under the pessimistic reference scenario, 2010-50



a. Change in population density

b. Percentage change in population density

Figure 5.24: Hotspots projected to have high levels of climate in-migration and climate out-migration in Mexico, 2030 and 2050



Note: High certainty reflects agreement across all three scenarios modeled, and moderate certainty reflects agreement across two scenarios. In- and out-migration hotspots are thus areas in which at least two scenarios concur on density changes in the top 10th percentile of the density distribution, which in Mexico and Central America represents an increased population density in 2050 of about 3.3 to 6.8 people per square kilometer, depending on the scenario. For decreased population density, it is about minus 1.8 to minus 3 people per square kilometer.

These findings are consistent with the current geography of domestic mobility in Mexico, including movements induced by climate change. Under future climate change scenarios, the central plateau around Mexico City will offer more favorable conditions for livelihoods and settlements than the arid north and low-lying states along the coast in the south and southeast. Low-lying coastal areas may also be prone to sea level rise, leading to out-migration. However, urban areas in the central plateau, Mexico City in particular, may face water shortage challenges if water management systems are not improved and prepared to accommodate increasing numbers of people (World Bank 2013a).

Climate migrants are projected to leave rural livelihoods in rainfed croplands and move to peri-urban or urban locations (Figure 5.25 and Figure 5.26). Magnitudes are small—generally no greater than plus or minus 300,000, or less than 0.2 percent of Mexico's 2050 population. Only in the case of rainfed croplands does the change approach three percent of the total population of the livelihood zone; in most zones, it is less than one percent. Trends and even changes in direction between periods need to be interpreted in this light, for example the declining trend occurring for dense settlements under the more inclusive development scenario in 2050.[36]

Rainfed cropland areas are likely to have the most climate out-migrants, mainly as a result of declining productivity in rainfall-dependent cropping areas (see Figure 5.26). The downward trend is more moderate for the more inclusive development scenario. Irrigated croplands display an upward trend, which is more pronounced for the more inclusive development scenario than in the more climate-friendly and pessimistic reference scenarios. Dense settlements enjoy net in-migration, with similar trends across scenarios up to 2040. In 2050, dense settlements continue to see net in-migration in the pessimistic reference and more climate-friendly scenarios but see net out-migration in the more inclusive development scenario as noted above. Likely related to the concentration of population on the dry central plateau, pastoral and rangeland areas also see net in-migration.

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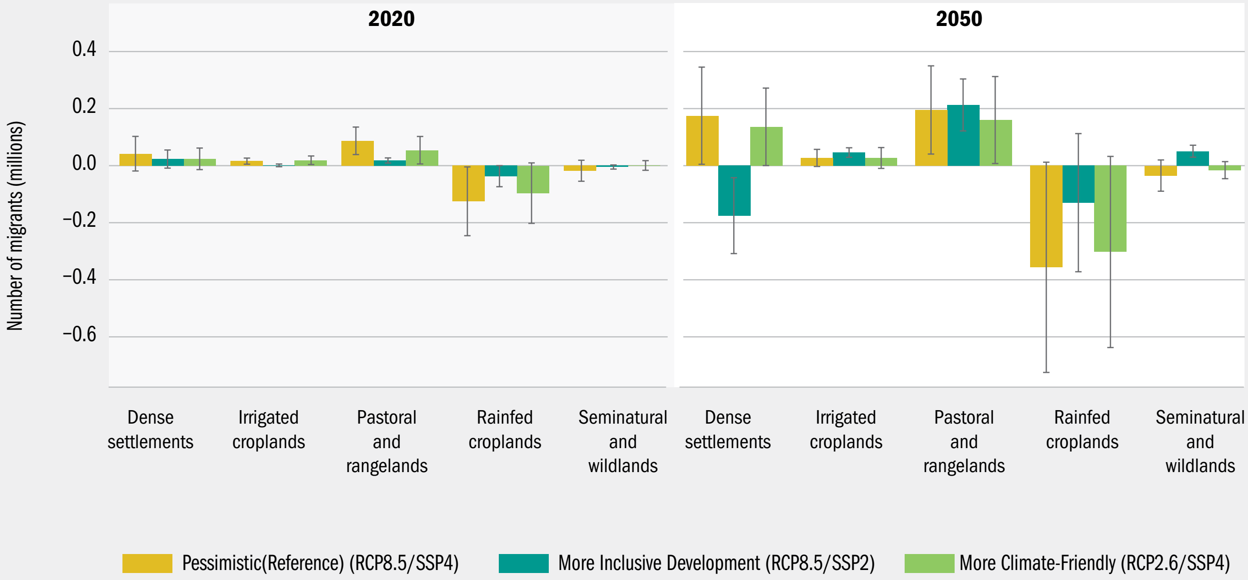
[36] This declining trend is associated with out-migration from Mexico City, a megalopolis of more than 20 million people. Even if all 200,000 climate migrants were to leave this city (an unlikely scenario), they would represent no more than one percent of the population.

Figure 5.25: Livelihood zones in Mexico, by anthropogenic biome, 2015

Source: Ellis and others (2010).

Figure 5.26: Projected net migration in and out of livelihood zones in Mexico under three scenarios, 2020–50



Note: Whiskers show 95th percent confidence intervals for climate migrants.

Results across crop and water models show that it is not solely water availability that drives crop yields but also increases in average and extreme temperatures, especially in low-lying (and therefore hotter) regions, such as coastal Mexico and especially the Yucatan. This finding is consistent with the agricultural pathway described by Feng, Krueger, and Oppenheimer (2010) and Nawrotzki and others (2015).

In-country consultations on modeling results

Consultations on the results in Mexico were held at both the national and local level in December 2017. This involved about 40 participants from academia, research, government, and community organizations. The consultations revealed a good level of awareness and strong research and analytics in the context of climate impacts and migration. Current attention on human movements relating to the environment was largely driven by extreme events and geophysical hazards, and in the context of cross-border movements. The participants welcomed the insights presented on the nexus between slow-onset climate change and internal migration. While some participants underscored the need for continued attention to displacements from extreme events in the near-term, others emphasized the need for anticipatory analysis to inform dialogue and decision support to manage the movements relating to slow-onset climate change for the medium to longer term. There was strong interest in more granular and customized modeling for Mexico.

Local level consultations in Oaxaca highlighted that presently socio-economic factors were perceived as the most important driver of out-migration, and climate change was not yet seen as a distinct contributor. The perception was that this was unlikely to change in the future. This observation aligns with the findings of this report, which shows this locality as a possible climate in-migration hotspot compared to movements away from the coast. The consultations also emphasized that communities were key players in managing migration through strong cultural and social ties, with remittances representing an important source of income support for many families.

In addition, the consultations noted a lag between research and policy; and called for stronger and more aligned policies on migration with action on the ground.

What do these results mean for Mexico's development future?

As an upper-middle-income country with a diversified and expanding economy, a predominantly urban population, and a large young population entering the labor force, Mexico has the potential to adapt to climate change, but needs to pay close attention to climate effects on pockets of poverty.

Mexico's economic growth and development have been erratic, with intermittent periods of strong growth and crisis (Loría and Salas 2014). Structural reforms and the North American Free Trade Agreement (NAFTA) helped shift the economy from overreliance on fossil fuel exports to a diversified economy with export-oriented manufacturing. The economy continues to perform well—despite relatively weak oil prices and escalating drug-related violence—thanks to strong domestic demand, low inflation, expansion of credit, and increasing international trade (Rivas 2016; OECD 2017).

The main sectors of the economy in 2016 were services (63 percent of GDP) and industry (33 percent), followed by agriculture (4 percent) (World Bank 2017b), with the composition differing substantially across states (INEGI 2012). As Mexico becomes a global manufacturing hub, the production of export goods is becoming highly concentrated in just a few cities (Sobrino 2016), adding to regional disparities.

Unemployment was at 3.9 percent in 2016 (World Bank 2017c). The country has a very large informal sector (54 percent of the nonagricultural workforce in 2013) (World Bank 2017c). The services sector is the largest employer (61 percent of total employment), followed by industry (25 percent) and agriculture (13 percent) (World Bank 2017c).

The main challenges include persistently high poverty rates and income inequality, low female labor force participation, lagging educational attainment (compared with other OECD countries), and pervasive financial exclusion (OECD 2017). As a result, income, wealth, social connections, education and skills, safety, and work-life balance are all affecting the average Mexican household (OECD 2017). The Human Development Index is higher in the capital and toward the north and lower in the southern states. Poverty rates are higher in rural areas, but the urban–rural poverty gap is narrowing because poverty rates have increased in urban areas (World Bank 2017b).

Adaptation efforts in Mexico have to pay close attention to these pockets of poverty. Stronger economies tend to have higher adaptive capacity and financial resources to target the most vulnerable areas and groups in a future with climate change, but they need to make use of them.

The rate of change of climate migration increases as the climate signal becomes stronger. How climate affects households' decision to move needs to be better understood and managed, alongside other types and drivers of migration.

The impacts of climate shocks on migration can be instantaneous or occur only after a delay. In their analysis of rural households' response to climate shocks, Nawrotzki and DeWaard (2016) find a time pattern in which the probabilities of migration are low immediately after a shock, increase to peak three years after the event, and then decline. This pattern suggests that adaptation in place may be behind this final decline and thus represents an important strategy, which has implications for policy interventions and planning.

Nawrotzki and others (2017) explore the impacts of climate shocks for adults 15–39 on four types of migration: rural to urban, rural to rural, urban to urban, and urban to rural. Their results reveal different timing, depending on the type of internal migration. Migration to rural destinations (rural to rural or urban to rural) shows a weak association with these shocks. In contrast, migration to urban destinations, particularly rural to urban migration, displays a strong and positive relationship with months of exposure to droughts and warm spells.

Findings for Mexico are in line with earlier literature indicating that climate variability can affect internal and international migration. Warmer temperatures and declining rainfall will have the greatest effects on rural populations, people heavily dependent on rainfed agriculture, people with low education, and domestic rural to urban and U.S.-bound migration flows (see Nawrotzki, Riosmena, and Hunter 2013; Nawrotzki and others 2015; Chort and Rupelle 2016; and Nawrotzki and others 2017). Jessoe, Manning, and Taylor (2017) project that internal out-migration from rural areas will increase by 0.67–1.4 percent (about 110,000–233,000 people) by 2075 in a medium-emissions scenario (depending on the climate model), with regional differences.[37] These forecasts are in line with the results of the modeling done for this report and support the overall conclusion that changes in water availability and crop yields affect mobility.

Climate migrants' share of the population is likely to increase to 0.8–1.2 percent by 2050, with movement out of rainfed croplands and low-lying coastal areas, especially in the south, to peri-urban or urban locations.

Projected spatial patterns of movement are in line with Mexico's high level of urbanization, the declining relevance of farming-only livelihoods, and the continuing depopulation of rural areas.

Internal mobility has contributed greatly to Mexico's changing population distribution. Between 1970 and 2015, the population concentrated in urban areas. Between-state mobility rates declined, and within-state rates intensified. Rural to urban flows are being replaced by intra-metropolitan mobility, and by mobility from the central downtown areas to the surrounding suburban and peri-urban areas (Figure 5.27). There was a decline in the number of municipalities in the "push" category over time, and there were changes in the status of several northern municipalities from areas of attraction (pull) to areas of expulsion (push). In addition to economic migration to Mexico's largest cities, there has also been growing internal migration to the country's coastal tourist centers, including Cancun, Los Cabos and Puerto Vallarta among others

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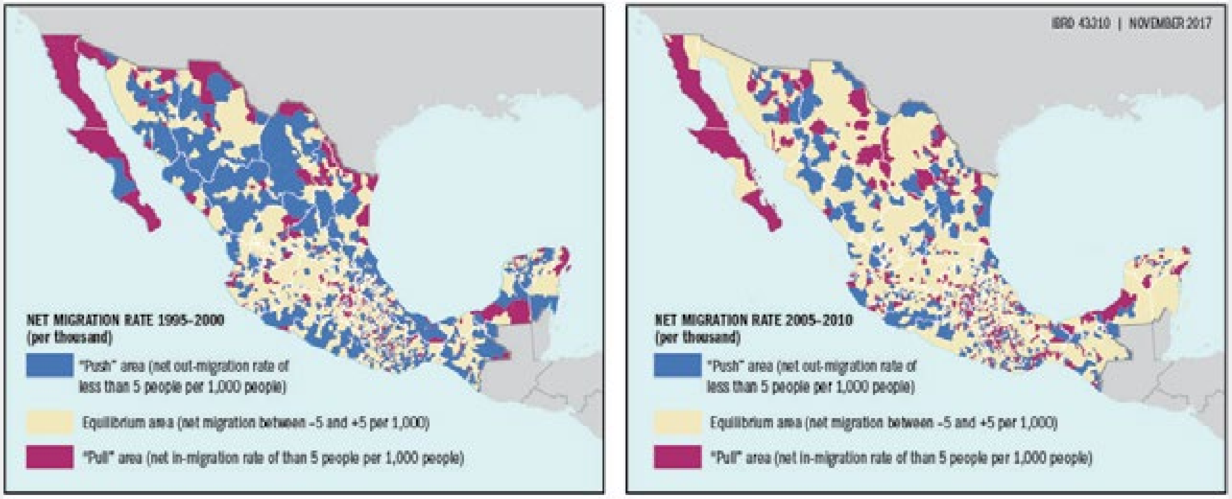
[37] Jessoe, Manning, and Taylor used two climate models (the Community Climate System Model 4 Community Earth System Model [CCSM4] and HadGEM2) and two emissions scenarios (medium [RCP 4.5] and high [RCP 6.0]).

(Aguayo-Téllez and Martínez-Navarro 2013; Gordillo and Plassot 2017; Romo Viramontes et al. 2013; Perez-Campuzano and Santos-Cerquera 2013). However, some of these coastal areas are vulnerable to extreme weather events. Los Cabos, for example, was severely impacted by Hurricane Odile in 2014 and Tropical Storm Lidia in 2017.

Figure 5.27: Net migration rates in Mexico, by municipality, 1995–2000 and 2005–10


a. 1995–2000

b. 2005–10

Source: Created by authors, based on data from Centro Latinoamericano de Demografia; cut off points for the categories are from Romo Viramontes, Tellez Vasquez, and Lopez Ramirez (2013).

Improvements in living conditions (education, job status, and income) and the diversification of labor markets in predominantly rural sending areas could lead to the decline of certain types of mobility (emigration flows) and the increase of others (urban commutes). Such improvements could also reduce the decline in the well-being gap between migrant and nonmigrant households (Jones 2014). For example, irrigation support for the production of Mexico's primary crop (corn [maize]) may reduce the odds of domestic migration from agriculture-dependent rural communities (Nawrotzki and others 2016).

As climate migration is unlikely to occur uniformly across rural livelihood zones, regional differences must be taken into account to strengthen adaptive capacity and avoid distress migration.

Agriculture, particularly corn production, is the economic activity most likely to be affected by climate change, putting farm owners, farm workers, and their families at risk (Ziervogel and others 2006; Smith and Olesen 2010; Hunter, Murray, and Riosmena 2013; World Bank 2014). Nationally, the share of Mexico's population that works in agriculture is low and declining. Some states—such as Chiapas and Oaxaca—have larger shares in agriculture. They also have higher rates of poverty, making them more vulnerable to climate impacts. Some analysts estimate that by 2050, climate change impacts could reduce the incomes of agricultural households by up to 15 percent, mainly through reductions in yields, especially in corn but also for barley (Calderón-García and others 2015) and coffee (Gay and others 2006). These populations are more likely to migrate in response to threats to their main income source.

Smallholders, self-employed farmers, and independent farmers tend to have higher poverty rates than the average rural residents (Galindo and others 2014), about 58 versus 37 percent in 2008 (Rodriguez and Meneses 2010) Poverty status varies greatly across rural households, depending on the degree of livelihood diversification, household structure, asset composition, and degree of local autonomous adaptation (through changes in land allocation, for example) (Skoufias, Rabassa, and Olivieri 2011).

Any analysis of the potential impacts of climate change on livelihoods and mobility needs to consider the possibility of “double exposure”—the interaction of climate risk with economic and political changes—which can amplify or reduce household vulnerability. Eakin (2005, page 1924) notes that “while adaptation is occurring and will occur spontaneously, the effectiveness of these adaptations for mitigating future sensitivity to climatic risk will be strongly influenced by the ways in which policy enables or inhibits households’ capacity to address climatic challenges.” Her case study of adaptive capacity (assets, capabilities, strategies, and their constraints) in three Tlaxcala communities during a period of agricultural reform uncovered multiple livelihood strategies, including subsistence corn production under land scarcity; crop diversification and livestock investment; irrigated vegetable production; and economic diversification into nonfarm activities, including giving up farming altogether and seasonal migration (see also Andersen and others 2016).

Several institutional and policy frameworks in Mexico can already accommodate the integration of climate migration.

Poverty reduction programs for rural areas can increase adaptive capacity to climate change in parallel with or as an alternative to mobility (Aksakal and Schmidt 2015). Those programs include the Fondo de Apoyo Rural para Contingencias Climatológicas (Rural Support Fund for Climatological Contingencies), which provides insurance against hydro-meteorological events (including droughts and floods) as well as early warning forecasts, targeting low-income producers; the cash-transfer program Oportunidades (Opportunities), a social protection program for the rural poor; and PROCAMPO, designed to support subsistence farmers. Some subprograms included in the Programa de Apoyos a Pequeños Productores (Support programs for Small Farmers) of the Secretary of Agriculture, Livestock, Rural Development, Fishing and Food (SAGARPA) outline actions to facilitate the permanence of young farmers in rural areas.

Going forward, climate migration could be explicitly referenced in policy instruments related to climate change (for example, the country’s Nationally Determined Contribution and the 2012 Climate Change Law), as well as other policies that may affect drivers of climate-related mobility, particularly rural to urban movements (Ochoa Lupián and Ayvar Campos 2015). Policy and planning instruments could outline actions aimed at reducing vulnerability and increasing resilience of populations, ecosystems, and infrastructure and prioritizing prevention rather than reconstruction (SEMARNAT-INEEC 2016). Examples include water management (Sanchez Cohen and others 2012) and climate change adaptation plans. Targeted interventions can build on ongoing adaptation efforts underway at the national and regional levels, through institutions such as the National Institute of Climate Change and Ecology, the National Water Commission (CONAGUA), and the Mexican Institute of Water Technology (IMTA). Future plans could harmonize agendas and policies on disaster management and prevention and on climate change. These plans could be articulated in existing programs, such as the Mesoamerica Integration and Development Project, which includes regional cooperation for risk management, adaptation, and mitigation.

REFERENCES

Adimassu, Z., A. Kessler, and L. Stroosnijder. 2014. "Farmers Strategies to Perceived Trends of Rainfall and Crop Productivity in the Central Rift Valley of Ethiopia." *Environmental Development* 11: 123–40.

Afifi, T., R. Govil, P. Sakdapolrak, and K. Warner. 2012. "Climate Change, Vulnerability and Human Mobility: Perspectives of Refugees from the East and Horn of Africa." Bonn: United Nations University, Institute for Environment and Human Security (UNU-EHS).

Aguayo-Téllez, Ernesto, and José Martínez-Navarro. 2013. "Internal and international migration in Mexico: 1995–2000." Applied Economics 45 (13):1647-1661. doi: 10.1080/00036846.2011.633894.

Aksakal, M., and K. Schmidt. 2015. "Migration and Social Protection as Adaptation in Response to Climate-Related Stressors: The Case of Zacatecas in Mexico." In *Environmental Change, Adaptation and Migration: Bringing in the Region*, ed. Felicitas Hillmann, Marie Pahl, Birte Raffenbeul, and Harald Sterly, 80–97. New York: Palgrave MacMillan.

Andersen, L. E., C. Breisinger, L. C. Jemio, D. Mason-D'Croz, C. Ringler, R. Robertson, D. Verner, and M. Wiebelt. 2016. "Climate Change Impacts and Household Resilience: Prospects for 2050 in Brazil, Mexico, and Peru." Washington, DC: International Food Policy Research Institute.

Andersson, C., A. Mekonnen, and J. Stage. 2011. "Impacts of the Productive Safety Net Program in Ethiopia on Livestock and Tree Holdings of Rural Households." *Journal of Development Economics* 94 (1): 119–126. doi:https://doi.org/10.1016/j.jdeveco.2009.12.002

Ayers, J. and T. Forsyth. 2009. "Community-Based Adaptation to Climate Change." *Environment: Science and Policy for Sustainable Development* 51 (4): 22–31.

Banerjee, P., S. Hazarika, M. Hussain, and R. Samaddar. 1999. "Indo-Bangladesh Cross-Border Migration and Trade." *Economic and Political Weekly* 34 (36): 2549–51.

Barnett, Jon, and Michael Webber. 2010. "Accommodating Migration to Promote Adaptation to Climate Change." Washington, DC: World Bank.

Berhane, G., D. O. Gilligan, J. Hoddinott, N. Kumar, and A. S. Taffesse. 2014. "Can Social Protection Work in Africa? The Impact of Ethiopia's Productive Safety Net Programme." *Economic Development & Cultural Change* 63 (1): 1–26.

Bewket, W., and D. Conway. 2007. "A Note on the Temporal and Spatial Variability of Rainfall in the Drought-Prone Amhara Region of Ethiopia." *International Journal of Climatology* 27 (11): 1467–77.

Bhatta, G. D., P. K. Aggarwal, S. Poudel, and D. A. Belgrave. 2015. "Climate-Induced Migration in South Asia: Migration Decisions and the Gender Dimensions of Adverse Climatic Events." *Journal of Rural & Community Development* 10 (4): 1–23.

Brecht, H., S. Dasgupta, B. Laplante, S. Murray, and D. Wheeler. 2012. "Sea-Level Rise and Storm Surges: High Stakes for a Small Number of Developing Countries." *Journal of Environment & Development* 21 (1): 120–38.

Brookings Institution, Georgetown University, and UNHCR (United Nations High Commissioner for Refugees). 2015. *Guidance on Protecting People from Disasters And Environmental Change through Planned Relocation*. http://www.unhcr.org/protection/environment/562f798d9/planned-relocation-guidance-october-2015.html.

Bryan, Elizabeth, Temesgen T. Deressa, Glwadys A. Gbetibouo, and Claudia Ringler. 2009. "Adaptation to Climate Change in Ethiopia and South Africa: Options and Constraints." *Environmental Science & Policy* 12 (4): 413–26.

Caesar, J., T. Janes, A. Lindsay, and B. Bhaskaran. 2015. "Temperature and Precipitation Projections over Bangladesh and the Upstream Ganges, Brahmaputra and Meghna Systems." *Environmental Science: Processes & Impacts* 17 (6): 1047–56. doi:10.1039/C4EM00650J.

Calderón-García, Joel O., Alejandro I. Monterroso-Rivas, and Jesús D. Gómez-Díaz. 2015. "Cambio climático en el centro de México: Impacto en la producción de cebada (hordeum vulgare) en Tlaxcala." *Ra Ximhai* 11 (5): 37–46. http://www.redalyc.org/pdf/461/46142593002.pdf.

Chindarkar, Namrata. 2012. "Gender and Climate Change–Induced Migration: Proposing a Framework for Analysis." *Environmental Research Letters* 7 (2): 25601.

Chort, Isabelle, and Maëlys De La Rupelle. 2016. "Determinants of Mexico–U.S. Outward and Return Migration Flows: A State-Level Panel Data Analysis." *Demography* 53 (5): 1453–76. doi:10.1007/s13524-016-0503-9.

Chowdhury, Iqbal Ahmed, Nadia Haque, Mohammad Mostufa Kamal, Tanjina Islam, Mohammad Maniruzzaman Khan, Mohammad Nazrul Islam, and Imtiaz Uddin. 2012. "Internal Migration and Socio-Economic Status of Migrants: A Study in Sylhet City, Bangladesh." *American Journal of Human Ecology* 1 (4): 123–33.

Christensen, J.H., K.K. Kanikicharla, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie, and T. Zhou. 2013. "Climate Phenomena and Their Relevance for Future Regional Climate Change." In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. T.F. Stocker D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge: Cambridge University Press.

Comenetz, Joshua, and César Caviedes. 2002. "Climate Variability, Political Crises, and Historical Population Displacements in Ethiopia." *Global Environmental Change Part B: Environmental Hazards* 4 (4): 113–27.

CONAPO (Consejo Nacional de Poblacion). 2015. *La situacion demografica de Mexico 2015*. Mexico City.

Cuaresma, J. C., W. Lutz, and W. Sanderson. 2014. "Is the Demographic Dividend an Education Dividend?" *Demography* 51 (1): 299–315. doi:10.1007/s13524-013-0245-x.

Dannecker, P. 2005. "Transnational Migration and the Transformation of Gender Relations: The Case of Bangladeshi Labour Migrants." *Current Sociology* 53 (4): 655–74.

Dasgupta, Susmita, Farhana Akhter Kamal, Zahirul Huque Khan, Sharifuzzaman Choudhury, and Ainun Nishat. 2014. "River Salinity and Climate Change: Evidence from Coastal Bangladesh." Policy Research Working Paper 6817, World Bank, Washington, DC.

Dasgupta, Susmita, M.D. Moqbul Hossain, Mainul Huq, and David Wheeler. 2016. "Facing the Hungry Tide: Climate Change, Livelihood Threats, and Household Responses in Coastal Bangladesh." *Climate Change Economics* 7 (3): 1650007.

Datta, Pranati. 2004. "Push-Pull Factors of Undocumented Migration from Bangladesh to West Bengal: A Perception Study." *Qualitative Report* 9 (2): 335–58.

Dearden, Lizzie. 2017. "Bangladesh Is Now the Single Biggest Country of Origin for Refugees on Boats as New Route to Europe Emerges." *The Independent*, May 5. http://www.independent.co.uk/news/world/europe/refugee-crisis-migrants-bangladesh-libya-italy-numbers-smuggling-dhaka-dubai-turkey-detained-a7713911.html. Accessed 20 May 2017.

Debela, B. L., G. Shively, and S. T. Holden. 2015. "Does Ethiopia's Productive Safety Net Program Improve Child Nutrition?" *Food Security* 7 (6): 1273–1289.

Debnath, Priyanka, and N. Selim. 2009. "Impact of Short Term Male Migration on Their Wives Left Behind: A Case Study of Bangladesh." In *Gender and Labour Migration in Asia*. Geneva: International Organization for Migration.

DECCMA (DEltas, vulnerability & Climate Change: Migration & Adaptation). 2017. *The Ganges Brahmaputra Meghna Delta: Understanding the Present State of Climate Change, Adaptation and Migration*. http://generic.wordpress.soton.ac.uk/deccma/wp-content/uploads/sites/181/2017/10/68439-A4-DECCMA-GBM_final_web.pdf?utm_content=buffera4c39&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer&t=1&cn=ZmxleGlibGVfcmVjc18y&refsrc=email&iid=28aa80ee4e1a47cbbb439ebc5c6dc136&uid=803549297207889920&nid=244+272699400.

Demeke, Abera Birhanu, and Manfred Zeller. 2012. "Weather Risk and Household Participation in off-Farm Activities in Rural Ethiopia." *Quarterly Journal of International Agriculture* 51 (1): 1–20.

de Sherbinin, A., M. Castro, F. Gemenne, M. M. Cernea, S. Adamo, P. M. Fearnside, G. Krieger, S. Lahmani, A. Oliver-Smith, A. Pankhurst, and T. Scudder. 2011. “Preparing for Resettlement Associated with Climate Change.” *Science* 334 (6055): 456–457. doi:10.1126/science.1208821.

Dessie, G., and J. Kleman. 2007. “Pattern and Magnitude of Deforestation in the South Central Rift Valley Region of Ethiopia.” *Mountain Research and Development* 27 (2): 162–68.

Diaz, Diana. 2017. “Hungry and Desperate, Thousands of Somalis trek to Ethiopia.” March 25, United Nations High Commissioner for Refugees, New York.

Eakin, H. 2005. “Institutional Change, Climate Risk, and Rural Vulnerability: Cases from Central Mexico.” *World Development* 33 (11): 1923–38. doi:http://dx.doi.org/10.1016/j.worlddev.2005.06.005.

El-Saharty, Sameh; Karar Zunaid Ahsan, and John F. May. 2014. “Harnessing the Demographic Dividend in Bangladesh.” Health, Nutrition and Population Global Practice Knowledge Brief, World Bank, Washington, DC. http://documents.worldbank.org/curated/en/667281468219893465/Harnessing-the-demographic-dividend-in-Bangladesh.

Ezra, Markos. 2003. “Environmental Vulnerability, Rural Poverty, and Migration in Ethiopia: A Contextual Analysis.” *Genus* 59 (2): 63–91.

Ezra, Markos, and Gebre-Egziabher Kiros. 2001. “Rural Out-Migration in the Drought Prone Areas of Ethiopia: A Multilevel Analysis.” *International Migration Review* 35 (3): 749–71.

FAO. 2013. Production Quantity of Rice, Paddy. FAOSTAT. Retrieved December 2, 2017 from http://www.fao.org/faostat/en/#rankings/countries_by_commodity

Farid, K.S., L. Mozumdar, M.S. Kabir, and K.B. Hossain. 2009. “Trends in International Migration and Remittance Flows: Case of Bangladesh.” *Journal of the Bangladesh Agricultural University* 7 (2): 387–94.

Feng, S., A.B. Krueger, and Oppenheimer, M., 2010. “Linkages among Climate Change, Crop Yields and Mexico–US Cross-Border Migration.” *Proceedings of the National Academy of Sciences* 107 (32): 14257–62.

Fransen, S., and K. Kuschminder. 2009. “Migration in Ethiopia: History, Current Trends and Future Prospects.” Migration and Development Country Profiles, Maastricht Graduate School of Governance, Maastricht, the Netherlands.

Funk, C. C., J. Rowland, G. Eilerts, E. Kebebe, N. Biru, L. White, and G. Galu. 2012. *A Climate Trend Analysis of Ethiopia.* Famine Early Warning Systems Network Informing Climate Change Adaptation Series, U.S. Geological Survey, Washington, DC.

Galindo, Luis Miguel, Joseluis Samaniego, Jose Eduardo Alatorre, Jimy Ferrer, and Orlando Reyes. 2014. “Cambio climático, agricultura y pobreza en América Latina. Una aproximación empírica.” Estudios del cambio climático en América Latina, United Nations Economic Commission for Latin America and the Caribbean, Santiago, Chile.

Gay, C., F. Estrada, C. Conde, H. Eakin, and L. Villers. 2006. “Potential Impacts of Climate Change on Agriculture: A Case of Study of Coffee Production in Veracruz, Mexico.” *Climatic Change* 79 (3): 259–88. doi:10.1007/s10584-006-9066-x.

Gebrehiwot, T., and A. van der Veen. 2013. “Farm Level Adaptation to Climate Change: The Case of Farmer’s in the Ethiopian Highlands.” *Environmental Management* 52 (1): 29–44. doi:10.1007/s00267-013-0039-3.

Gemenne, F. 2011. “Why the numbers don’t add up. A review of Estimates and Predictions of People Displaced by Environmental Changes.” *Global Environmental Change* 21: S41–S49.

Gibson, Mhairi A., and Eshetu Gurmu. 2012. “Rural to Urban Migration Is an Unforeseen Impact of Development Intervention in Ethiopia.” *PLoS One* 7 (11): e48708.

Gilligan, D. O., J. Hoddinott, and A. S. Taffesse. 2009. “The impact of Ethiopia’s Productive Safety Net Programme and Its linkages.” *Journal of Development Studies* 45 (10): 1684–706.

Ginnetti, J., and T. Franck. 2014. "Assessing Drought Displacement Risk for Kenyan, Ethiopian and Somali Pastoralists." Technical Paper, Internal Displacement Monitoring Centre, Geneva. http://www.internal-displacement.org/assets/publications/2014/201405-horn-of-africa-technical-report-en.pdf.

Government of Bangladesh. 2013. *National Sustainable Development Strategy*. Dhaka. http://www.plancomm.gov.bd/national-sustainable-development-strategy/.

———. 2015. *National Strategy on the Management of Disaster and Climate Induced Internal Displacement (NSMDCIID).* Dhaka. http://www.preventionweb.net/files/46732_nsmdciidfinalversion21sept2015withc.pdf.

Gordillo, Gustavo, and Thibaut Plassot. 2017. "Migraciones internas: un análisis espacio-temporal del periodo 1970-2015." Economía UNAM 14 (40):67-100. doi: http://dx.doi.org/10.1016/j.eunam.2017.01.003.

Gray, C., and V. Mueller. 2012. "Drought and Population Mobility in Rural Ethiopia." *World Development* 40 (1): 134–45.

Habib, A., M. Shahidullah, and D. Ahmed. 2012. "The Bangladesh Cyclone Preparedness Program: A Vital Component of the Nation's Multi-Hazard Early Warning System." In *Institutional Partnerships in Multi-Hazard Early Warning Systems*. Berlin: Springer.

Haider, S.K.U. 2010. "Factors of Migration on Urban Bangladesh: An Empirical Study of Poor Migrants in Rajshahi City." *Pakistan Journal of Social Sciences* 30 (2): 307–23.

Haileslassie, Amare, Joerg Priess, Edzo Veldkamp, Demil Teketay, and Jan Peter Lesschen. 2005. "Assessment of Soil Nutrient Depletion and Its Spatial Variability on Smallholders' Mixed Farming Systems in Ethiopia Using Partial versus Full Nutrient Balances." *Agriculture, Ecosystems & Environment* 108 (1): 1–16.

Headey, Derek, Alemayehu Seyoum Taffesse, and Liangzhi You. 2014. "Diversification and Development in Pastoralist Ethiopia." *World Development* 56: 200–213. doi:https://doi.org/10.1016/j.worlddev.2013.10.015.

Hermans-Neumann, K., J. Priess, and M. Herold. 2017. "Human Migration, Climate Variability, and Land Degradation: Hotspots of Socio-Ecological Pressure in Ethiopia." *Regional Environmental Change* 17 (5): 1479–92.

Hijioka, Y., E. Lin, J.J. Pereira, R.T. Corlett, X. Cui, G.E. Insarov, R.D. Lasco, E. Lindgren, and A. Surjan. 2014. "Asia." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. ed. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White. Cambridge: Cambridge University Press.

Hunter, Lori M., Sheena Murray, and Fernando Riosmena. 2013. "Rainfall Patterns and U.S. Migration from Rural Mexico." *International Migration Review* 47 (4): 874–909. doi:10.1111/imre.12051.

IDMC (Internal Displacement Monitoring Centre). 2015. *Global Estimates 2015: People Displaced by Disasters.* Geneva. http://www.internal-displacement.org/assets/library/Media/201507-globalEstimates-2015/20150713-global-estimates-2015-en-v1.pdf.

Immerzeel, W.W., L.P. Van Beek, and M.F. Bierkens. 2010. "Climate Change Will Affect the Asian Water Towers." *Science* 328 (5984): 1382–85.

INEGI (Instituto Nacional de Estadística y Geografía). 2009. *Estados Unidos Mexicanos. Censo agropecuario 2007, VIII censo agrícola, ganadero y forestal.* Aguascalientes, Mexico City: INEGI.

———. 2012. *SCNM: Sistema de cuentas nacionales de México: Producto interno bruto por entidad federativa 2007–2011: Año base 2003*. Mexico City: INEGI.

———. 2015. *Anuario estadístico y geográfico por entidad federativa 2015*. Mexico City: INEGI. http://internet.contenidos.inegi.org.mx/contenidos/productos//prod_serv/contenidos/espanol/bvinegi/productos/nueva_estruc/AEGPEF_2015/702825077297.pdf.

———. 2016. *Anuario estadístico y geográfico de los Estados Unidos Mexicanos 2016.* Mexico City: INEGI. http://www3.inegi.org.mx/sistemas/biblioteca/ficha.aspx?upc=702825087340.

IOM (International Organization for Migration). 2017. "GMDAC Migfacts: International Migration." https://gmdac.iom.int/gmdac-migfacts-international-migration.

Islam, Nazrul, Gustavo Angeles, A.Q.M. Mahbub, Peter Lance, and Nurul Islam Nazem. 2006. "Slums of Urban Bangladesh: Mapping and Census 2005." Center for Urban Studies, National Institute of Population Research and Training and MEASURE Evaluation, Dhaka, Bangladesh and Chapel-Hill, NC.

Jessoe, Katrina, Dale T. Manning, and J. Edward Taylor. 2017. "Climate Change and Labour Allocation in Rural Mexico: Evidence from Annual Fluctuations in Weather." *Economic Journal*. doi:10.1111/ecoj.12448.

Jones, R.C. 2014. "The Decline of International Migration as an Economic Force in Rural Areas: A Mexican Case Study." *International Migration Review* 48 (3): 728–61. doi:10.1111/imre.12085.

Jónsson, Gunvor. 2010. "The Environmental Factor in Migration Dynamics: A Review of African Case Studies." International Migration Institute, University of Oxford, Oxford, United Kingdom.

Kabir M.E., P. Davey, S. Serrao-Neumann, and M. Hossain. 2017. "Seasonal Drought Thresholds and Internal Migration for Adaptation: Lessons from Northern Bangladesh." In *Pathways to a Sustainable Economy*, ed. M. Hossain, R. Hales, and T. Sarker. Cham, Switzerland: Springer.

Kassie, B. T., H. Hengsdijk, R. Rotter, H. Kahiluoto, S. Asseng, and M. Van Ittersum. 2013. "Adapting to Climate Variability and Change: Experiences from Cereal-Based Farming in the Central Rift and Kobo Valleys, Ethiopia." *Environmental Management* 52 (5): 1115–31. doi:10.1007/s00267-013-0145-2.

Kassie, B.T., R.P. Rötter, H. Hengsdijk, S. Asseng, M. Van Ittersum, Helena Kahiluoto, and H. Van Keulen. 2014. "Climate Variability and Change in the Central Rift Valley of Ethiopia: Challenges for Rainfed Crop Production." *Journal of Agricultural Science* 152 (1): 58–74.

Loría, Eduardo, and Emmanuel Salas. 2014. "Ciclos, crecimiento economico, y crisis en Mexico 1980.1-2013.4." *Estudios Económicos* 29 (2): 131–61. http://www.jstor.org/stable/24368259.

Magrin, G.O., J.A. Marengo, J.-P. Boulanger, M.S. Buckeridge, E. Castellanos, G. Poveda, F.R. Scarano, and S. Vicuña. 2014. "Central and South America." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White, 1499–566. Cambridge: Cambridge University Press.

Marshall, R., and S. Rahman. 2013. *Internal Migration in Bangladesh: Character, Drivers and Policy Issues.* Bangladesh: United Nations Development Programme.

Mberu, Blessing. 2006. "Internal Migration and Household Living Conditions in Ethiopia." *Demographic Research* 14 (21): 500–40.

Mearns, R., and A. Norton. 2010. *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*. New Frontiers of Social Policy. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/2689 License: CC BY 3.0 IGO.

Minnick, Aaron, Tesfay Woldemariam, Chris Reij, Fred Stolle, Florence Landsberg and James Anderson. 2014. "Ethiopia Commits to Restore One-Sixth of its Land." Blog. World Resources Institute, Washington, DC. http://www.wri.org/blog/2014/10/ethiopia-commits-restore-one-sixth-its-land.

Moller, Lars Christian. 2015. *Ethiopia's Great Run: The Growth Acceleration and How to Pace It*. World Bank, Washington, DC.

Moniruzzaman, Shaikh. 2015. "Crop Choice as Climate Change Adaptation: Evidence from Bangladesh." *Ecological Economics* 118: 90–98. doi:https://doi.org/10.1016/j.ecolecon.2015.07.012.

Morrissey, J.W. 2013. "Understanding the Relationship between Environmental Change and Migration: The Development of an Effects Framework Based on the Case of Northern Ethiopia." *Global Environmental Change* 23 (6): 1501–10.

Muttarak, Raya, and Wolfgang Lutz. 2014. "Is Education a Key to Reducing Vulnerability to Natural Disasters and Hence Unavoidable Climate Change?" *Ecology and Society* 19 (1). doi:10.5751/ES-06476-190142.

Nava-Bolaños, Isalia, and Roberto Ham-Chande. 2016. "Demographic Dividends and Households Saving in Mexico." In *Demographic Dividends: Emerging Challenges and Policy Implications,* ed. R. Pace and R. Ham-Chande. Cham, Switzerland: Springer International Publishing.

Nawrotzki, R.J., and J. DeWaard. 2016. "Climate Shocks and the Timing of Migration from Mexico." *Population and Environment* 38 (1): 72–100. doi:10.1007/s11111-016-0255-x.

Nawrotzki, R.J., J. DeWaard, M. Bakhtsiyarava, and J. Trang Ha. 2017. "Climate Shocks and Rural-Urban Migration in Mexico: Exploring Nonlinearities and Thresholds." *Climatic Change* 140 (2): 243–58. doi:10.1007/s10584-016-1849-0.

Nawrotzki, R. J., F. Riosmena, and L.M. Hunter. 2013. "Do Rainfall Deficits Predict U.S.-Bound Migration from Rural Mexico? Evidence from the Mexican Census." *Population Research and Policy Review* 32 (1): 129–58. doi:10.1007/s11113-012-9251-8.

Nawrotzki, R.J., D.M. Runfola, L.M. Hunter, and F. Riosmena. 2016. "Domestic and International Climate Migration from Rural Mexico." *Human Ecology* 44 (6): 687–99. doi:10.1007/s10745-016-9859-0.

Nawrotzki, R.J., F. Riosmena, L.M. Hunter, and D.M. Runfola. 2015. "Amplification or Suppression: Social Networks and the Climate Change—Migration Association in Rural Mexico." *Global Environmental Change* 35: 463–74. doi:http://dx.doi.org/10.1016/j.gloenvcha.2015.09.002.

ND-GAIN. 2017. "Notre Dame Global Adaptation Index, Section Vulnerability, Data from 2015." South Bend, IN: University of Notre Dame. http://index.gain.org/ranking/vulnerability.

New Climate Economy. 2015. Unlocking the Power of Ethiopia's Cities: A report by Ethiopia's New Climate Economy Partnership. http://static.newclimateeconomy.report/wp-content/uploads/2015/03/Unlocking-the-Power-of-Cities-in-Ethiopia.pdf

Nguyen, Liem, Brenda S.A. Yeoh, and Mika Toyota. 2006. "Migration and the Well-Being of the 'Left Behind' in Asia: Key Themes and Trends." *Asian Population Studies* 2 (1): 37–44.

Ochoa Lupián, Luz Elena, and Francisco Javier Ayvar Campos. 2015. "Migración y cambio climático en México." *Revista CIMEXUS* 10 (1): 35–51.

OECD (Organisation for Economic Co-operation and Development). 2017. *OECD Economic Surveys: Mexico 2017 Overview.* http://www.oecd.org/eco/surveys/economic-survey-mexico.htm.

Oliver-Smith, A., and A. de Sherbinin. 2014. "Resettlement in the Twenty-First Century." *Forced Migration Review* 45: 23–25. http://www.fmreview.org/crisis/oliversmith-desherbinin.html.

Pender, James. 2008. "Community-Led Adaptation in Bangladesh." *Forced Migration Review* 31: 54–55. http://www.fmreview.org/sites/fmr/files/FMRdownloads/en/FMRpdfs/FMR31/54-55.pdf.

PÉREZ-CAMPUZANO, Enrique, and Clemencia SANTOS-CERQUERA. 2013. "Tendencias recientes de la migración interna en México." Papeles de Poblacion 19 (76):53-88.

Rahaman, O., and J. Sheikh. 2016. "A Geopolitical Understanding of Bangladeshi Migration and Refugee Issues in India: A Case Study of West Bengal." *Indian Journal of Regional Science* 48 (2): 160–63.

Rahman, A.K.M.F., and S. Rana. 2016. "Migration and Its Effect on Extreme Poor Households' Trajectories." Working Paper 32, SHIREE (Stimulating Household Improvements Resulting in Economic Empowerment), Dhaka, Bangladesh. http://www.shiree.org/wp-content/uploads/2012/02/32-Migration-and-its-effect-on-extreme-poorhouseholds-trajectories-JO-proof.pdf. Accessed on 23 July 2016.

Ringler, Claudia. 2010. "Climate Change and Hunger: Africa's Smallholder Farmers Struggle to Adapt." *EuroChoices* 9 (3): 16–21.

Rivas, J. C. 2016. "Mexico." In Estudio económico de América Latina y el Caribe 2016. La agenda 2030 para el desarrollo sostenible y los desafíos del financiamiento para el desarrollo. Santiago, Chile: Comisión Económica para América Latina y el Caribe (CEPAL).

Rodríguez, Adrián, and Javier Meneses. 2010. “Condiciones socioeconómicas y laborales de los hogares rurales en doces países de América Latina.” Paper presented at the 48th Congreso de la sociedad Brasileña de economía, administración y sociología rural, Campo Grande, Mexico.

Romero-Lankao, P., J.B. Smith, D.J. Davidson, N.S. Diffenbaugh, P.L. Kinney, P. Kirshen, P. Kovacs, and L. Villers Ruiz. 2014: North America. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1439-1498.

Romo Viramontes, Raul, Yolanda Tellez Vazquez, and Jorge Lopez Ramirez. 2013. “Tendencias de la migración interna en México en el periodo reciente.” In *La situacion demografica de Mexico 2013*, ed. Consejo Nacional de Poblacion, 83–106. Mexico City.

Sabates-Wheeler, Rachel, and Stephen Devereux. 2010. “Cash Transfers and High Food Prices: Explaining Outcomes on Ethiopia’s Productive Safety Net Programme.” *Food Policy* 35 (4): 274–85. DOI:https://doi.org/10.1016/j.foodpol.2010.01.00.

Saha, S.K. 2017. “Cyclone Aila, Livelihood Stress, and Migration: Empirical Evidence from Coastal Bangladesh.” *Disasters* 41 (3): 505–26.

Sanchez Cohen, Ignacio, Úrsula Oswald Spring, Gabriel Díaz Padilla, Julian Cerano Paredes, Marco A Inzunza Ibarra, Rutilo López López, and José Villanueva Díaz. 2013. “Forced Migration, Climate Change, Mitigation and Adaptive Policies in Mexico: Some Functional Relationships.” International Migration 51 (4). Blackwell Publishing Ltd: 53–72. doi:10.1111/j.1468-2435.2012.00743.x.

Sarker, J. R., M.R.U. Mian, S.S. 2012. “Farmers’ perception about causes and remedies of Monga in Hatibandha upazila of Lalmonirhat district.” *Journal of the Bangladesh Agricultural University* 10, no. 1 (2012): 107-118.

Selvaraju, Ramasamy, A. R. Subbiah, Stephan Baas, and Ingmar Juergens. 2006. *Livelihood Adaptation to Climate Variability and Change in Drought-Prone Areas of Bangladesh: Developing Institutions and Options*. Food and Agricultural Organization, Rome.

SEMARNAT (Secretaria del Medio Ambiente y Recursos Naturales). 2016. Informe de la Situación del Medio Ambiente en México. Compendio de Estadísticas Ambientales. Indicadores Clave, de Desempeño Ambiental y de Crecimiento Verde. Edición 2015. Seccion: Cambio Climatico Mexico DF, SEMARNAT.

SEMARNAT, and INECC (Secretaría del Medio Ambiente y Recursos Naturales and Instituto Nacional de Ecología y Cambio Climático). 2016. *Mexico’s Climate Change Mid-Century Strategy.* Mexico City: SEMARNAT and INECC.

Skoufias, Emmanuel, Mariano Rabassa, and Sergio Olivieri. 2011. *The Poverty Impacts of Climate Change.* World Bank, Economic Premise Poverty Reduction and Economic Management (PREM) Network, Washington, DC.

Smith, P., and J.E. Olesen. 2010. “Synergies between the Mitigation of, and Adaptation to, Climate Change in Agriculture.” *Journal of Agricultural Science* 148 (5): 543–52. doi: 10.1017/S0021859610000341.

Stojanov, R., B. Duží, I. Kelman, D. Němec, and D. Procházka. 2016. “Local Perceptions of Climate Change Impacts and Migration Patterns in Malé, Maldives.” *Geographical Journal* 183 (4): 370–85.

Thomas, Timothy S., Khandaker Mainuddin, Catherine Chiang, Aminur Rahman, Anwarul Haque, Nazria Islam, Saad Quasem, and Yan Sun. 2013. *Agriculture and Adaptation in Bangladesh: Current and Projected Impacts of Climate Change,* vol. 1281. International Food Policy Research Institute, Washington, DC.

UNDESA (United Nations Department of Economic and Social Affairs). 2014. *World Urbanization Prospects*. https://esa.un.org/unpd/wup/DataQuery/.

———. 2015. "World Population Prospects: The 2015 Revision, Key Findings and Advance Tables." Working Paper ESA/P/WP.241. New York.

———.2017. World Population Prospects: The 2017 Revision. New York.

United Nations University. 2016. *World Risk Report 2016*. http://weltrisikobericht.de/wp-content/uploads/2016/08/WorldRiskReport2016.pdf

Walter, P. 2015. "Floods and Urban-Rural Migration in Bangladesh." In *The State of Environmental Migration 2015*. Geneva: International Organization for Migration.

Wassmann, R., Jagadish, S. V. K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A. Serraj, E. Redona, R.K. Singh, and S. Heuer. 2009. "Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for adaptation." *Advances in Agronomy* 102: 91–133.

Whitehead, P.G., E. Barbour, M.N. Futter, S. Sarkar, H. Rodda, J. Caesar, D. Butterfield, L. Jin, R. Sinha R. Nicholls, and M. Salehin. 2015. "Impacts of Climate Change and Socio-Economic Scenarios on Flow and Water Quality of the Ganges, Brahmaputra and Meghna (GBM) River Systems: Low Flow and Flood Statistics." *Environmental Science: Processes & Impacts* 17 (6). 1057–69. doi:10.1039/C4EM00619D.

WHO (World Health Organization). 2017. *Ethiopia: WHO Statistical Profile*. http://www.who.int/gho/countries/eth.pdf?ua=1. Accessed May 26, 2017.

Wiseman, William, Julie Van Domelen, and Sarah Coll-Black. 2010. *Designing and Implementing a Rural Safety Net in a Low Income Setting: Lessons learned from Ethiopia's Productive Safety Net Program 2005–2009*. World Bank, Washington, DC.

Woodhead, M., J. Rossiter, A. Dawes, and A. Pankhurst. 2017. "Scaling-up Early Learning as a Sustainable Development Priority: A Case Study of Ethiopia." In *The SAGE Handbook of Early Childhood Policy*, ed. L. Miller, C. Cameron, C. Dalli, and N. Barbour. Thousand Oaks, CA: Sage Publications.

World Bank. 2013a. "*Mexico*: Agua urbana en el Valle de Mexico: un camino verde para mañana?" Washington, DC. http://documentos.bancomundial.org/curated/es/295391468049168354/Mexico-Agua-urbana-en-el-Valle-de-Mexico-un-camino-verde-para-ma-241-ana.

———. 2013b. *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*. Washington, DC.

———. 2014. *Turn Down the Heat: Confronting the New Climate Normal*. Washington, DC. https://openknowledge.worldbank.org/handle/10986/20595.

———. 2016. *Bangladesh Development Update: Sustained Development Progress*. Washington, DC.

———. 2017a. *Pacific Possible: Long-Term Economic Opportunities and Challenges for Pacific Island Countries.* Washington, DC. https://openknowledge.worldbank.org/bitstream/handle/10986/28135/ACS22308-PUBLIC-P154324-ADD-SERIES-PPFullReportFINALscreen.pdf?sequence=1&isAllowed=y.

———. 2017b. *World Development Indicators*. Washington, DC. https://data.worldbank.org/country.

Yang, Y.C. Ethan, Sungwook Wi, Patrick A. Ray, Casey M. Brown, and Abedalrazq F. Khalil. 2016. "The Future Nexus of the Brahmaputra River Basin: Climate, Water, Energy and Food Trajectories." *Global Environmental Change* 37: 16–30. doi:https://doi.org/10.1016/j.gloenvcha.2016.01.002.

Yu, W., M. Alam, A. Hassan, A.S. Khan, A. Ruane, C. Rosenzweig, D. Major, and J. Thurlow. 2010. *Climate Change Risks and Food Security in Bangladesh.* London: Routledge.

Ziervogel, Gina, Anthony Nyong, Balgis Osman, Cecilia Conde, Sergio Cortes, and Tom Downing. 2006. "Climate Variability and Change: Implications for Household Food Security." AIACC Working Paper 20, Assessments of Impacts and Adaptations to Climate Change, Washington, DC.

Chapter 6

Managing the Growing Reality of Internal Climate Migration

Using a novel scenario-based approach, this report shows that slow-onset climate change is becoming a potent driver of internal climate migration. Beyond the scale and trajectory of climate migration within countries, the analysis reveals that migration patterns are not uniform—some areas and livelihoods are more adversely impacted than others. While some climate migration cannot be avoided due to the lock-in of climate effects of past emissions, the results also indicate that future trajectories of climate migration are not set in stone.

In other words, internal climate migration will be a reality, but it does not have to become a crisis, if concerted and targeted action is taken now to better predict and prepare for its likely effects and to harness its potential as an adaptation strategy. Importantly, policy decisions made today will shape the extent to which the effects of climate change will be positive for migrants and their families, sending and receiving communities, and for equitable national economic growth. Inaction would mean missing a vital opportunity to reconfigure where, when, and how climate-resilient investments are made in support of robust economies.

As noted in previous chapters, the report's main findings include the following:

- **The scale of internal climate migration could be substantial but good development policies together with action on climate change mitigation and adaptation could reduce these numbers.** By 2050, up to 143.3 million people or 2.8 percent of the population of Sub-Saharan Africa, South Asia and Latin America could be internal climate migrants under the pessimistic reference scenario. The number of climate migrants is projected to reach a high of 85.7 million in Sub-Saharan Africa, 40.5 million in South Asia, and 17.1 million in Latin America by 2050. In the more inclusive development scenario, internal climate migration could drop to between 65.1 million and 105.3 million across the three regions. The largest declines would occur in Sub-Saharan Africa and South Asia, with smaller declines in Latin America. The more climate-friendly scenario projects the fewest internal climate migrants, ranging from 31.2 to 71.7 million and implying reductions of up to 80 percent of the pessimistic reference scenario. These results represent lower-bound estimates of the likely overall impact of climate change on migration. As noted earlier in the report, the analysis is limited to climate-induced migration within countries in three regions and has a focus on slow-onset climate impacts (water availability, crop productivity, and sea level rise) rather than on rapid-onset events such as floods and hurricanes. The analysis done in this report could be extended to cover other countries and other regions.

- **The poorest and most climate-vulnerable regions of Sub-Saharan Africa and South Asia will be hardest hit.** Sub-Saharan Africa is projected to have the largest numbers of internal climate migrants: ranging from 56.6 to 85.7 million in the pessimistic reference scenario by 2050. This represents an average of 3.5 percent of the region's total population, which is more than twice the proportion of the other two regions. Two factors may be driving this. First, Sub-Saharan Africa is highly vulnerable to climate impacts, especially in already fragile drylands and along exposed coastlines. Second, the region's agriculture, which employs a significant portion of the labor force, depends on rainfall for almost all its crop production. South Asia is projected to have between 30.9 to 40.5 million internal climate migrants by 2050 under the pessimistic reference scenario. This is 1.6 percent of the region's total population in 2050. Bangladesh, which is very densely populated and highly exposed to climate risks, accounts for almost one-third of the region's total climate migrants. In Latin America by 2050, the pessimistic reference scenario projects between 4.3 to 17.1 million internal climate migrants, or an average of 1.6 percent of the region's total population. These lower numbers may reflect generally stronger economies in the region with higher adaptive capacity and less reliance on climate sensitive sectors, with some exceptions in the low-income countries in Central America.

- **Climate in- and out-migration hotspots emerge by 2030, and by 2050, the scenarios increasingly converge on their growing number, intensity, and spatial extent.** Climate out-migration will occur in areas where livelihood systems are increasingly compromised by climate impacts, while in-migration will occur in areas with better livelihood opportunities. The geographic distribution of climate in- and out-migration hotspots will vary widely across the three regions. Climate out-migration hotspots across the three regions will include low-lying cities, coastlines vulnerable to sea level rise, and areas of high water and agriculture stress. Even with expected out-migration, many climate-vulnerable areas will continue to support significant numbers of people. Climate in-migration hotspots emerge in locations with better climatic conditions for agriculture as well as cities able to provide better livelihood opportunities. Major cities in all three regions may become hotspots of climate in-migration. Declining crop productivity, coupled with existing rural to urban migration pathways, means a high likelihood of movement toward non-climate-related sources of income and cities. Some of the large urban and coastal cities (e.g. Addis Ababa, Dhaka) will need to balance climate out-migration against broader trends of population growth through longer-term planning and investments in adaptive capacity to secure resilience in the face of climate impacts. Climate in- and out-migration projections do not consider technological advances or adaption and development responses that might allow cities or rural areas to sustain larger populations.

Looking ahead, there are several takeaways policy makers should heed to better plan and prepare for future climate migration.

MIGRATION CAN BE A SENSIBLE CLIMATE CHANGE ADAPTATION STRATEGY IF MANAGED CAREFULLY AND SUPPORTED BY GOOD DEVELOPMENT POLICIES AND TARGETED INVESTMENTS.

While development strategies can support people to adapt locally in areas where it makes sense to do so, adaptation "in place" has its limits. Where there is no credible long-term pathway to viable livelihoods, there is a risk that people will be induced to remain in places where conditions are deteriorating (McAdam and Saul 2010). For example, about 20 million people in coastal Bangladesh are already having their health affected from saltwater intrusion in drinking water supplies related to sea level rise. Remittances from family members working elsewhere can induce people to stay, possibly against their long-term best interests. Without appropriate policy interventions, perverse incentives to stay in place could undermine community health and well-being (McKenzie and Yang 2014; McLeman 2016b; Waldinger 2015). To avoid trapping people in increasingly unviable areas, opportunities should be identified for a transition out of climate-sensitive areas and sectors, for example by pursuing livelihood diversification outside places of origin, through skills training and other education.

Migration as an adaptation strategy can be a pathway out of poverty (Adger and others 2014; Elllis 2003). Under certain circumstances, voluntary migration can be a desirable form of adaptation, not a reflection of failure to adapt (McLeman and Smit 2006; Black and others 2011b; Tacoli 2011). However, migration must be addressed holistically and embedded in development policies and planning through inclusive and participatory approaches. Strengthening adaptive capacities and increasing readiness in the face of climate change (Warner 2010), can create an enabling environment for positive migration.

Climate migration demands development policies that respond to the scale of the issue over the medium to long term. Incremental, low-regrets measures only may not be sufficient to counter the magnitude of climate impacts. Sequences of flexible incremental adaptation should be explored alongside more transformational adaptation, which include measures that are taken at a much larger scale or intensity, those that are new to a particular region or resource system, and those that transform places and shift locations (Kates and others 2012; Park and others 2012; Rickards and Howden 2012), to secure resilience over longer time-scales.

In some cases, an economic transition toward sectors that are less sensitive to climate change need to be part of the longer-term solution. These shifts can provide alternative job opportunities for climate migrants and growing populations and help strengthen the resilience of economies. For example, Bangladesh's shift to manufacturing is absorbing some migrants into less climate-sensitive sectors, but the country needs to ensure that these migrants are not disadvantaged. Mexico is an upper middle-income country with a diversified and expanding economy that is relatively less climate-sensitive, though attention needs to be paid to pockets of poverty, and vulnerable coastal areas. To support such shifts, countries can provide training to potential migrants, identify destination labor markets, and support integration (ADB 2012).

Good management of demographic transitions and investment in human capital can also reduce climate vulnerability. Reduced mortality and fertility rates translate into smaller, young and dependent populations and larger, working-age populations. This "demographic dividend" can boost the economy (Bloom and others 2003; IMF 2006). For example, both Bangladesh and Mexico may have the opportunity to benefit from demographic dividends and gains in educational attainment. Advances in education, especially for girls, can help reduce vulnerability to climate risks, as educated individuals are more empowered and adaptive in their response to, preparation for, and recovery from such risks. But to tap the dividend, demographic transitions need to be accompanied by policies to absorb larger working-age populations into productive and climate-resilient labor markets—and to ensure that they have good access to health care, employment, and education (PRB 2012). For example, countries such as Ethiopia, which could see a population increase of up to 85 percent by 2050 and experience lower agricultural productivity due to climate change, will need to absorb labor and a large youth bulge into non-agricultural and less climate-sensitive sectors. Good management of migration, driven by climate change over longer time scales, can produce positive momentum for such shifts.

Targeted interventions can be deployed in the short and medium term to support migrants. Some good practices stand out from development projects and programs:

- *Facilitating informed migration decisions.* Migration choices are based partly on perceptions of vulnerability and opportunities, which are often based on scant information (Koubi and others 2016; Zickgraf and others 2016). Migrants sometimes overestimate the benefits of moving (Munshi 2003; Bryan, Chowdhury, and Mobarak 2012). Without material resources, information, and contacts, they may move, not to the most suitable next habitat, but to the most accessible one (Waldinger 2015). Policies that provide pre-departure orientation, increase migrants' financial literacy, and secure their legal status, and access to financial resources can ease migrants' adjustment to host areas, protect them from abuse, and improve financial decision making by migrants and the families they leave behind (McKenzie and Yang 2014; Waldinger 2015). World Bank projects such as the China Rural Migrant Skills Development and Employment Project have tailored interventions to both rural and urban areas to help address migrants' needs in both sending and receiving areas by providing skills training, information, and legal support.

- *Making social protection portable and scalable*. Lack of portability in safety nets can tie poor people to places that no longer support their livelihoods (Holzmann, Koettl, and Chernetsky 2005; Kuriakose and others 2013; Gentilini 2015). Strategies to increase the portability of social protection benefits and programs include: (i) establishing program offices in major urban centers where migrants can register on arrival; (ii) ensuring channels for information, including on how to remain in a program and where registration offices are; (iii) making it easier to access benefits, by using mobile money, biometric verification of beneficiaries, and real-time online monitoring; and (iv) building social welfare systems that can be scaled up or down in response to changing needs. Examples include the Bolsa Familia program in Brazil; and the World Bank's Third Northern Uganda Social Action Fund, and China Guangdong Social Security Integration and Rural Worker Project (Gentilini and Omamo 2011).

- *Tapping the potential of financial and social remittances*. Migration and remittances tend to increase in response to climate shocks; both may support coping (Wodon and Blankespoor 2014). Research shows that remittances have the capacity to protect people from income shocks and lifecycle risks, increase household income, and improve living conditions (de Haas 2010). Remittances tend to be more stable than other private capital flows during crises (Kapur 2004). Facilitating remittance flows through institutional frameworks that foster cheaper, faster, more stable, and secure channels can increase their value (de Haas 2010). Linking migrants to their areas of origin—by, for example, easing the transfer of remittances at the sending end and facilitating financial literacy at the receiving end—can improve disaster recovery and to some extent preparedness and adaptation (Mohapatra, Joseph, and Ratha 2009; Joseph, Wodon, and Blankespoor 2014; Manandhar 2016; Banerjee and others 2017). Meanwhile, remittances can also create inequalities within a community and destabilize local markets, and in other cases create perverse incentives to stay in place in increasingly climate-vulnerable areas. Remittances cannot replace sound development, but policy interventions can help maximize their potential. In addition to lowering transactions fees, efforts include facilitating disaster relief from diasporas, and facilitating investments through remittances (Zickgraf and Gemenne 2017). When social remittances enter receiving communities through local social networks and interactions, as they do in Mexico for example, they also benefit people who are not direct beneficiaries of financial remittances (Cascone and others 2016).

INTERNAL CLIMATE MIGRATION MAY BE A REALITY, BUT IT DOESN'T HAVE TO BE A CRISIS. ACTION ACROSS THREE MAJOR AREAS COULD HELP REDUCE THE NUMBER OF PEOPLE BEING FORCED TO MOVE IN DISTRESS.

Countries will be locked into a certain level of climate migration—but these trajectories are not set in stone. Even at current level of warming, countries will be locked into a certain level of internal climate migration. Climate migration patterns will play out differently both within and across countries. The distribution of climate migrants between hotspots of climate in- and out-migration depends on each country's climate vulnerability and development context. Early action on good development policy alongside global action on emissions towards the Paris targets could help counter the upward trend and reduce the overall scale of climate migration. The window of opportunity is still open to plan and act before climate change impacts are expected to worsen—perhaps irretrievably—after 2050.

The consequences of inaction are ominous. Without early and concerted action, the results of this report indicate that the upward trend of climate migration ramps up across all regions, for all scenarios. The 2016 World Bank *Shock Waves* report found that climate conditions or climate events can be the impetus that pushes households into poverty through price shocks linked to lower agricultural production; natural disasters that destroy poor people's assets; and health shocks influenced by climate and environmental conditions (Hallegatte and others 2016). These consequences, compounded with slow-onset climate impacts, could greatly diminish options for adapting in place and migrating under favorable conditions, while increasing climate migration under distress.

PURSUING EARLY AND CONCERTED ACTION IN THREE AREAS IS KEY.

Cut global greenhouse gas emissions now

Rapid reductions in global emissions can reduce the pressures on people's lives and livelihoods, the scale of climate migration, and movements under distress. Lower global emissions reduce climate pressure on ecosystems and livelihoods and broaden the opportunities for people to stay in place or move under better circumstances. In the more climate-friendly scenario, the number of internal climate migrants could be reduced by as much as 80 percent by 2050 across the regions of focus. Stringent global climate action would be needed to adhere to the Paris Agreement and limit future temperature increases to less than 2°C by the end of this century, close to the more climate-friendly scenario in this report.

There is a window of opportunity for the global community to adjust and amplify mitigation measures before the climate signal is likely to worsen beyond 2050, putting increasing pressure on livelihoods and escalating the scale of climate migration. In the latter half of the century, water and crop sectoral models suggest much stronger climate impacts for some sectors and regions. However, even with the best mitigation measures, there is a lock-in of climate change impacts from past and predicted emissions (World Bank 2013), leading to pressures on livelihoods and driving climate migration that cannot be ignored.

Embed climate migration in development planning

Climate migration is currently inadequately built into policies and long-term planning (Martin 2009; Leighton, Shen, and Warner 2011; Martin 2012; Warner and others 2014; Warner and others 2015). In most regions, laws, policies, and strategies for dealing with human movements from increasing climate risks and enabling positive development outcomes are weak or absent (Nansen Initiative 2015). A "sedentary" bias overemphasizes development and adaptation in place and frames internal migration as negative, even though households regularly use it to cope with and adapt to climate change (Bakewell 2008, Agrawal and Perrin 2009, Ober 2014). The lack of frameworks for planned relocation as a measure of last resort is worrisome (Brookings Institution, Georgetown University, and UNHCR 2015; Georgetown University, UNHCR, and IOM 2017). Governments will require guidance, technical assistance, and capacity building on implementing international frameworks, laws, policies, and strategies relating to climate migration (Leighton, Shen, and Warner 2011; Melde, Laczko, and Gemenne 2017).

Given the possible acceleration of climate migration trends and the closing window of opportunity, long-term planning is imperative. National development planning provides a chance to integrate climate migration issues systematically beyond five-year cycles. Nationally Determined Contributions under the Paris Agreement as well as National Adaptation Plans and National Adaptation Programs of Action are also key instruments. Longer-term planning with an eye toward transformative end-points are vital in setting countries on pathways that mitigate or adapt to climate risks and reduce poverty. For example, Ethiopia's Growth and Transformation Plan and the Climate Resilient Green Economy has set targets for diminishing the weight of agriculture from 42 percent to 29 percent of GDP through a shift from agricultural jobs to services and industry, aiming to make livelihoods less climate-dependent. Bangladesh's Perspective Plan for 2041 factors in climate change as a driver of future migration and recognizes migration as a potential adaptation option for people living in the most vulnerable areas.

National agencies need to integrate climate migration into all facets of policy. The scale of projected climate impacts will also require substantial improvement of frameworks and organizational capacities, especially climate change adaptation and disaster risk reduction. For example, Nepal's draft Climate Migration and Strategy Plan proposes an interagency steering committee that would help all key ministries address climate migration (Government of Nepal, ICIMOD 2017).

Development frameworks will need to consider migration along each phase of its life cycle (before, during, and after moving) (Figure 6.1). Securing resilience means:

a. ***Adapt in place—help communities stay in place where local adaptation options are viable and sensible,*** in order to prevent distress migration or displacement, while continuing to look at the viability of landscapes and livelihoods over time. Components of successful local adaptation include: investing in climate-smart infrastructure, diversifying income-generating activities, building more responsive financial protection systems for vulnerable groups, and educating and empowering women. Local adaptation also requires strengthening safety nets for people remaining in traditional agriculture (Hallegatte and others 2016). Sustainable land management can help communities stay in place by expanding options for local adaptation and improving the flow of remittances.

b. ***Enable mobility—for people who need to move away from unavoidable climate risks,*** by facilitating safe, orderly, and dignified migration (or, as a last resort, planned relocation) toward areas of lower risk and higher opportunity that will not be maladaptive. Adaptation in place should never be an end in itself (McAdam and Saul 2010), and when the limits of local adaptation are expected to be reached, orderly migration can be a path to successful adaptation (Adger and others 2014). Countries need to create enabling environments for migration and create incentives in a sequenced, sensitive, and inclusive manner to areas of low risk and high opportunity. They can also start creating "pulls" in other locations, instead of waiting for "pushes" to materialize. Policies should also be careful not to constrain individuals who would benefit from moving from doing so, by creating bureaucratic, financial, informational, or other constraints (McKenzie and Yang 2014).

Photo Credit: World Bank

c. ***After migration—ensure that sending and receiving areas, and their people, are well connected and adequately prepared***, including in terms of numbers of inhabitants, the security of livelihoods, and provision of infrastructure and basic services. Many urban and peri-urban areas in particular will need to prepare for an influx of people, including through improved housing and transportation infrastructure, social services, and employment opportunities. These urban areas will need to ensure that climate migrants live in adequate housing, in safe circumstances, and prevent discrimination in terms of access to employment and social services. Programs fostering integration and social cohesion are also among the basic needs related to in-migration. The urban poor and women require special attention to ensure delivery of basic services and infrastructure in an inclusive manner. Policy makers should develop and implement migration preparedness plans for the additional long-term population growth that will come from climate migration. Such plans should include viable livelihood opportunities, critical infrastructure and services, registration systems for migrants (to access services and labor markets), and the inclusion of migrants in planning and decision making.

Figure 6.1: Strategic entry points for action along the life cycle of climate-related mobility

BEFORE MIGRATION

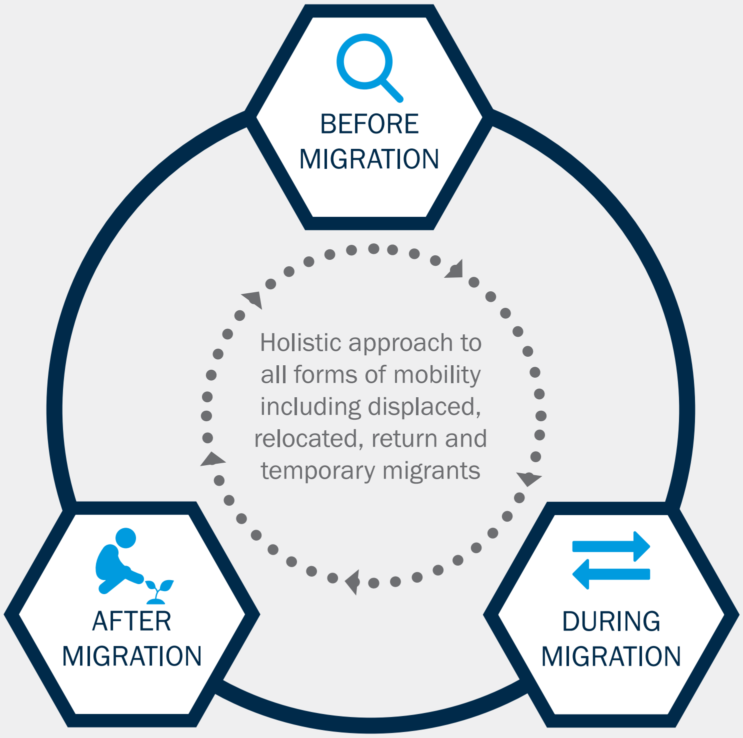
- Invest in better knowledge, anticipation and monitoring
- Foster emissions mitigation and inclusive development
- Embed climate migration in policies and national bodies
- Facilitate adaptation in place
- Enable adaptive mobility

DURING MIGRATION

Support people on the move (holistic approach to all of those migrating, displaced, relocated)

AFTER MIGRATION

Prepare, support, and connect sending and receiving areas and their people—especially in hotspots



Source: Adapted and expanded from Martin (2009).

Global dialogue and action on climate migration also need to be strengthened. Several global initiatives and processes are underway that are beginning to consider climate change as a driver of migration, migration as an adaptation strategy, and to address the climate risks associated with movements (Box 6.1). National efforts on managing the growing reality and challenge of internal climate migration could be greatly supported by global dialogue and consensus.

Box 6.1: Global frameworks and processes on migration

Some key initiatives and global frameworks and platforms addressing climate change and migration issues include:

- The **United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP)** called for respecting, promoting, and considering the respective obligations of parties on migrants. It established a task force to develop recommendations for integrated approaches to avert, minimize, and address displacement related to adverse impacts of climate change.

- The **Nansen Initiative**, a state-led consultative process, built consensus among states on a protection agenda for disaster displacement. It provides comprehensive guidance on effective practices as well as challenges for reducing vulnerability and building resilience to displacement. This important work by the Nansen Initiative continues under the Platform on Disaster Displacement.

- The **Platform for Disaster Displacement**, a state-led process addressing the protection needs of people displaced across borders in the context of disasters and climate change.

- The **Migrants in Countries in Crisis (MICIC) Initiative** provides guidance for the protection of people who migrate in response to natural disasters or conflicts.

- The **Sendai Framework for Disaster Risk Reduction 2015-30** emphasizes the role of mobility in risk reduction, but also the increased disaster risks that migrants often face.

- The **September 2016 New York Declaration for Refugees and Migrants** recognizes the environment and climate change as drivers of migration and displacement. The **Global Compacts for Migration and on Refugees** are expected to be proposed at the UN Global Assembly in 2018.

- The **2030 Agenda for Sustainable Development** incorporates migration into mainstream development policy for the first time. Target 10.7 seeks to "facilitate orderly, safe, and responsible migration and mobility of people."

- The **Addis Ababa Action Agenda (2015)**, the foundation for implementing the global sustainable development agenda, explicitly recognizes the "positive contribution of migrants for inclusive growth and sustainable development in countries of origin, and transit and destination countries."

- The **International Organization for Migration (IOM)** became a Related Organization of the United Nations in 2016.

The engagement of international organizations, private actors, and civil society is key to guiding policy frameworks and capacity. Development institutions, including the World Bank, are increasingly recognizing migration as a key cross-cutting issue with implications for meeting its development goals and targets (Box 6.2). Cooperation and stepped-up action by development, humanitarian, and disaster communities across the mobility continuum could greatly assist countries in pursuing more holistic and durable solutions.

Box 6.2: Migration at the World Bank

The World Bank is increasingly recognizing migration as a complex and cross-cutting issue with important implications for reducing poverty and promoting shared prosperity. Recent publications include:

- A paper by the World Bank–*Migration and Development*: *A Role for the World Bank Group* (World Bank 2016) discusses (a) the major drivers of international migration; (b) the benefits and costs associated with global labor mobility in both sending and receiving countries; (c) the global architecture for governance of migration; and (d) areas in which the Bank could design context-specific solutions to address migration.

- The International Development Association (IDA) 18th Replenishment, approved in 2016, calls for adopting a migration lens in IDA countries where migration has a significant economic and social impact in the context of jobs and economic transformation.

- A study by the United Nations and the World Bank (2017)—*Pathways for Peace*: *Inclusive Approaches to Preventing Violent Conflict*—examines migration, forced displacement, and refugees. The report notes that climate change contributes to drought, food insecurity and migration.

- A report by the World Bank and the United Nations High Commissioner for Human Rights—*Forcibly Displaced*: *Toward a Development Approach Supporting Refugees, the Internally Displaced, and Their Hosts* (World Bank 2017a)—provides insight into the scope and scale of the forced displacement of the 65 million people who were living under such conditions at the end of 2015. The report proposes ways to help people before, during, and after forced displacement and provides recommendations for development actors at each stage.

- *Maximizing the Impact of the World Bank Group in Fragile and Conflict-Affected Situations* (World Bank 2017b) provides a comprehensive overview of the Bank's engagement, highlighting strategies and operations in contexts of fragility, conflict, and violence.

- *The Global Knowledge Partnership on Migration and Development (KNOMAD)* is a global hub of knowledge and policy expertise on migration and development issues coordinated by the World Bank.

Invest now to improve understanding of internal climate migration

More investment is needed to better contextualize and understand climate migration, particularly at scales ranging from regional to local, where climate impacts may deviate from the broader trends identified in a global-scale analysis (Box 6.3). In many cases, a richer, more detailed set of climate, biophysical, socioeconomic, and political indicators is available at regional, national, and local levels. There are inherent uncertainties in the way climate impacts will play out in a given locale and this will affect the magnitude and pattern of climate change-induced movements. Over time, as more data become available on climate change and its likely impacts on water availability, crop productivity, and sea level rise, the scenarios and models would need to be updated. Increasing the modeling resolution and improving data inputs to produce more spatially-detailed projections are among the possible future applications of the approach used in this report.

Building country-level capacity to collect and monitor relevant data can increase understanding of the interactions among climate impacts, ecosystems, livelihoods, and mobility and help countries tailor policy, planning, and investment decisions. Including climate-related and migration questions in national census and existing surveys is a cost-effective way to advance understanding. Decision-making techniques under deep uncertainty need to be further developed and applied for policy making and development planning. Evidence-based research, complemented by country-level modeling is vital. In support of this, new data sources—including from satellite imagery and mobile phones—combined with advances in climate information can be beneficial to improving the quality of information about internal migration. In order to make sense of the data, research capacities on local as well as global-scale methods and models need to be enhanced at the same time. In all of these efforts, the privacy of personal data needs to be protected.

Internal climate migration must be addressed holistically with other forms of climate-induced mobility. While internal migration is expected to be the most frequent form of such mobility, cross-border migration is another serious policy concern (Foresight 2011; Groschl and Steinwachs 2016; McLeman et al. 2016). Several hotspots of climate in-migration are in transboundary areas—migration does not necessarily stop at borders. Climate change can be an inhibitor or a driver of cross-border migration, depending on a range of factors that propel individuals to decide to move or stay. Although this study did not focus on cross-border climate migration, potential agglomerations around border hotspots must be explored for their opportunities and managed for their challenges.

Slow-onset climate change and sudden-onset extreme events may have compounding effects on internal migration, and displacement patterns, and thus should be considered and monitored together. Climate change can affect disaster displacement (Black, Kniveton and Schmidt-Verkerk 2013; Black and others 2013; see also Box 2.2). Rapid-onset events such as floods and cyclones displaced an average of more than 26 million people a year from 2008–15, according to the Internal Displacement Monitoring Center (IDMC 2015). These numbers are expected to rise as such disasters become more frequent and severe (Adger and others 2014). Immobility—estimated to affect millions of people who are unwilling or unable to leave strained environments—may be one of the most important blind spots in the current debate (Adger and others 2015; Foresight 2011).

Photo Credit: World Bank

Box 6.3: Deepening the understanding of climate migration: Avenues for future research

Systematic investment in gathering the best available information related to climate change and migration and robust empirical work complemented by country-level applications are critical for supporting policy and planning efforts. This report provides an initial basis to inform these efforts by using novel and transparent modeling to quantify the potential impacts of climate change on the intensity of internal migration, over time and across space. Extending global and regional-scale modeling of the type applied in this report can further enhance confidence in the large-scale patterns of climate impacts and related migration outcomes. Multiple avenues are open for future enquiry:

- *Applying the model to countries or smaller regions.* One of the key features of the model used in this report is its flexibility. It can be applied at varying spatial scales, including the country level. The model can accommodate alternative national and subnational projections of urban/rural change and different assumptions about the habitability of land parcels, among other parameters. It is easily expanded or altered to consider a richer, more detailed set of climate, biophysical, socioeconomic, and sectoral impacts and political indicators at the national, subnational, and local level that may help tailor the model to countries, regions, or localities. In regions for which detailed historic migration data exist, the model can be expanded to project bilateral migration flows. If complemented with ground-truthing, through local consultations and use of local information, future work using this model could inform specific policy and development planning recommendations at various levels.

- *Incorporating additional climate impacts, geophysical characteristics, and climate feedback.* This report considers the climate impact on two sectors, agriculture and water. Future work could examine the effect of climate change on other sectors, such as health. Geophysical characteristics such as projected changes in coastlines could also be included, as could the projected availability of certain resources, responses to climate feedback, and policies designed to affect settlement patterns.

- *Considering the impacts of extreme events.* This report includes some extreme events (such as drought and extreme temperatures) to the extent that they affect water availability and crop productivity. It does not examine short-duration, rapid-onset events if they do not add up to successive shocks over several years that affect water availability and crop productivity. Future work could find ways to also look at short and sudden-onset events.

- *Quantifying the economic consequences of climate migration.* Climate migration affects economic activity. Depending on their specific contexts, regions that receive migrants will likely show increases in output; regions that experience net out-migration will likely decline. The change in production will depend on how much surplus labor there is in different regions and on the relationship between the demand for and the supply of labor by sector. Methodologies such as computable general equilibrium (CGE) modeling can help assess the economic implications of projected shifts in population.

A CALL TO ACTION

Climate migration is projected to intensify over the next several decades and could accelerate even more after 2050. The window of opportunity for action is still open now. Stakeholders should act together by cutting global emissions and pursuing climate-smart development. Policies and planning should encompass climate migration and all other forms of climate change–induced movement, without forgetting about people who are unable or unwilling to leave increasingly unviable environments.

States also need to manage climate migration along its life cycle, helping communities stay in places that are viable, while enabling welfare-enhancing migration where needed as an adaptation strategy, and addressing climate migration hotspots. More systematic investments in knowledge and data are needed at all levels to anticipate and address all forms of climate movement holistically.

Given the lock-in of past and predicted emissions, some climate migration will occur. It need not create a crisis, however, if all actors—global, national, and local, and the private sector, civil society, and international organizations—use the window of opportunity to invest in knowledge, mitigation, and adaptation and take steps now to secure resilience for all.

REFERENCES

ADB (Asian Development Bank). 2012. “Addressing Climate Change and Migration in Asia and the Pacific.” Manila, Philippines. http://www.worldcat.org/oclc/780416971.

AfDB (African Development Bank). 2017. *African Economic Outlook 2017: Entrepreneurship and Industrialisation*. Paris.

Addis Ababa Action Agenda. 2015. Addis Ababa Action Agenda of the Third International Conference on Financing for Development. New York: United Nations.

Adger, W. N., N. W. Arnell, R. Black, S. Dercon, A. Geddes, and D. Thomas. 2015. “Focus on Environmental Risks and Migration: Causes and Consequences.” *Environmental Research Letters* 10 (6): 60201.

Adger, W. N., J. M. Pulhin, J. Barnett, G. D. Dabelko, G. K. Hovelsrud, M. Levy, Ú. Oswald Spring, and C. H. Vogel. 2014. “Human Security.” In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, 755–791. Cambridge, UK and New York, NY: Cambridge University Press.

Agrawal, A. and N. Perrin. 2009. “Climate Adaptation, Local Institutions and Rural Livelihoods.” In *Adapting to Climate Change:* Thresholds, Values, Governance, ed. W.N. Adger, I. Lorenzoni and K. O’Brien, 350–367. Cambridge, UK: Cambridge University Press.

Aksakal, M., and K. Schmidt. 2015. “Migration and Social Protection as Adaptation in Response to Climate-Related Stressors: The Case of Zacatecas in Mexico.” In *Environmental Change, Adaptation and Migration: Bringing in the Region*, ed. Felicitas Hillmann, Marie Pahl, Birte Raffenbeul, and Harald Sterly, 80–97. New York: Palgrave MacMillan.

Bakewell, O. 2008. “‘Keeping Them in Their Place:’ The Ambivalent Relationship between Development and Migration in Africa.” *Third World Quarterly* 29 (7): 1341–1358.

Banerjee, S., D. Kniveton, R. Black, S. Bisht, P. J. Das, B. Mahapatra, and S. Tuladhar. 2017. “Do Financial Remittances Build Household-Level Adaptive Capacity? A Case Study of Flood-Affected Households in India.” KNOMAD Working Paper 18, World Bank, Washington, DC.

Barnett, J., and S. O’Neill. 2010. “Maladaptation.” *Global Environmental Change* 20 (2010): 211–213.

Black, R, N. W. Arnell, W. N. Adger, D. Thomas, and A. Geddes. 2013. “Migration, Immobility and Displacement Outcomes Following Extreme Events.” *Environmental Science and Policy* 27 (S1): S32–43. doi:org/10.1016/j.envsci.2012.09.001.

Black, R., D. Kniveton, and K. Schmidt-Verkerk. 2013. “Migration and Climate Change: Toward an Integrated Assessment of Sensitivity.” In *Disentangling Migration and Climate Change*, 29–53. Dordrecht, Netherlands: Springer International Publishing.

Black, R., W. N. Adger, N. W. Arnell, S. Dercon, A. Geddes, and D. Thomas. 2011a. “The Effect of Environmental Change on Human Migration.” *Global Environmental Change* 21 (S1): S3–11

Black, R., S. R. G. Bennett, S. M. Thomas, and J. R. Beddington. 2011b. “Climate Change: Migration as Adaptation.” *Nature* 478 (7370): 447–49. doi:10.1038/478477a.

Bloom, David, David Canning, and Jaypee Sevilla. 2003. “The Demographic Dividend: A New Perspective of the Economic Consequences of Population Change.” Santa Monica, CA: RAND Corporation.

Bronen, R. 2015. “Climate-Induced Community Relocations: Using Integrated Social-Ecological Assessments to Foster Adaptation and Resilience.” *Ecology and Society* 20 (3). doi:10.5751/ES-07801- 200336.

Brookings Institution, Georgetown University, and UNHCR (United Nations High Commissioner for Refugees). 2015. “Guidance On Protecting People From Disasters And Environmental Change Through Planned Relocation.” Washington, DC. http://www.unhcr.org/protection/environment/562f798d9/planned-relocation-guidance-october-2015.html.

Bryan, G., S. Chowdhury, and A. M. Mobarak. 2012. “Seasonal Migration and Risk Aversion.” CEPR Discussion Paper DP8739, Center for Economic Policy Research, London.

Cascone, N., Ana Elisa Peña del Valle Isla, and Andrea Milan. 2016. “Circular Migration and Local Adaptation in the Mountainous Community of Las Palomas (Mexico).” In *Migration, Risk Management and Climate Change: Evidence and Policy Responses,* ed. A. Milan, B. Schraven, K. Warner, and N. Cascone, 63–83. Dordrecht, Netherlands: Springer International Publishing.

Cervigni, R., and M. L. Morris. 2016. “Confronting Drought in Africa’s Drylands: Opportunities for Enhancing Resilience.” Africa Development Forum Series. Washington, DC: World Bank.

Curtain, R., M. Dornan, J. Doyle, and S. Howes. 2016. *Pacific Possible: Labour Mobility: The Ten Billion Dollar Prize.* Washington, DC: World Bank. http://pubdocs.worldbank.org/en/555421468204932199/pdf/labour-mobility-pacific-possible.pdf.

Dabelko, G.D., L. Herzer, S. Null, M. Parker, and R. Sticklor. 2013. “Backdraft: the conflict potential of climate change adaptation and mitigation.” Washington DC: Woodrow Wilson Center Environmental Change and Security Program Report, 14(2): 1-60.

de Haas H. 2010. “Migration and Development: A Theoretical Perspective.” *The International Migration Review* 44 (1): 227–264. doi:10.1111/j.1747-7379.2009.00804.x.

de Sherbinin, A., M. Levy, S. Adamo, K. MacManus, G. Yetman, V. Mara, L. Razafindrazay, B. Goodrich, T. Srebotnjak, C. Aichele, and L. Pistolesi. 2012. “Migration and Risk: Net Migration in Marginal Ecosystems and Hazardous Areas.” *Environmental Research Letters* 7 (4).

Ellis, Frank. 2003. A livelihoods approach to migration and poverty reduction. Paper Commissioned by the Department for International Development (DFID).

FAO (Food and Agricultural Organization of the United Nations). 2017. Sustainable Land Management (SLM) in practice in the Kagera Basin. Lessons learned for scaling up at landscape level - Results of the Kagera Transboundary Agro-ecosystem Management Project (Kagera TAMP). Food and Agriculture Organization of the United Nations, Rome, Italy.

Fay, M., S. Hallegatte, A. Vogt-Schilb, J. Rozenberg, U. Narloch, and T. Kerr. 2015. “Decarbonizing Development: Three Steps to a Zero-Carbon Future.” Washington, DC: World Bank.

Foresight. 2011. *Migration and Global Environmental Change: Final Project Report*. London: The Government Office for Science. https://www.gov.uk/government/uploads/system/uploads/attachment_ data/file/287717/11-1116-migration-and-global-environmental-change.pdf

Geddes, A., and A. Jordan. 2012. “Migration as Adaptation? Exploring the Scope for Coordinating Environmental and Migration Policies in the European Union.” *Environment and Planning* C 30 (2012): 1029–44.

Gemenne, F. 2011a. “How They Became the Human Face of Climate Change: The Emergence of ‘Climate Refugees’ in the Public Debate, and the Policy Responses It Triggered.” In *Migration and Climate Change*. Cambridge, UK: Cambridge University Press.

Gentilini, U. 2015. “Entering the City: Emerging Evidence and Practices with Safety Nets in Urban Areas.” World Bank Social Protection and Labor Discussion Paper No.1504. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/656081467980515244/Entering-the-city-emerging- evidence-and-practices-with-safety-nets-in-urban-areas

Gentilini, U., and S. Omamo. 2011. “Social Protection 2.0: Exploring Issues, Evidence and Debates in a Globalizing World.” *Food Policy* 36 (3): 329–340

Georgetown University, UNHCR (United Nations High Commissioner for Refugees), and IOM (International Organization for Migration). 2017. “A Toolbox: Planning Relocations to Protect People from Disasters and Environmental Change.” http://www.unhcr.org/protection/environment/596f1bb47/planned-relocation- toolbox.html.

Government of Nepal, ICIMOD. 2017. Climate Change and Migration Strategy of Nepal.

Gray, Erin, Norbert Henninger, Chris Reij, Robert Winterbottom, Paola Agostini. 2016. Integrated Landscape Approaches for Africa's Drylands. World Bank Studies. Washington, DC: World Bank. © World Bank.

Groschl, J., and T. Steinwachs. 2016. "Do Natural Hazards Cause International Migration?" CESifo Economic Studies No. 6145, Center for Economic Studies, Munich, Germany.

Gubert, F. 2007. Migration and Development: Mixed evidence from western Mali. Development. [Online] 50 (4): 94–100.

Hallegatte, S., M. Fay, M. Bangalore, T. Kane, J. Rozenberg, A. Vogt-Schilb, and U. Narloch. 2016. *Shock Waves: Managing the Impacts of Climate Change on Poverty. Climate Change and Development.* Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/22787 License: CC BY 3.0 IGO.

Holzmann, R., J. Koettl, and T. Chernetsky. 2005. "Portability Regimes of Pension and Health Care Benefits for International Migrants: An Analysis of Issues and Good Practices (Vol. 23)." Geneva, Switzerland: Global Commission on International Migration.

Hunter, Lori M., Jessie K. Luna, and Rachel M. Norton. 2015. "Environmental dimensions of migration." Annual Review of Sociology 41: 377-397.

IDA18. 2016. http://ida.worldbank.org/financing/replenishments/ida18-overview

IDMC (Internal Displacement Monitoring Center). 2015. *Global Estimates 2015: People Displaced by Disasters.* Geneva.

IMF (International Monetary Fund). 2006. "What is the Demographic Dividend?" *Finance and Development* 43 (3). https://www.imf.org/external/pubs/ft/fandd/2006/09/basics.htm

IOM (International Organization for Migration). 2016. "Adapting to Climate Change through Migration: A Case Study of the Vietnamese Mekong River Delta." ed. Han Entzinger and Peter Scholten. Geneva.

———. 2017. *Assessing the Climate Change Environmental Degradation and Migration Nexus in South Asia.*

Geneva: International Organization for Migration.

Ionesco, D., F. Gemenne, and C. Zickgraf. 2015. "Introduction." In *The State of Environmental Migration 2015,* ed. Dina Ionesco, François Gemenne, and Caroline Zickgraf, 7-10. Paris: Sciences Po.

Jones, R.C. 2014. "The Decline of International Migration as an Economic Force in Rural Areas: A Mexican Case Study." *International Migration Review* 48 (3): 728–61. doi:10.1111/imre.12085.

Joseph, G., Q. Wodon, and B. Blankespoor. 2014. "Do Remittances Reach Households Living in Unfavorable Climate Areas? Evidence from the Republic of Yemen." In *Climate Change and Migration: Evidence from the Middle East and North Africa*, ed. Q. Wodon, A. Liverani, G. Joseph, and N. Bougnoux. Washington, DC: World Bank.

KNOMAD (The Global Knowledge Partnership on Migration and Development). 2014. "International Symposium on Environmental Change and Migration: Symposium Report." World Bank, Washington, DC, May 28–29.

———. 2015. "Longitudinal Research on Environmental Change and Migration: A Workshop on Objectives, Methods, and Applicability to Policy and Practice." World Bank, Washington, DC, March 19–20.

———. 2016. "Summary Report on Workshop Quantitative Assessment of Environmentally-Induced Migration." World Bank, Washington, DC, May 9–10.

Kapur, D. 2004. *Remittances: the new development Mantra. United Nations Conference on trade and development* (No. 19). G-24 discussion paper series.

Kates, R.W., W.R. Travis, and T.J. Wilbanks. 2012. "Transformational Adaptation When Incremental Adaptations to Climate Change Are Insufficient." *Proceedings of the National Academy of Sciences* 109 (19): 7156–7161.

Koubi, V., G. Spilker, L. Schaffer, and T. Bernauer. 2016. "Environmental Stressors and Migration: Evidence from Vietnam." *World Development* 79: 197–210.

Kuriakose, A.T., R. Heltberg, W. Wiseman, C. Costella, R. Cipryk, and S. Cornelius. 2013. "Climate Responsive Social Protection." *Development Policy Review* 31 (s2).

Leighton, M., X. Shen, and K. Warner (eds.). 2011. *Climate Change and Migration: Rethinking Policies for Adaptation and Disaster Risk Reduction.* No. 15/2011. United Nations University, Institute for Environment and Human Security, Bonn.

Lu, Xin, David J Wrathall, Pål Roe Sundsøy, Md Nadiruzzaman, Erik Wetter, Asif Iqbal, Taimur Qureshi, Andrew Tatem, Geoffrey Canright, and Kenth Engø-Monsen. 2016. "Unveiling Hidden Migration and Mobility Patterns in Climate Stressed Regions: A Longitudinal Study of Six Million Anonymous Mobile Phone Users in Bangladesh." *Global Environmental Change* 38: 1–7.

Manandhar, B. 2016. Remittance and earthquake preparedness. International Journal of Disaster Risk Reduction, 15: 52-60.

Martin, S. F. 2009. "Managing Environmentally Induced Migration." In *Migration, Environment and Climate Change: Assessing the Evidence*, ed. Frank Laczko and Christine Aghazarm, 353–85. Geneva: International Organization for Migration.

———. 2012. "Environmental Change and Migration: Legal and Political Frameworks." *Environment and Planning C: Government and Policy* 30 (6): 1045–60.

McAdam, J. and B. Saul. 2010. "Displacement with Dignity: International Law and Policy Responses to Climate Change Mitigation and Security in Bangladesh." *German Yearbook of International Law* 53: 233.

McKenzie, D., and D. Yang. 2014. "Evidence on Policies to Increase the Development Impacts of International Migration." KNOMAD Working Paper, World Bank, Washington, DC. http://www.knomad.org/ docs/working_papers/KNOMAD Working Paper 2_McKenzie-Yang_12-19-2014.pdf.

McLeman, Robert. 2011. 2013. "Developments in Modelling of Climate Change-Related Migration." Climatic Change 117 (3): 599–611. doi: 10.1007/s10584-012-0578-2.

———. 2016a. "Interconnectivity of Climate Change, Ecosystems, Livelihoods, and Migration: Implications for Long Term, Climate-Resilient Development Planning." Background paper produced for this report.

———. 2016b. "Migration as Adaptation: Conceptual Origins, Recent Developments, and Future Directions." In Migration, Risk Management and Climate Change: Evidence and Policy Responses, ed. A. Milan, B. Schraven, K. Warner, and N. Cascone, 213-229. Dordrecht: Springer International Publishing.

McLeman, Robert, and Barry Smit. 2006. "Migration as an adaptation to climate change." *Climatic change* 76 (1-2): 31-53.

McLeman, Robert, Michael Opatowski, Betina Borova, and Margaret Walton-Roberts. 2016. "Environmental Migration and Displacement: What We Know and Don't Know." Presented at the Laurier/US Embassy Workshop on Environmental Migration and Displacement on January 22, 2016 in Waterloo, Ontario.

Melde, S., F. Laczko, and F. Gemenne. 2017. "Making Mobility Work for Adaptation to Environmental Changes: Results from the MECLEP Global Research." Geneva. https://publications.iom.int/system/files/ pdf/meclep_comparative_report.pdf.

Mohapatra, S., G. Joseph, and D. Ratha. 2009. "Remittances and Natural Disasters: Ex-Post Response and Contribution to Ex-Ante Preparedness." World Bank Policy Research Working Paper 4972, World Bank, Washington, DC.

Munshi, Kaivan. 2003. "Networks in the Modern Economy: Mexican Migrants in the US Labor Market."

The Quarterly Journal of Economics 118 (2): 549–99.

Nansen Initiative. 2015. "Agenda for the Protection of Cross-Border Displaced Persons in the Context of Climate Change: Volume I." Geneva. https://nanseninitiative.org/wp-content/uploads/2015/02/PROTECTION-AGENDA-VOLUME-1.pdf.

Nash, J., N. Halewood, and S. Melhem. 2013. Unlocking Africa's agricultural potential: an action agenda for transformation. Africa region sustainable development series. Washington DC: World Bank. http://documents.worldbank.org/curated/en/795321468191670202/Unlocking-Africas-agriculturalpotential-an-action-agenda-for-transformation

OECD (Organisation for Economic Co-operation and Development). 2017. "OECD Economic Surveys: Mexico 2017 Overview." Paris. http://www.oecd.org/eco/surveys/economic-survey-mexico.htm.

Ober, Kayly. 2014. “Migration as Adaptation: Exploring Mobility as a Coping Strategy for Climate Change.” Oxford, UK: UK Climate Change and Migration Coalition. doi:10.13140/2.1.2483.6806.

Park, S.E., N.A. Marshall, E. Jakku, A.M. Dowd, S.M. Howden, E. Mendham, and A. Fleming. 2012. “Informing Adaptation Responses to Climate Change through Theories of Transformation.” *Global Environmental Change* 22 (1): 115–126.

Platform on Disaster Displacement. 2017. http://disasterdisplacement.org/

PRB (Population Reference Bureau). 2012. “The Challenge of Attaining the Demographic Dividend.” Policy Brief. Washington, DC. http://www.prb.org/pdf12/demographic-dividend.pdf

Rickards, Lauren, and S. M. Howden. 2012. “Transformational adaptation: agriculture and climate change.” Crop and Pasture Science 63(3): 240-250.

Rosenzweig, C., W.D. Solecki, S.A. Hammer, and S. Mehrotra (eds). 2011. *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network.* New York: Cambridge University Press.

Schwilch Gudrun, Anu Adhikari, Michel Jaboyedoff, Stéphanie Jaquet, Raoul Kaenzig, Hanspeter Liniger, Ivanna M. Penna, Karen Sudmeier-Rieux, and Bishnu Raj Upreti. 2017. “Impacts of Outmigration on Land ManagementinaNepaliMountainArea” In: Sudmeier-K. Rieux, M. Fernández, I. Penna, M. Jaboyedoff, J. Gaillard (eds.) Identifying Emerging Issues in Disaster Risk Reduction, Migration, Climate Change and Sustainable Development. Springer, Cham. https://link.springer.com/chapter/10.1007%2F978-3-319-33880-4_11.

Skeldon, R. 2006. “Interlinkages between internal and international migration and development in the Asian region.” Population, space and place, 12(1): 15-30.

Sobrino, Jaime. 2016. “Localización Industrial Y Concentración Geográfica En México.” *Estudios Demográficos Y Urbanos* 31: 9–56. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0186- 72102016000100009&nrm=iso.

Tacoli, Cecilia. 2011. *Not only climate change: mobility, vulnerability and socio-economic transformations in environmentally fragile areas in Bolivia, Senegal and Tanzania*. No. 28. IIED.

TerrAfrica. 2015. Frequently Asked Questions. http://terrafrica.org/faq/.

UNCCD (United Nations Convention to Combat Desertification) and IOM (International Organization for Migration). 2014. West Africa: Promoting sustainable land management in migration-prone areas through innovative financing mechanisms. Rome, Italy. http://www.environmentalmigration.iom.int/sites/default/files/Flyer-SLM-Migration%20project.pdf.

UNDESA (United Nations Department of Economic and Social Affairs). 2013. “Cross-National Comparisons of Internal Migration: An Update on Global Patterns and Trends.” Population Division Technical Paper No. 2013/1, New York. http://www.un.org/en/development/desa/population/publications/pdf/technical/TP2013-1.pdf.

———. 2015. World Urbanization Prospects Final Report: 2014 Revision. New York. https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Report.pdf.

———. 2017. World Population Prospects: Key Findings & Advance Tables: 2017 Revision. New York. https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf.

UNDP (United Nations Development Programme). 2009. *Human Development Report 2009.* New York. http://hdr.undp.org/sites/default/files/reports/269/hdr_2009_en_complete.pdf.

UNEP (United Nations Environment Programme). 2016. “Loss and Damage: The Role of Ecosystem Services.” United Nations Environment Programme. http://collections.unu.edu/view/UNU:5614.

UNGA (UN General Assembly). 2015. *Transforming our world: the 2030 Agenda for Sustainable Development*, 21 October 2015, A/RES/70/1, available at: http://www.refworld.org/docid/57b6e3e44.html

UNHCR (United Nations High Commissioner for Refugees). 2017. *Global Trends: Forced Displacement In 2016.* Geneva.

WEF (World Economic Forum). 2017. Migration and Its Impact on Cities. http://www3.weforum.org/docs/Migration_Impact_Cities_report_2017_low.pdf

Waldinger, M. 2015. "The Effects of Climate Change on Internal and International Migration: Implications for Developing Countries." Working Paper No. 217, Centre for Climate Change Economics and Policy, London.

Warner, K., M. Hamza, A. Oliver-Smith, F. Renaud, and A. Julca. 2010. "Climate Change, Environmental Degradation and Migration." *Natural Hazards* 55 (3): 689–715.

Warner, K., W. Kälin, S. F. Martin, Y. Nassef, S. Lee, S. Melde, H. E. Chapuisa, M. Franck, and T. Afifi. 2014. "Integrating Human Mobility Issues within National Adaptation Plans." Policy Brief 9, United Nations University Institute for Environment and Human Security (UNU-EHS), Bonn, Germany.

Warner, K., W. Kälin, S. F. Martin, and Y. Nassef. 2015. "National Adaptation Plans and Human Mobility." Forced Migration Review 49: 8–9. http://www.fmreview.org/en/climatechange-disasters/warner-kaelin- martin-nassef.pdf.

Webber, Michael, and Jon Barnett. 2010. Accommodating Migration to Promote Adaptation to Climate Change. Washington, DC: World Bank.

Wodon, J. G. Q., and B. Blankespoor. 2014. "Do Remittances Reach Households Living in Unfavorable Climate Areas? Evidence from the Republic of Yemen." Munich, Germany: University Library of Munich.

Wodon, Quentin, Andrea Liverani, George Joseph, and Nathalie Bougnoux. 2014. Climate Change and Migration: Evidence from the Middle East and North Africa. Washington, DC: World Bank. http://documents. worldbank.org/curated/en/748271468278938347/Climate-Change-and-Migration-Evidence-from-the-Middle-East-A.

World Bank. 2013. Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience. Washington, DC: World Bank.

———. 2016. Migration and Development: A Role for the World Bank Group. Washington, DC.

———. 2017a. Pacific Possible: Long-Term Economic Opportunities and Challenges for Pacific Island Countries. Washington, DC. https://openknowledge.worldbank.org/bitstream/handle/10986/28135/ACS22308-PUBLIC-P154324-ADD-SERIES-PPFullReportFINALscreen.pdf?sequence=1&isAllowed=y.

———. 2017b. "Maximizing the Impact of the World Bank Group in Fragile and Conflict-Affected Situations." Washington, DC.

Zickgraf, C., and F. Gemenne. 2017. "How Remittances Address Poverty and Resilience in the Context of Climate Change: A Synthesis of the Existing Evidence." Background paper produced for this report.

Zickgraf, C., S. Vigil, F. de Longueville, P. Ozer, and F. Gemenne. 2016. "The Impact of Vulnerability and Resilience to Environmental Changes on Mobility Patterns in West Africa." KNOMAD Working Paper 14, World Bank, Washington, DC.

Appendix A

Technical Details on the Modeling Data and Methods

This section provides details on model inputs (Section A.1) and methodology (Section A.2).

A.1 DATA INPUTS

Section A.1.1 provides justifications on climate and impact model input choices, and Section A.1.2 provides information on uncertainties inherent in the population data.

A.1.1 Choice of ISIMIP Models

As mentioned in Chapter 3, the modeling team needed to choose among a number of global climate models (GCMs) and crop and water models. Here the rationale is provided for the models used in this effort.

A.1.1.1 Climate models

Of the more than 30 global climate models (GCMs) that participated in the Coupled Model Intercomparison Project phase 5 (CMIP5; Taylor, Stouffer, and Meehl 2012), five models were used in the ISIMIP Fast Track to drive the crop and hydrological models. These were already selected to cover a large fraction of the range of temperature and precipitation projections across the whole CMIP5 ensemble, although the entire range cannot be represented with only five models (Warszawski and others 2014; McSweeney and Jones 2016). For the present study, the climate model ensemble had to be further reduced to make its application in the population modeling framework feasible. From the five ISIMIP GCMs, the HadGEM2-ES and IPSL-CM5A-LR models were chosen. One reason for choosing these models is that the future precipitation trends differ substantially in magnitude, and partly even in sign, between these models for the case study regions of this report (Schewe and others 2014), so that at least for these regions a large range of possible future climate changes can be covered with only these two models. Further, both models are also being used currently for producing new impact simulations within the ISIMIP2b project (Frieler and others 2016), so that the analysis presented in this report could easily be updated when those new impact simulations become available. Moreover, the HadGEM2-ES model has a particularly fine native resolution, potentially rendering it more realistic than other models at the regional scale.

It is noted that the crop yield and water indicators exist for all five ISIMIP GCMs, so that the methodology of this report could easily be extended to include more GCMs. Further, while it would be desirable to use climate impacts data at a higher spatial resolution, so far no consistent set of impact model simulations is available that have been forced by regional climate models (RCMs). It is worth recalling that the use of global impact simulations in this study presents an advance over using purely climate model-based indicators because they represent the actual resources (crops, water) relevant for human livelihoods.

A.1.1.2 Crop models

Muller and others (2017) provide an evaluation of global crop models by comparing simulations driven with observations-based climate input (within the ISIMIP2a project) to reported crop yields. Six of these models contributed future simulations within the ISIMIP FastTrack, which could have been used in the work underlying this report. Among these, at the global level, one of the best-performing models (in terms of time-series correlation and mean bias in global yield) for both maize and wheat is LPJmL (Bondeau and others 2007). For maize, GEPIC (Liu and others 2007) also performs very well; both models also have a reasonable performance for rice. Another advantage of this choice is that LPJmL is an ecosystem model, while GEPIC is a site-based model; thus, two of the major structural model types are covered.

It should be noted that, for some crop-country combinations (e.g. wheat in Mexico), very few models show a good performance at the national scale in terms of time-series correlation and mean bias (Müller and others 2017), which is, however, not to say that they cannot capture longer-term trends. To reflect overall agricultural productivity, the four major crops—maize, wheat, rice, and soybean—were combined into a total production index. Depending on the country, other crops are also important, but are not simulated by most of the global crop models.

A.1.1.3 Water models

The ISIMIP hydrological models have so far been evaluated (Gosling and others 2017; Hattermann and others 2017) mainly for 11 large river basins, of which the Ganges (Bangladesh) and Blue Nile (Ethiopia) are relevant for the present set of case study countries. Moreover, in these studies the models have been anonymized, i.e. individual models cannot be identified. One criterion that narrows down the choice is that only a few models can provide simulations, including human water abstraction, dams, and reservoirs, which are major non-climatic human influences on the water cycle. These simulations are normally closer to observed discharge, and of the models that participated in both ISIMIP2a and the ISIMIP FastTrack, these are available from H08, WaterGAP, PCR-GLOBWB, MPI-HM, or LPJmL. From these, LPJmL and WaterGAP (Flörke and others 2013; Döll, Kaspar, and Lehner 2003) were selected. LPJmL integrates crop yields, water resources, and ecosystems in a single model. WaterGAP, on the other hand, can be calibrated separately for each basin and therefore matches observed river discharge better than other global models in many river basins. It is noted that none of the ISIMIP global models include glacier dynamics. Work is ongoing to include glacier dynamics both in PIK's regional hydrological model SWIM and in WaterGAP.

A.1.2 Uncertainties in the Population Data Inputs

Uncertainties in GPWv4 2010 population count grid generally relate to the timeliness and accuracy of the underlying census data and to the input resolution of the census units. In terms of timeliness and accuracy, a number of low- and middlie-income countries have censuses that are either out of date or that are known to contain inaccuracies. Hillson and others (2014) discuss the accuracy and uncertainties in census data, especially in countries with rapidly growing and urbanizing populations. CIESIN (2011) and Cohen (2004) address issues of timeliness in the context of GPWv3. All of these factors affect the degree to which the baseline population distribution for 2010 is accurately mapped.

In terms of the spatial resolution of inputs, while GPWv4 incorporates significantly higher resolution census inputs than prior versions (12.5 million input units in GPWv4 versus about 400,000 in GPWv3), there are still significant portions of the developing world in which the spatial resolution of input units is suboptimal. The average input unit resolution for very high development regions is 944 km2, whereas the low and medium human development countries have an average input resolution of 3,518 km2 and 4,700 km2, respectively. Further uncertainties in the year 2000 estimates relate to the lowest common denominator spatial units that match between the years in GPWv3 and GPWv4, or for which growth rates are available. These units are used to apply consistent rates of change across all sub-units. So, for example, if only admin1 units (state or province) match between censuses, population is backcast from 2010 to 2000 by using consistent rates of change across those units, even if GPWv3 and GPWv4 included population count data for 2010 at a significantly higher resolution. This affects the confidence in the decadal population change grids used for model calibration.

In general, the aggregation of the higher resolution population count and change grids to coarser 7.5 arc-minute grids (equivalent to about 193 square kilometers at the equator) reduces the uncertainty in the data, since all things being equal, uncertainty tends to increase with resolution for census-based population grids.

A.2 TECHNICAL DETAILS ON THE POPULATION MODEL

As described in Chapter 3, the value A_i (from equation 3.2) is calculated as a function of these indicators, and represents an adjustment to the relative attractiveness of (or aversion to) specific locations (grid-cells) reflecting current water availability and crop yield relative to "normal" conditions.

$$\mathrm{v_i} = \mathrm{A_i l_i} \sum_{j=1}^{m} P_j^{\alpha} e^{-\beta d_{ij}} \qquad \text{(Equation 3.2)}$$

In order to carry out the procedure, model estimates of the α and β parameters for the urban and rural populations are necessary, and A_i (Equation 3.2) must be calibrated. Two separate procedures are employed and carried out both for the urban and rural population distributions separately. As mentioned in Chapter 3, urban and rural populations interact in the model, but changes in both are projected separately at the grid-cell level in the same manner. Here the procedure is described once, and, unless otherwise noted, the process is redundant for urban/rural components.

The α and β parameters are designed to capture broad-scale patterns of change found in the distance-density gradient, which is represented by the shape/slope of the distance decay function (parabolas) depicted in Equation 3.2. The negative exponential function described by Equation 3.2 is very similar to Clark's (1951) negative exponential function which has been shown to accurately capture observed density gradients throughout the world (Bertaud and Malpezzi 2003). To estimate α and β, the model in Equation 3.2 is fitted to the 1990-2000 urban and rural population change from GPWv3 and to the 2000-2010 urban and rural population change data from GPWv4, and we compute the values of α and β that minimize the sum of absolute deviations:

$$S(\alpha, \beta) = \sum_{i=1}^{n} \left| P_{i,t}^{mod} - P_{i,t}^{obs} \right| \qquad \text{(A.1)}$$

where $\mathrm{P}_{i,t}^{mod}$ and $\mathrm{P}_{i,t}^{mod}$ are the modeled and observed populations in cell *i,* and S is the sum of absolute error across all cells. We fit the model for two decadal time steps (1990-2000 and 2000-2010) and take the average of the α and β estimates.

In this modified version of the population potential model the index A_i is a cell-specific metric that weights the relative attractiveness of a location (population potential) as a function of environmental and socioeconomic conditions. The modeling approach requires that the relationship between A_i and the different sectoral impact indicators is estimated, which are hypothesized to impact population change. When α and β are estimated from historic data (e.g. observed change between 1990 and 2000 and between 2000 and 2010), a predicted population surface is produced that reflects optimized values of α and β*,* such that absolute error is minimized. Figure A.1 includes a cross-section (one-dimension) of grid cells illustrating observed and predicted population for 10 cells. Each cell contains an error term that reflects the error in the population change projected for each cell over a 10-year time step. It is hypothesized that this error can at least partially be explained by a set of omitted variables, including environmental and sectoral impacts. To incorporate these effects we first calculate the value of $\mathrm{A_i}$ such as to eliminate ε_i (from Figure A.1) for each individual cell (which is labeled observed $\mathrm{A_i}$):

$$\Delta P_{i,t}^{obs} = A_i * \Delta P_{i,t}^{mod} \qquad \text{(A.2)}$$

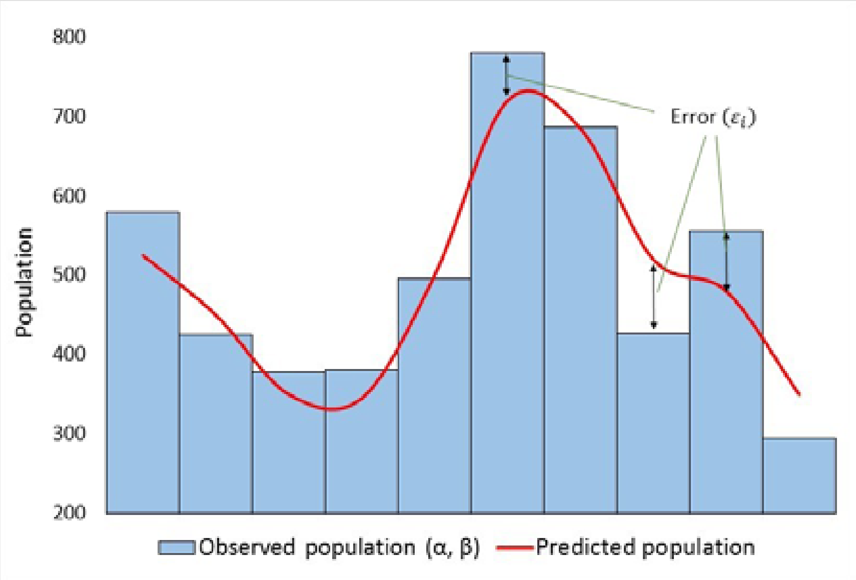
where $\Delta P^{obs}_{i,t}$ and $\Delta P^{obs}_{i,t}$ are the observed and modeled population change for each cell *i* and A_i is the factor necessary to equate the two.

The second step is to estimate the relationship between observed index A_i and cell-specific water availability and crop production metrics by fitting a spatial lag model:

$$A_{i,t} = \rho W A_{i,t+} \beta_1 C_{i,t} + \beta_2 H_{i,t} + \varepsilon_{i,t} \tag{A.3}$$

where *C* and *H* are the set of explanatory variables that go into producing index A_i (crop production and water availability, respectively), ρ is the spatial autocorrelation coefficient and *W* is a spatial weight matrix. From this procedure, a set of cell specific A(i) values is estimated for both urban and rural population change.

Figure A.1: Cross-section of grid cells illustrating observed and projected population distributions



Note: The error term is used to calibrate the index A(i).

For future projections (for urban and rural populations), projected values of $C_{i,t}$ and $H_{i,t}$ and coefficient estimates from Equation A.3 are used to estimate spatially and temporally explicit values of A_i. Finally, to produce a spatially explicit population projection, estimates of α and β are adjusted to reflect the SSPs (e.g. the SSP4 storyline implies a more concentrated pattern of development than SSP5, see Jones and O'Neill 2016), incorporate spatio-temporally variant estimates of A_i for the RCPs, and exogenous projections of national urban and rural population change, and the model applied as specified in Equation 3.2.

It is important to note that, as a result of testing, cells meeting certain criteria are excluded from the calibration procedure. First, cells that are 100 percent restricted from future population growth by the spatial mask (*l,* Equation 3.2) are excluded, as the value of V_i in these cells (0), renders the observed value of A_i inconsequential. Second, the distribution of observed A_i was found, in most cases, to include significant outliers that skewed coefficient estimates in Equation A.3. In most cases, these values were found to correspond with very lightly populated cells where a small over or under-prediction of the population in absolute terms (e.g. 100 persons) is actually quite large relative to total population within in the cell (e.g. large percent error). The value of A_i (the weight on potential), necessary to eliminate these errors, is often proportional to the size of the error in percentage terms, and thus can be quite large even though a very small portion of the total population is affected. Including these large values in Equation A.3 would have a substantial impact on coefficient estimates. To combat this problem, the most extreme 2.5 percent of observations are eliminated on either end of the distribution. Third, because the model is calibrated to urban and rural change separately, cells in which rural population was reclassified as 100 percent urban over the decade (2000-2010) were excluded, as the effect would be misleading (in the rural distribution of change it would appear an entire cell was depopulated, while in the urban change distribution the same cell would appear to grow rapidly). It would be incorrect to attribute these changes to sectoral impacts when, in fact, they are the result of a definitional change. In most cases these exclusions eliminate 5-10 percent of grid cells.

A.3 FUTURE DIRECTIONS

Key features of the gravity approach to modeling future population distributions include its flexibility in producing alternative outcomes that are consistent with qualitative global change narratives such as the Shared Socioeconomic Pathways (SSPs), as well the ability to calibrate the model to historical data, thus grounding the results in observed outcomes. Additionally, the model can accommodate alternative national and sub-national projections of urban/rural change, additional parameters and/or alternative mathematical forms of distance decay, varying assumptions regarding the habitable of land parcels, and is applicable at varying spatial scale and/or levels of aggregation. The gravity framework is also advantageous in that it is easily expanded or altered to consider additional spatially explicit climate, sectoral impact, socio-economic, or geopolitical data that may aid tailoring the model to specific countries, regions, or localities. The novel approach to estimating climate change-induced internal migration introduced here considered a specific set of scenarios and sectoral impacts corresponding to two plausible socio-economic and climate futures. However, as a tool for generating scenarios and exploratory research the gravity structure appears to hold significant promise.

A.3.1 Country and Regional Downscaling

For purposes of comparability across countries and regions, as well as scenarios, the approach adopted for this work required that all model inputs were spatially and temporally consistent across all countries. This constraint restricts data inputs largely to those that are globally available. However, in many cases a richer, more detailed set of climate, biophysical, socio-economic, and political indicators are available at the regional, national, sub-national, and local level. Downscaling can easily be achieved. Significant model refinements resulting in higher resolution and therefore more detailed projections (free from the constraint of global data consistency) are one of many possible future applications of the gravity approach.[38] Additionally, in regions for which detailed historic migration data exist, the model can be expanded to project bi-lateral migration flows potentially incorporating machine learning techniques to improve scenario-based predictive capacity. At the national or subnational and city levels there is significant opportunity for the enhanced application of the approach presented here.

A.3.2 Adding Additional Climate Impacts, Geophysical Detail, and Climate Feedbacks

In this report we considered the climate impact on two sectors, agriculture and water, in addition to sea-level rise and storm surges (coastal populations and infrastructure). The ISIMIP fast-track projections include projections related to two additional sectors (biomes and health). The ISIMIP 2 was launched in May of 2013 and is intended to last four years, broken into two, two-year segments (ISIMIP 2.1 and ISIMIP 2.2). The fisheries, permafrost, biodiversity, and energy sectors have been added to the original fast-track sectors for this phase of the project. Some of the data from ISIMIP 2.1 are already becoming available. These data are easily incorporated into the gravity framework, either through the existing A(i)

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[38] Impact simulations driven by regional climate models (RCMs) are not yet available via ISIMIP. RCM-driven impact simulations are a desirable next step, and would particularly be beneficial for mountainous countries in which orography plays a strong role in local rainfall.

index or through additional indices that exert influence over the attractiveness or repulsiveness of specific locations. Future work should, where appropriate, include an expanded catalog of sectoral impact data relating to a wider range of livelihoods. In addition to sectoral impacts, the existing geospatial mask can be expanded to include additional geophysical characteristics deemed important, including those that are not temporally static such as projected changes in coastlines, and the gravity field can easily accommodate additional detail including, but not limited to, the projected availability of certain resources, anticipated response to climate feedbacks, resource availability, and policy designed to influence settlement patterns.

A.4 GEOSPATIAL PROCESSING AND DATA VISUALIZATION METHODS

In addition to the modeling methods, it is important to describe the methods used for generation of climate migrant estimates and data visualization. This section describes those methods.

Beyond the population distribution modeling that includes the sectoral climate impacts for crops and water, as well as sea level rise, results presentation depended on two additional sets of spatial population projections (Table A.1). In one set of projections, only the SSPs are used to produce a no climate impacts (development only) set of population distributions. Also, a counterfactual population projection based on 2010 population distributions, but scaled according to the SSP2 and SSP4 population totals by country and decade, was produced. It is “counterfactual” because it is a scenario in which there is no migration, and all population growth is a function of natural increase within each grid cell. These additional spatial population projections were produced in order to develop estimates of climate migrants and other internal migrants in ways described under Section A.4.1.

Table A.1: Spatial population projection scenarios

Climate impacts scenarios (combining ISIMIP sectoral impacts by RCP with SSPs)	No climate impacts (SSP-only) population projections used for comparison	Counterfactual population projections
Pessimistic reference (RCP8.5/SSP4): Population is projected based on ISIMIP sectoral impacts model outputs for RCP8.5 and on development trajectories found in SSP4	SSP4: Population is projected based on development trajectories found in SSP4	SSP4 Counterfactual: Population is projected using the spatial population distribution in 2010, but proportionally scaled to match the population totals for each decade under SSP4
More inclusive development (RCP8.5/SSP2): Population is projected based on ISIMIP sectoral impacts model outputs for RCP8.5 and on development trajectories found in SSP2	SSP2: Population is projected based on development trajectories found in SSP2	SSP2 Counterfactual: Population is projected using the spatial population distribution in 2010, but proportionally scaled to match the population totals for each decade under SSP2
More climate-friendly (RCP2.6/SSP4): Population is projected based on ISIMIP sectoral impacts model outputs for RCP2.6 and on development trajectories found in SSP4	SSP4: Population is projected based on development trajectories found in SSP4	SSP4 Counterfactual: Population is projected using the spatial population distribution in 2010, but proportionally scaled to match the population totals for each decade under SSP4

Note: Shared Socioeconomic Pathways—SSP2 (moderate development) and SSP4 (unequal development); Representative Concentration Pathways—RCP 2.6 (low emissions) and RCP 8.5 (high emissions); ISIMIP = Inter-Sectoral Impact Model Intercomparison Project

Three approaches were used to develop summaries for data visualization. These are described in the following three sections.

A.4.1 Climate Migration Estimates

In the first approach, totals of climate change-induced migrants (“climate migrants”) are shown for the three scenarios, along with confidence intervals, to understand the scale and trend of migration. To produce these estimates, the total populations in each grid cell for the respective no climate impact (development only) population projections are subtracted from the three spatial population projection scenarios that include climate impacts—i.e. the pessimistic reference, more inclusive development, and more-climate-friendly scenarios. Then, all those grid cells that have positive totals in the region are summed to estimate the number of climate migrants.[39] To arrive at other migrants—shifting populations as a result of the development (SSP) pathways—no climate impacts (SSP only) scenarios were subtracted from the counterfactual population projection. Again, positive grid cells were summed to estimate other migrants (those who move because of development trajectories).

Two types of graphs are used to present the data: linear trend and categorical bar charts. The linear trend charts are used to display the trend in number of climate migrants and climate migrants as a percentage of the total population from 2020 to 2050. The dark line represents the average, and the white area around the dark lines represents the confidence interval across the four model runs. Bar charts were used to display climate migrants and other migrants by scenario and decade, with confidence intervals for bars representing the climate migrants. The other migrants bar has no confidence interval because the results are based on subtracting the counterfactual population distribution from the population distribution of a single SSP model run (SSP2 or SSP4). Confidence intervals for climate migration estimates are generally fairly wide owing to the small number of model runs per scenario, and for reasons further described in Chapter 3 (Box 3.1). The statistical formula for calculating the confidence interval is found in Section A.4.3.

A.4.2 Hotspot Mapping

A second approach of hotspots and coldspots mapping of climate in and out migration, respectively, is used to indicate top areas of attraction and/or repellence across the landscape. These in-migration hotspots are identified for each scenario by taking the top 10 percent of the distribution in increased population densities compared to the respective no climate impact scenarios. The out-migration hotspots reflect the bottom 10 percent of the distribution of decreased population densities compared to the respective no climate impact scenarios. We then overlay the areas for the top 10 percent in-migration hotspots and the bottom 10 percent out-migration hotspots across the three scenarios, and we identify those areas where at least two out of three scenarios coincide. An area qualifies as a hotspot when results are consistent across at least two out of the three scenarios. These are termed climate in- and out-migration hotspots, respectively.

A combination of ArcGIS tools and Python scripting were used to identify which grids cells represented the top and bottom 10 percent referenced above. For example, in the case of in-migration hotspots, for each of the three scenarios a grid cell was flagged with a “1” if it was greater than or equal to the lowest possible population density value for climate migrants in the top or bottom 10 percent. These flags were then added together to determine the total number of scenarios identifying the grid cell as a hotspot. Table A.2 displays the possible results in each grid cell after the flags were added together.

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[39] At the country and regional levels, all in-migration (positive grid cells) must necessarily be balanced by out-migration (negative grid cells), so total migrants can be assessed by summing differences in the positive cells.

Table A.2: Flags for climate in- and out-migration hotspots

Number of scenarios in agreement	Description
0	This grid cell is not within the top or bottom 10 percent. This grid cell is not considered a hotspot.
1	One scenario identifies this grid cell as being in the top or bottom 10 percent. This grid cell is not considered a hotspot.
2	Two scenarios identify this grid cell as being in the top or bottom 10 percent. This grid cell is considered a hotspot.
3	Three scenarios identify this grid cell as being in the top or bottom 10 percent. This grid cell is considered a hotspot.

A.4.3 Climate Migration Estimates for Zones

A third approach addresses migration in select natural and urban zones. This provides a deeper narrative in relation to the coastal zone, urban areas, and rural livelihood zones – reflecting a combination of attractiveness and viability of ecosystems. Within the zones, trends in positive or negative population differences between the three scenarios (pessimistic reference, more inclusive development, and more climate-friendly) and the respective no climate impact scenarios are examined (Table A.1). Positive differences in zones reflect the likelihood that these zones will be more attractive to migrants owing to climate impacts on the water and crop sectors, and negative differences reflect the likelihood that the zone will be less attractive to migrants owing to climate impacts on the water and crop sectors as well as sea level rise. Again, confidence intervals are applied reflecting the range across the four model inputs (see Table 3.3) for each of the three scenarios. The following are the zones used in this analysis:

i. The coastal zone is defined as those areas within 10km of the coastline.
ii. Urban areas are defined by identifying all those areas that have a population of ≥ 300 persons per square kilometer[40], except for South Asia where ≥ 3,000 persons per sq. km is applied (owing to much higher population densities there).
iii. Livelihood zones are aggregations of “anthropogenic biomes”, which reflect a combination of agricultural livelihood types and population densities.

The Zonal Statistics tool summarizes the values of a data set based on its spatial overlay with another data set. This tool was crucial for determining the counts of various projected populations described above in each of the zones, so that differences among the different climate impact scenarios, SSP-only scenarios, and the counterfactuals could be assessed. To produce estimates by zone, we ran the results for each scenario (including the four members of each climate impacts scenario) through zonal statistics in ArcGIS. The zones used for the item (i) was a 10km coastal buffer; the zone used for item (ii) was the urban areas mask dynamically generated for two time slices; and the zone used for (iii) were livelihood zones derived from an aggregation of anthropogenic biomes for the year 2015 (also referred to as “anthromes”; Ellis et al. 2010). Note that the anthropogenic biomes are static, in the sense that their boundaries do not change over the 40 year time horizon from 2010 to 2050 owing to either increases in population density (a key parameter in their definition) or climate changes. This was a necessary simplifying assumption, since projected anthropogenic biomes do not exist.

ArcGIS’s Zonal Statistics as Table tool was used to obtain the total population for each scenario within zones (i) and (iii). For zone (i), the PLACE III data set (CIESIN 2012) – used for the 10km coastal buffer – has a significantly smaller cell size, roughly 1km compared to the scenario’s 14km. When their grid cells are spatially aligned, there are 225 PLACE grid cells within one scenario grid cell. Consequently,

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[40] This is the Eurostat definition of urban densities at 1km resolution, and includes the proviso that contiguous pixels must add up to 5,000 persons to qualify a location as urban (http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban-rural_typology). When applied to grid cell size used in this modeling of approximately 200 sq. km at the equator (193 sq. km to be precise), the total population per grid cell would be 57,880 people if the average population density is 300 persons per sq. km. This would qualify as a small city in most regions of the world.

determining the population within the coastal zone was a multi-step process. First, the number of PLACE grid cells within each scenario grid cell was calculated by running the ArcGIS Zonal Statistics as Table tool and using the COUNT field function within the tools output table. The COUNT field function provides the total number of PLACE cells within a single scenario cell. Within the output table, values within the COUNT field ranged from zero to 225, with 225 identifying the scenario grid cell as completely covered by coastal grid cells. A proportion of the coverage was obtained by dividing the COUNT field by 225. Finally, each grid cell was labeled as "majority coastal" if the proportion was greater than .50 or "not majority coastal" if the proportion was equal to or less than .50. Scenario grid cells that did not intersect with PLACE grid cells were left as NULL. Using the calculated proportions and the majority labels, the total population within the coastal buffer zone could be calculated.

For zone (iii), the livelihood zones, the anthropogenic biomes data set originally had 19 different anthropogenic classes. Using the ArcGIS Reclassify tool these classes were reclassified to create six different classification groups. Table A.3 shows how the values were reclassified.

Table A.3: Reclassification of anthropogenic biomes to create livelihood zones

Original Description	Reclassification
Urban	Dense settlements (populated >=100 persons per sq km)
Mixed settlements	
Rice villages	Rice growing areas
Irrigated villages	Irrigated croplands grouping
Residential irrigated croplands	
Rainfed villages	Rainfed croplands grouping
Residential rainfed croplands	
Populated croplands	
Remote croplands	
Pastoral villages	Pastoral and rangeland grouping
Residential rangelands	
Populated rangelands	
Remote rangelands	
Residential woodlands	Seminatural and wild grouping
Populated woodlands	
Remote woodlands	
Inhabited treeless and barren lands	
Wild woodlands	
Wild treeless and barren lands	

After the data set was reclassified, the ArcGIS Zonal Statistics as Table tool was used to determine which anthropogenic biomes intersected with each scenario grid cell. Since multiple anthropogenic biomes can intersect a grid cell, the "Majority" zonal statistics type was selected. The final output table produced by the tool contained a MAJORITY field. This field contained the value that corresponded to the anthropogenic biome that covered the greatest area of the scenario grid cell. The final output table also included the scenario population projections. Therefore, the total population within each anthropogenic biome could also be calculated, in order to derive the climate migrants as a percent of population.

Creating the urban extents and obtaining the total population within those extents, as described in item (ii), was also a multi-step process. ArcGIS and Python were used together for automation. First, for each of the scenarios, the grid cells that were within the population density threshold were identified. A subset of the original data, comprised of the identified cells, was created. Each individual grid cell within the subset was part of the urban extent and contained the population count value for that area. The ArcGIS Summary Statistics tool was used to calculate the total population within the urban extent area by summing all the grid cell's population count values. The data were saved in tabular format.

For all of the aforementioned zones, and for each country and region of focus, the tabular data, saved in CSV (Coma Separated Values) format, was imported into R and manipulated using "reshape" and "plyr" packages (R Development Core Team 2008). The table was first reshaped from "wide" (i.e. information for each pixel ID was included in multiple columns) to "long" to facilitate the representation of the data by four categories: decades, scenarios, models and anthropogenic biomes. In the next step, the data were aggregated using "ddply" function by summing the climate migrant population (the climate impacts *minus* no climate impacts populations) in each of these four categories. We further aggregated the data by calculating the average and standard deviation of the four model runs per scenario described in Chapter 3 (Table 3.3). These statistics helped us calculate the 95 percent confidence intervals using the following formula:

$$AVG \ \pm z$$

SE is the standard error, and is calculated as $\frac{SD}{\sqrt{n}}$, where SD is the standard deviation and n is the number of model runs.

The z value for the 95 percent confidence interval is 1.96. The value of 1.96 is based on the fact that 95 percent of the area of a normal distribution is within 1.96 standard deviations of the mean.

Thus, the upper/lower limit of the CI is calculated as:

$$\text{AVG} \pm 1.96 * \frac{SD}{\sqrt{n}}$$

In the final step, we plotted data using ggplot function of "ggplot2" R package.

Bar charts were used to represent the climate migration by livelihood zone by scenario and decade, with whiskers used for confidence intervals. For the other zones (coastal and urban), linear trend charts were to display the decadal change along with confidence intervals. The confidence intervals are generally fairly wide owing to the small number of model runs per scenario, and for reasons further described in Chapter 3 (Box 3.1).

REFERENCES

Bertaud, A. and S. Malpezzi. 2003. The spatial distribution of population in 48 world cities: Implications for economies in transition. *Center for Urban Land Economics Research, University of Wisconsin*, *22*.

Bondeau, A., P.C. Smith, S. Zaehle, S. Schaphoff, W. Lucht, W. Cramer, D. Gerten, H. Lotze-Campen, C. Müller, M. Reichstein and B. Smith. 2007. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Change Biology*, 13(3): 679-706.

Clark, C. 1951. "Urban Population Densities." *Journal of the Royal Statistical Society Series a-Statistics in Society,* 114 (4): 490–96. doi: 10.2307/2981088.

Cohen, B. 2004. "Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts." *World Development,* 32 (1): 23–51. doi:10.1016/j.worlddev.2003.04.008.

CIESIN (Center for International Earth Science Information Network), Columbia University. 2011. "Migration and Global Environmental Change: MR4: Estimating Net Migration by Ecosystem and Decade: 1970-2010." London: UK Foresight. http://www.ciesin.columbia.edu/documents/foresight-2011-oct.pdf.

Döll, P., F. Kaspar, and B. Lehner. 2003. A global hydrological model for deriving water availability indicators: Model tuning and validation, *J. Hydrol*., 270(1), 105–134, doi:10.1016/S0022-1694(02)00283-4.

Florke, M, E Kynast, I Barlund, S Eisner, F Wimmer, and J Alcamo. 2013. "Domestic and Industrial Water Uses of the Past 60 Years as a Mirror of Socio-Economic Development: A Global Simulation Study." *Global Environmental Change-Human and Policy Dimensions,* 23 (1): 144–56. doi:10.1016/j.gloenvcha.2012.10.018.

Frieler R. Betts, E. Burke, P. Ciais, S. Denvil, D. Deryng, K. Ebi, T. Eddy, K. Emanuel, J. Elliott, E. Galbraith, S.N. Gosling, K. Halladay, F. Hattermann, T. Hickler, J. Hinkel, V. Huber, C. Jones, V. Krysanova, S. Lange, H.K. Lotze, H. Lotze-Campen, M. Mengel, I. Mouratiadou, H. Müller Schmied, S. Ostberg, F. Piontek, A. Popp, C.P.O. Reyer, J. Schewe, M. Stevanovic, T. Suzuki, K. Thonicke, H. Tian, D.P. Tittensor, R. Vautard, M. van Vliet, L. Warszawski, and F. Zhao, K. 2017. "Assessing the Impacts of 1.5 °C Global Warming — Simulation Protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b)." *Geosci. Model Dev.* 10, 4321-4345. doi:10.5194/gmd-2016-229.

Gosling, S.N., J. Zaherpour, N. J. Mount, F. F. Hattermann, R. Dankers, B. Arheimer, L. Breuer, J. Ding, I. Haddeland, R. Kumar, D. Kundu, J. Liu, A. van Griensven, T. I. E. Veldkamp, T. Vetter, X. Wang, X. Zhang. 2017. *Climatic Change*, 141: 577. https://doi.org/10.1007/s10584-016-1773-3.

Hattermann, F.F., V. Krysanova, S. N. Gosling, R. Dankers, P. Daggupati, C. Donnelly, M. Flörke, S. Huang, Y. Motovilov, S. Buda, T. Yang, C. Müller, G. Leng, Q. Tang, F. T. Portmann, S. Hagemann, D. Gerten, Y. Wada, Y. Masaki, T. Alemayehu, Y. Satoh, L. Samaniego. 2017. *Climatic Change,* 141: 561. https://doi.org/10.1007/s10584-016-1829-4.

Hillson, R., J. D. Alejandre, K. H. Jacobsen, R. Ansumana, A. S. Bockarie, U. Bangura, J. M. Lamin, A. P. Malanoski and D. A. Stenger. 2014. "Methods for Determining the Uncertainty of Population Estimates Derived from Satellite Imagery and Limited Survey Data: A Case Study of Bo City, Sierra Leone." *PLoS One,* 9 (11). doi:ARTN e112241 10.1371/journal.pone.0112241.

Liu, J., J. R. Williams, A. J. B. Zehnder, and H. Yang. 2007. "GEPIC - Modelling Wheat Yield and Crop Water Productivity with High Resolution on a Global Scale." *Agricultural Systems,* 94 (2): 478–93. doi:10.1016/j.agsy.2006.11.019.

McSweeney, C., and R. Jones. 2016. "How Representative Is the Spread of Climate Projections from the 5 CMIP5 GCMs Used in ISI-MIP?" *Climate Services,* 1: 24–29. doi:https://doi.org/10.1016/j.cliser.2016.02.001.

Müller, C., J. Elliott, J. Chryssanthacopoulos, A. Arneth, J. Balkovič, P. Ciais, D. Deryng, C. Folberth, M. Glotter, S. Hoek, T. Iizumi, R.C. Izaurralde, C. Jones, N. Khabarov, P. Lawrence, W. Liu, S. Olin, T.A.M. Pugh, D. Ray, A. Reddy, C. Rosenzweig, A.C. Ruane, G. Sakurai, E. Schmid, R. Skalsky, C.X. Song, X. Wang, A. de Wit, and H. Yang, 2017: Global gridded crop model evaluation: Benchmarking, skills, deficiencies and implications. *Geosci. Model Dev.*, 10, 1403-1422, doi:10.5194/gmd-10-1403-2017.

Schewe, Jacob, Jens Heinke, Dieter Gerten, Ingjerd Haddeland, Nigel W. Arnell, Douglas B. Clark, Rutger Dankers, Stephanie Eisner, Balázs M. Fekete. Felipe J. Colón-González, Simon N. Gosling, Hyungjun Kim, Xingcai Liu, Yoshimitsu Masaki, Felix T. Portmann, Yusuke Satoh, Tobias Stacke, Qiuhong Tang, Yoshihide Wada, Dominik Wisser, Torsten Albrecht, Katja Frieler, Franziska Piontek, Lila Warszawski, and Pavel Kabat. 2014. "Multimodel Assessment of Water Scarcity under Climate Change." *Proceedings of the National Academy of Sciences,* 111 (9): 3245–50. doi:10.1073/pnas.1222460110.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl. 2012. "An Overview of Cmip5 and the Experiment Design." *Bulletin of the American Meteorological Society,* 93 (4): 485–98. doi:10.1175/Bams-D-11-00094.1.

Warszawski, L., K. Frieler, V. Huber, F. Piontek, O. Serdeczny, and J. Schewe. 2014. "The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): Project Framework." *Proceedings of the National Academy of Sciences*, 111 (9): 3228–32. doi:10.1073/pnas.1312330110.

Appendix B

ISIMIP Water and Crop Model Results

Climate impacts on water availability and crop productivity will have important impacts on the population potential of given locations in the gravity model. This appendix provides the water and crop production indices and the climate background for each of the regions. This is important background information for the modeling results described in Chapters 4 and 5. This is because the climate impacts are an input to the gravity model and, when combined with parameters derived from the development scenarios (the SSPs), directly affect the population potential of regions within countries. Thus, these results aid in the interpretation of results related to population redistribution and climate migration.

In each section major results for the regions from the IPCC Fifth Assessment report or more recent climate science are summarized. Then, ISIMIP average index values for annual surface water availability and crop productivity during the period 2010-50 are discussed, with reference to respective map figures. White (blank) areas on maps representing crop model results represent areas where there is no current crop production. While crop areas may change in the future, our modeling is based on the assumption of constant crop areas.

Recall from Equation 3.1 in Chapter 3, that the index represents the deviation from the long-term average, with values such as 0.2 representing 20 percent above the baseline average, and -0.6 representing 60 percent below the baseline average. Positive and negative values are represented in blue scale and red scale, respectively, with increasing color saturation representing higher values (more positive or negative values, respectively) on both scales.

The long-term averages depicted in the map figures are useful to consider in the context of projected population outcomes, as differences across population distribution scenarios and relative to the no-climate scenarios are driven in part by these indicators. It is important to remember, however, that the modeling approach explicitly considers 10-year time steps, not one 40-year time stretch. Over each period the projected change in urban and rural population is influenced by decadal deviation from baseline conditions in water availability and crop production. Thus, this 40-year index could mask, for example, above average results in the first two decades, and below average results in the last two decades.

It is also important to remember that these model results represent plausible scenarios of future changes in water resources and agriculture, which are consistent with the scientific literature; but they do not represent predictions, nor the most likely outcomes. Consequently, the same is true for the population model results based on these scenarios. The reader is referred to the IPCC's Working Group 1 Fifth Assessment Report report (especially chapters 11 and 12) for a comprehensive account of uncertainties and likelihood estimates of future climatic changes.

B.1 ISIMIP WATER AND CROP MODEL RESULTS FOR EAST AFRICA

The ISIMIP models, which are driven by two different GCMs, reflect different patterns and uncertainties in the region (Box B.1). The water models driven by the HADGEM2-ES GCM (Figure B.1, top four maps) mostly project the region to have higher average water availability in 2010-50 than in the baseline, except eastern Tanzania, northern Mozambique, Malawi, and eastern Zambia. Water declines relative to baseline are particularly strong in northern Tanzania. Water models driven by the IPSL-CM5A GCM (Figure B.1, bottom four maps) show drying in northern Mozambique under RCP2.6 and southern Mozambique under RCP8.5.

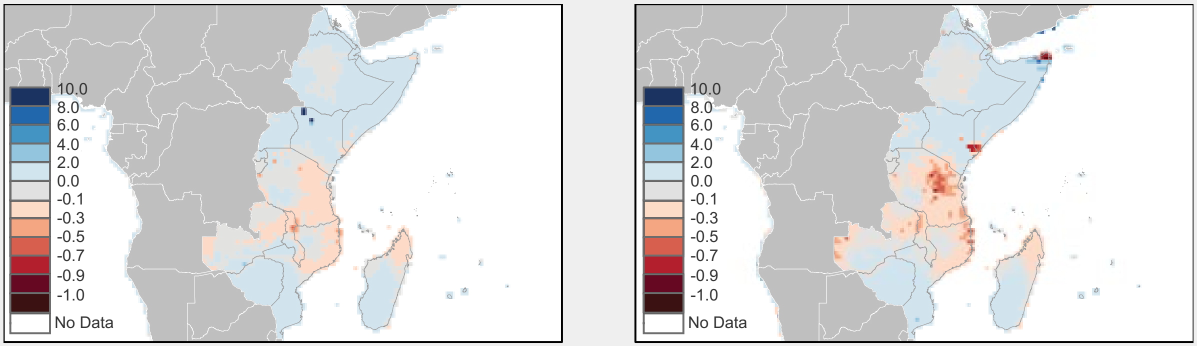
For crop production, the greater differences are between the two crop models—IPJmL-crops and GEPIC. Under LPJmL there are generally modest deviations from the baseline except for parts of Ethiopia (Figure B.2, maps on left side), where there are stronger positive signals in the northern highlands. Under GEPIC, northern Kenya has strong negative impacts, and in some scenarios there are also negative impacts around Lake Victoria.

Overall, this region shows fairly distinct trends that are driven more by the GCM-sectoral model combinations than by the warming reflected in the RCPs. One sees fairly strong negative impacts in selected sub-regions under both RCPs. This may reflect the fact that between now and 2050, the differences in total temperature increase between the high and low RCPs are not that great, and they only bifurcate substantially after 2050 (Figure B.2).

Box B.1: Uncertainties in climate projections in East Africa

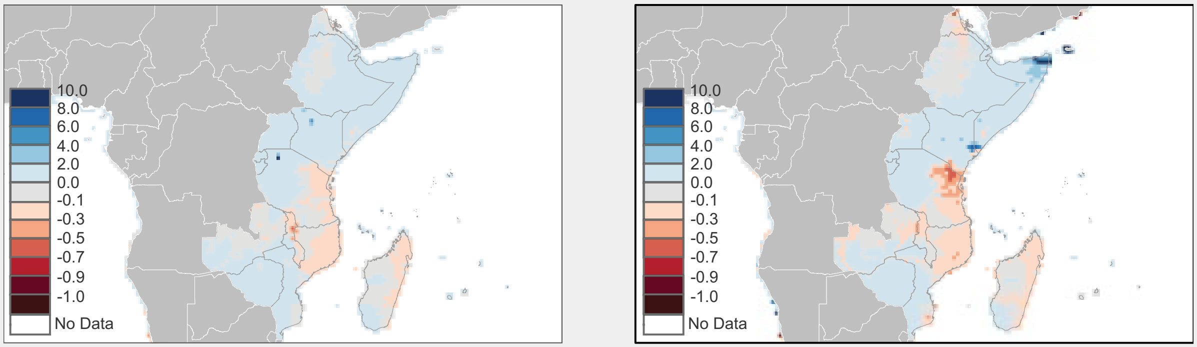
The East Africa region—from Zimbabwe and Swaziland in the south to Ethiopia in the north—comprises three distinct climatic regions, with varying degrees of uncertainty in each. The smallest of the three climatic regions in East Africa is the eastern Sahel, which is only found in northern Ethiopia. The eastern Sahel has sometimes divergent precipitation projections across GCMs, but broadly speaking, the models used in the IPCC fifth assessment report suggest a reasonably robust wetting (increased precipitation trend) for the region (Biasutti 2013). This wetting is mostly concentrated at the end of the rainy season. For coastal East Africa, which comprises the majority of the countries in this region, the climate is very different. Here there are two rainy seasons that lie between the northern hemisphere summer and winter monsoons. In terms of average annual rainfall, coastal East Africa is semi-arid due to the cool waters offshore (Yang and others 2015a). Climate models tend to, in general, underestimate east-west sea surface temperature (SST) gradients and to weaken them further under greenhouse gas forcing (Yang and others 2015b). Hence, they predict coastal East Africa to get wetter. However, coastal East Africa has gotten drier over the past century (Williams and Funk 2011). This may partially be due to natural variability; however, it may also be that the GCMs do not well-represent the role of ocean dynamics in influencing tropical SSTs. This inability means the models do not correctly represent the seasonal cycle of precipitation in coastal East Africa (Yang and others 2015b). Furthermore, it may be that the east-west SST gradients could actually increase, which would tend to result in drier conditions, not wetter (R. Seager, *personal communication*). Finally, the southern Africa region—comprising Zimbabwe, Zambia, southern Mozambique, and southern Madagascar—is an already dry region that is likely to get drier owing in part to increased temperature trends (Christenson and others 2014). There is medium confidence in projections showing reduced precipitation in the Austral winter in this region.

Figure B.1: ISIMIP average index values during 2010-50 against 1970-2010 baseline for water availability, from LPJmL/water (left) and WaterGap (right), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5, East Africa



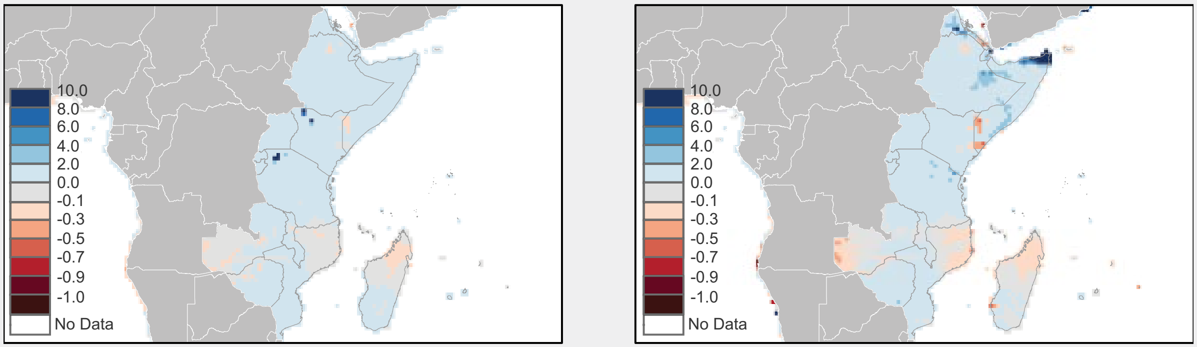
LPJmL, HadGEM2-ES, RCP2.6

WaterGAP, HadGEM2-ES, RCP2.6



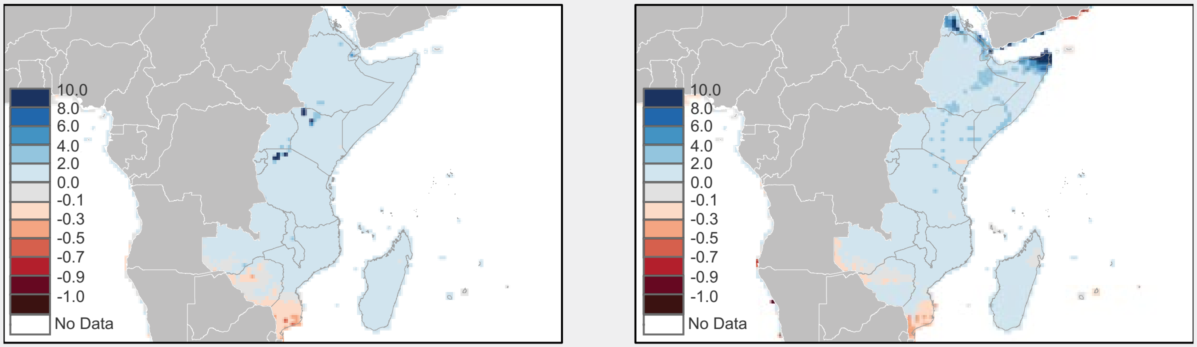
LPJmL, HadGEM2-ES, RCP8.5

WaterGAP, HadGEM2-ES, RCP8.5



LPJmL, IPSL-CM5A, RCP2.6

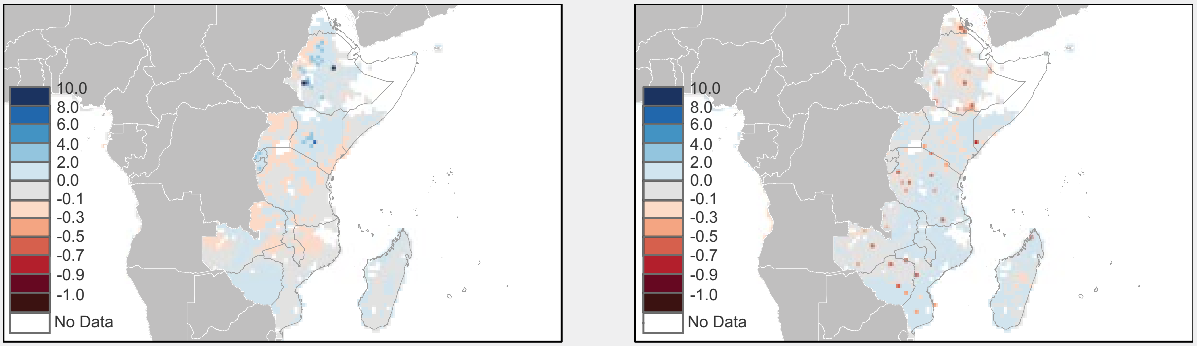
WaterGAP, IPSL-CM5A, RCP2.6



LPJmL, IPSL-CM5A, RCP8.5

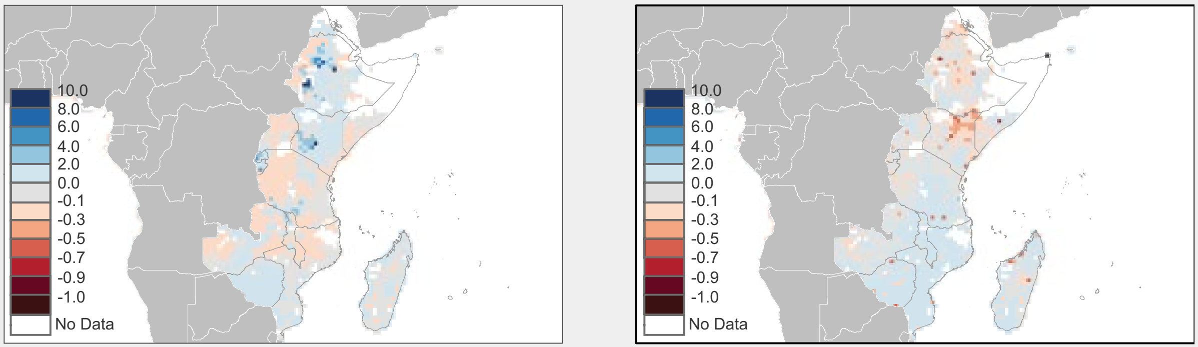
WaterGAP, IPSL-CM5A, RCP8.5

Figure B.2: ISIMIP average index values during 2010-50 against 1970-2010 baseline for crop production, from LPJmL/crop (left) and GEPIC (right), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5, East Africa



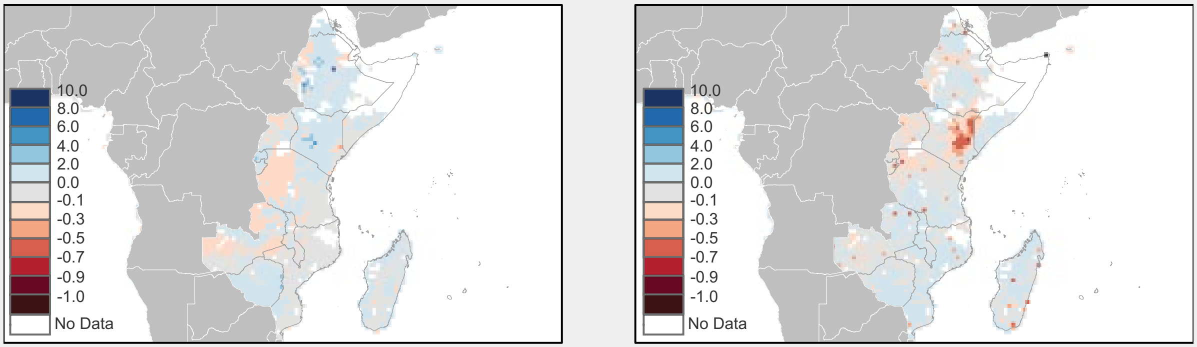
LPJmL, HadGEM2-ES, RCP2.6

GEPIC, HadGEM2-ES, RCP2.6



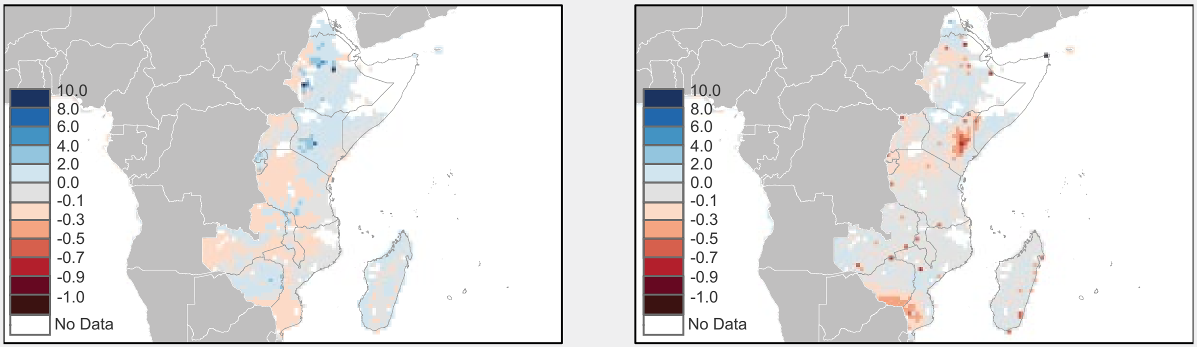
LPJmL, HadGEM2-ES, RCP8.5

GEPIC, HadGEM2-ES, RCP8.5



LPJmL, IPSL-CM5A, RCP2.6

GEPIC, IPSL-CM5A, RCP2.6



LPJmL, IPSL-CM5A, RCP8.5

GEPIC, IPSL-CM5A, RCP8.5

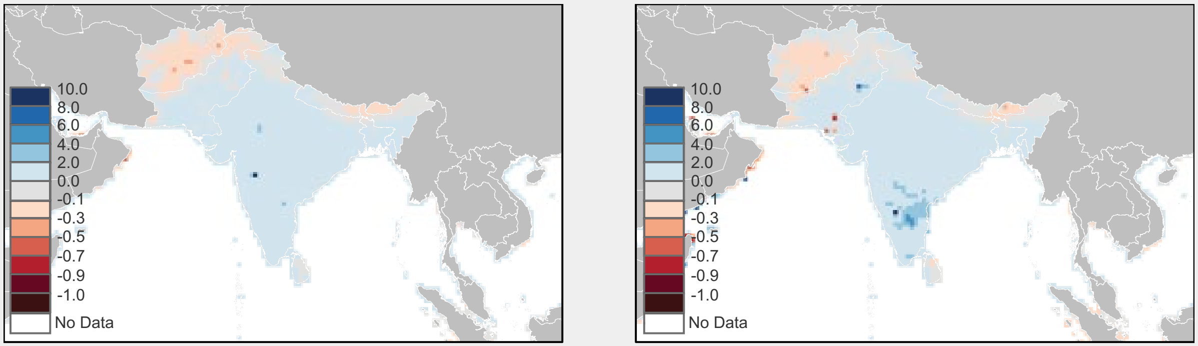
B.2 ISIMIP WATER AND CROP MODEL RESULTS FOR SOUTH ASIA

According to the IPCC (Christensen and others 2014), in South Asia changes in the summer monsoon dominate annual rainfall. There is medium confidence in summer monsoon precipitation increase in the future over South Asia. Overall, projections indicate that more rainfall will be very likely at higher latitudes of South Asia by the mid-21st century under the RCP8.5 scenario. Under the RCP2.6 scenario, more rainfall at higher latitudes is likely by mid-century but substantial changes in rainfall patterns are not likely at low latitudes. Besides these long-term average trends, rainfall variability both within the rainy season and between years is projected to increase in the South Asian monsoon region (Menon, Levermann and Schewe 2013; Menon and others 2013), consistent with observational evidence (Singh and others 2014).

ISIMIP average index values for water availability and crop production during the period 2010-50 are provided in Figures B.3 and B.4, respectively. The ISIMIP water model results are largely consistent with the IPCC projections, showing relatively unchanged or increased water availability during the period 2010-50 (Figure B.3). The only country that shows consistently negative deviations from the long-term baseline is Afghanistan.

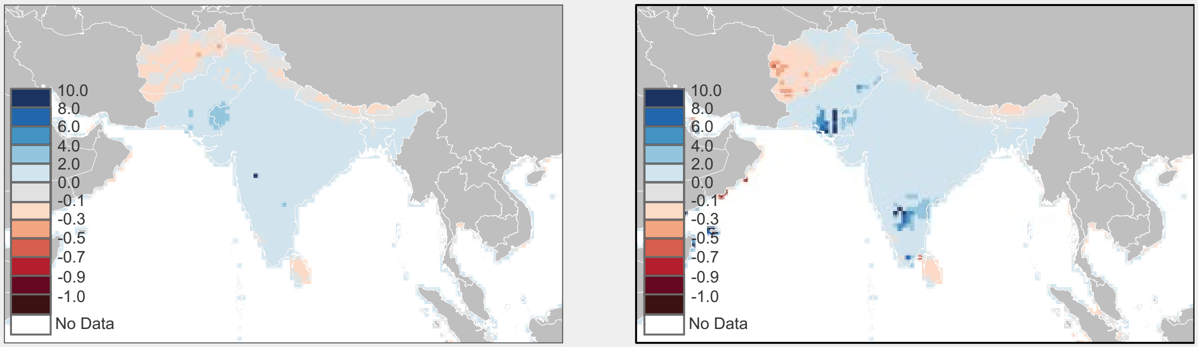
Crop model results are more muted across all GCM-crop model combinations, reflecting the heavy reliance on irrigation across South Asia. The GEPIC model driven by the HADGEM2—ES model (Figure B.4, top two right-hand maps) shows pockets of modest declines along the Indus in Pakistan and the Ganges in India. In the GEPIC model driven by the IPSL-CM5A model, there are more widespread parts of northern India and the highlands in the south that would see declines in crop productivity. These become more intense and cover wider areas under the higher emissions scenario.

Figure B.3: ISIMIP average index values during 2010-50 against 1970-2010 baseline for water availability, from LPJmL/water (left) and WaterGap (right), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5, South Asia



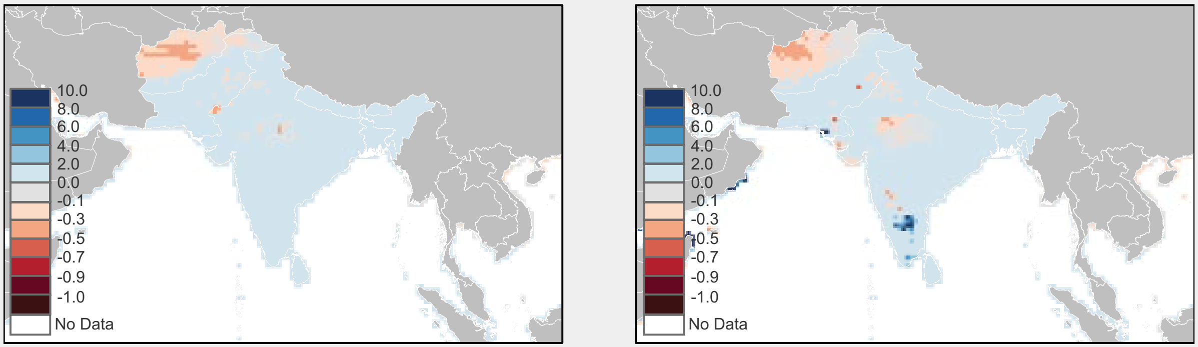
LPJmL, HadGEM2-ES, RCP2.6

WaterGAP, HadGEM2-ES, RCP2.6



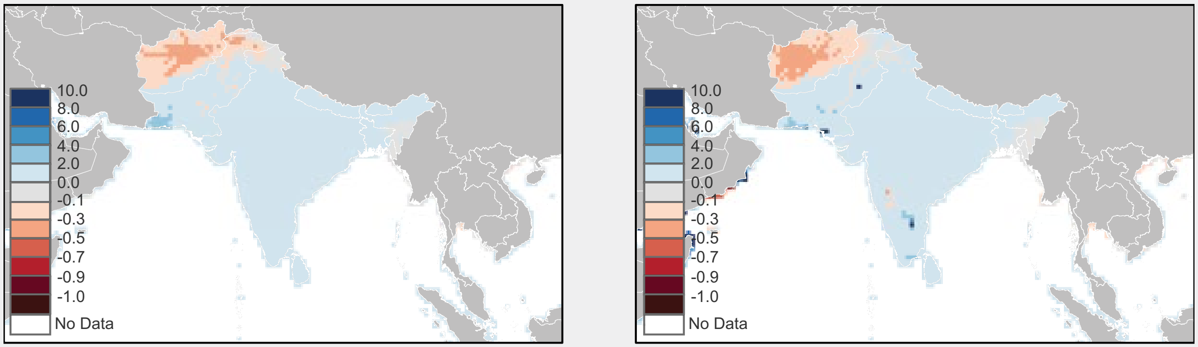
LPJmL, HadGEM2-ES, RCP8.5

WaterGAP, HadGEM2-ES, RCP8.5



LPJmL, IPSL-CM5A, RCP2.6

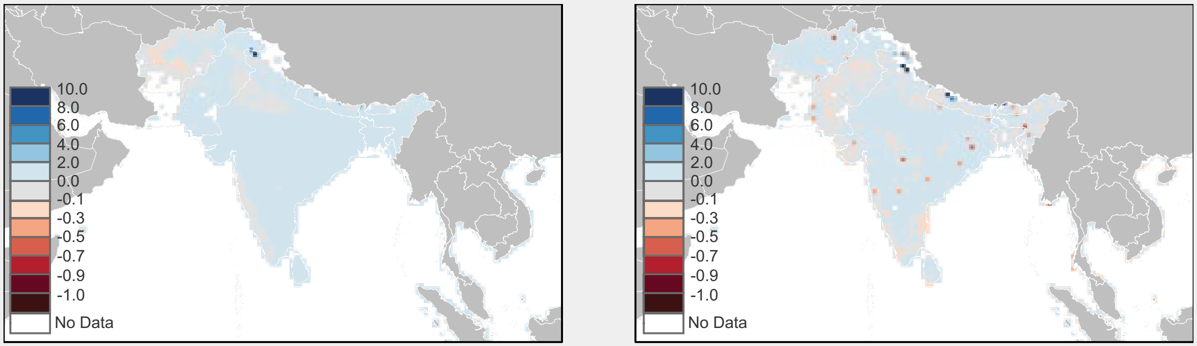
WaterGAP, IPSL-CM5A, RCP2.6



LPJmL, IPSL-CM5A, RCP8.5

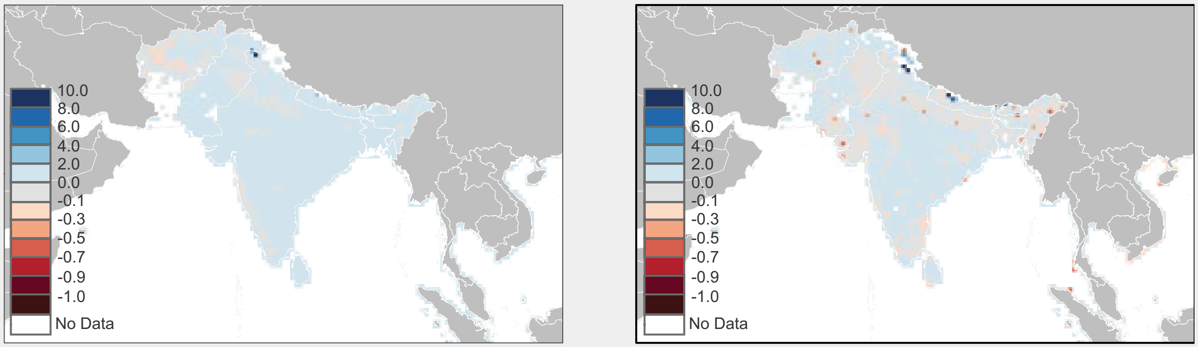
WaterGAP, IPSL-CM5A, RCP8.5

Figure B.4: ISIMIP average index values during 2010-50 against 1970-2010 baseline for crop production, from LPJmL/crop (left) and GEPIC (right), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5, South Asia



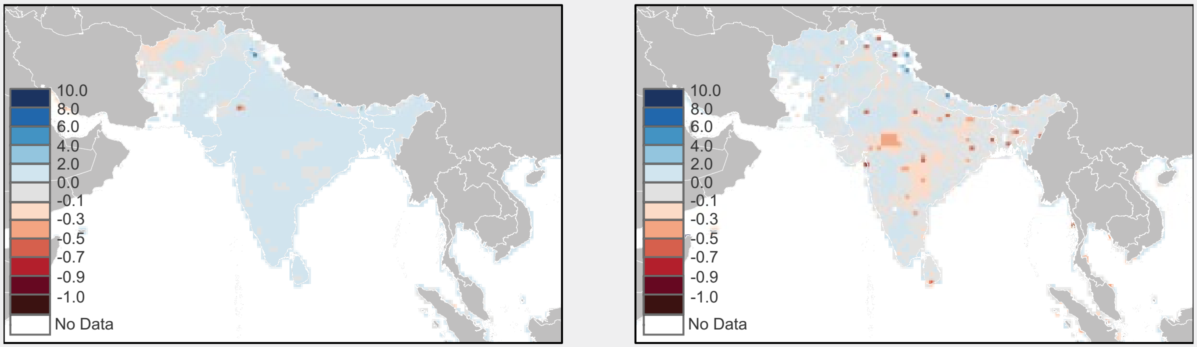
LPJmL, HadGEM2-ES, RCP2.6

GEPIC, HadGEM2-ES, RCP2.6



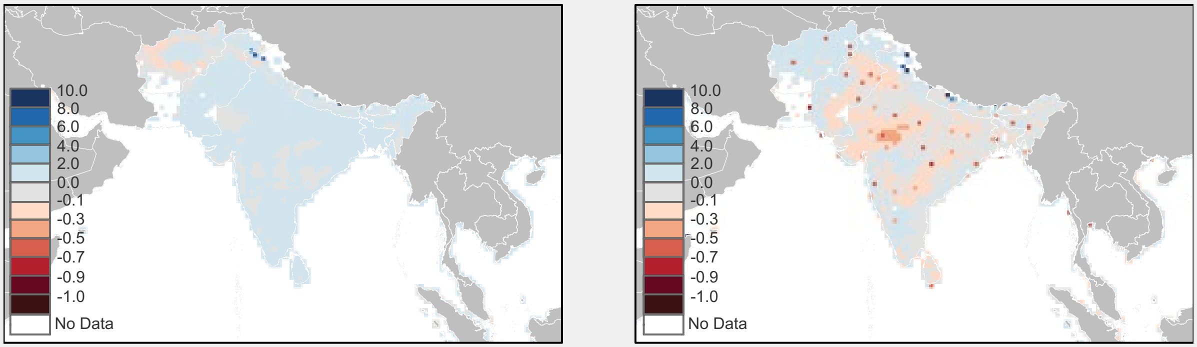
LPJmL, HadGEM2-ES, RCP8.5

GEPIC, HadGEM2-ES, RCP8.5



LPJmL, IPSL-CM5A, RCP2.6

GEPIC, IPSL-CM5A, RCP2.6



LPJmL, IPSL-CM5A, RCP8.5

GEPIC, IPSL-CM5A, RCP8.5

B.3 ISIMIP WATER AND CROP MODEL RESULTS FOR MEXICO AND CENTRAL AMERICA

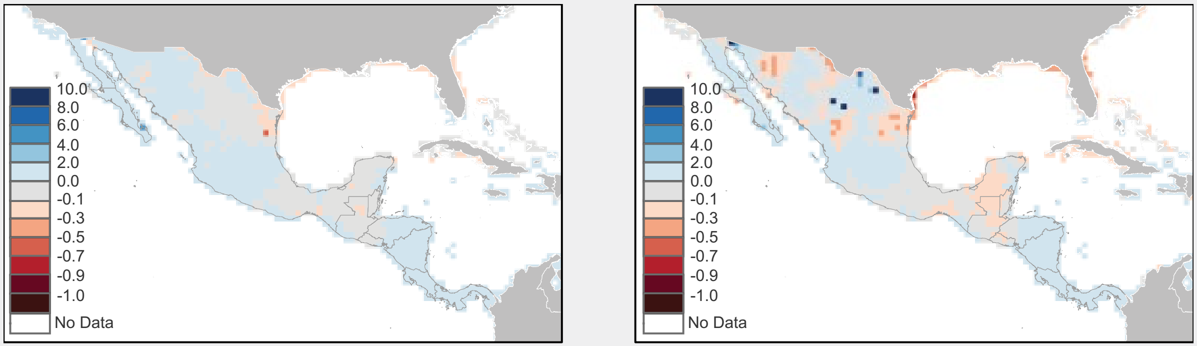
In terms of IPCC results, there is medium confidence that Mexico and Central America will experience a decrease in precipitation over the coming century. Specifically, ensemble mean projections indicate a precipitation decrease from October to March in northern Central America and Mexico, by the end of the century (Christensen and others 2014). CMIP5 GCMs and regional models model project precipitation reductions over Mexico and all of Central America from June to September. The El Niño Southern Oscillation (ENSO) is the main driver of inter-annual climate variability, with El Niño generally being associated with dry conditions in the southern part of the region and wet conditions in the northern part; and La Niña with the opposite pattern (Mason and Goddard 2001). ENSO will continue to influence Mexico and Central America's climate, but changes in ENSO frequency or intensity remain uncertain, although there is some evidence for more extreme El Niño events in the future (Cai and others 2014).

ISIMIP average index values for water availability and crop production during the period 2010-50 are provided in Figures B.5 and B.6, respectively. Consistent with the short-term (Kirtman and others 2013) and long-term (Collins and others 2011) precipitation projections, as reported by the IPCC, water availability changes are different between the different climate models, but show an overall decreasing trend. The water models driven by the IPSL-CM5A GCM (Figure 8.5, bottom for maps) show very sharp decreases in water availability across much of the region, with particularly strong reductions in the Yucatan in the WaterGap model. Under the high emissions scenario with this GCM, much of the region sees strong declines in water availability. For the HadGEM2-ES model, the results are more muted, and the highlands of Mexico and much of Central America actually see no change or even increases in water availability under both emissions scenarios.

There is less disagreement across crop model results. For GEPIC (Figure B.6, right hand maps), the northwest corner of Mexico shows strong production decreases relative to the 1970-2010 period. The LPJmL crop model also shows declines in this region, but they are more muted, and some of the areas of decline under GEPIC actually overlap with increases under LPJmL. Honduras also sees modest declines under LPJmL.

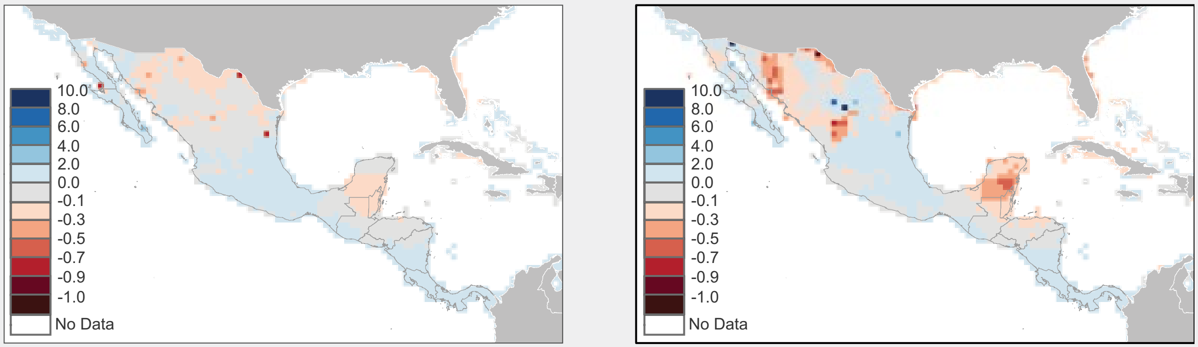
There are differences between RCPs 2.6 and 8.5 across water models, with significantly lower water availability compared to baseline under RCP8.5 than under RCP2.6 in many regions. For the crop models, there are fewer significant differences across emissions scenarios.

Figure B.5: ISIMIP average index values during 2010-50 against 1970-2010 baseline for water availability, from LPJmL/water (left) and WaterGap (right), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5, Mexico and Central America



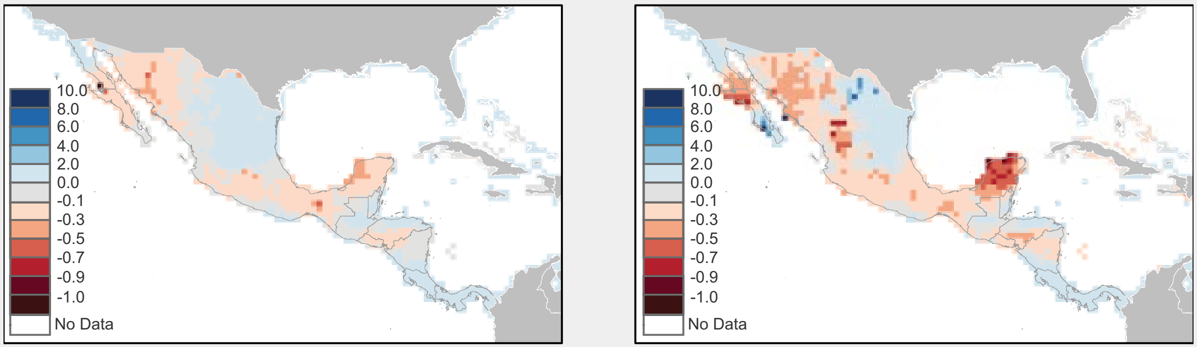
LPJmL, HadGEM2-ES, RCP2.6

WaterGAP, HadGEM2-ES, RCP2.6



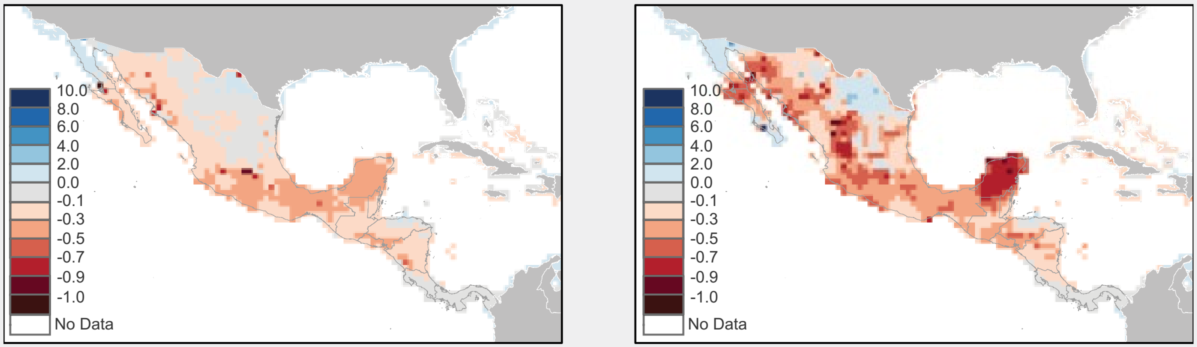
LPJmL, HadGEM2-ES, RCP8.5

WaterGAP, HadGEM2-ES, RCP8.5



LPJmL, IPSL-CM5A, RCP2.6

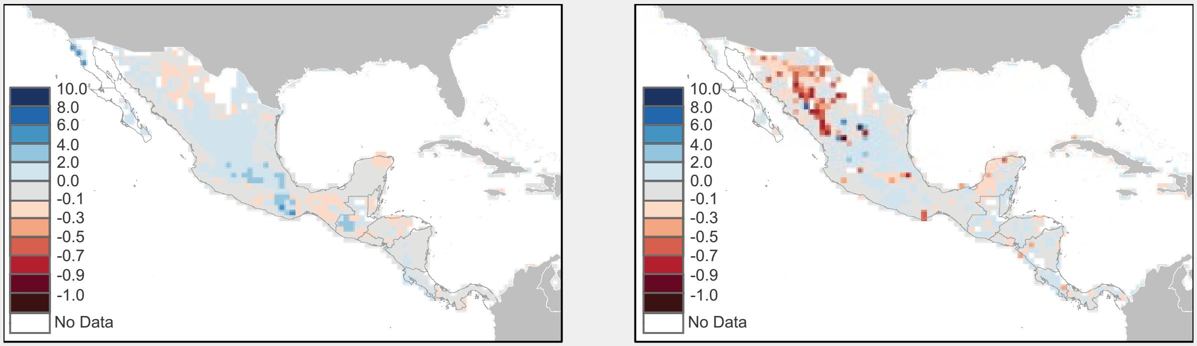
WaterGAP, IPSL-CM5A, RCP2.6



LPJmL, IPSL-CM5A, RCP8.5

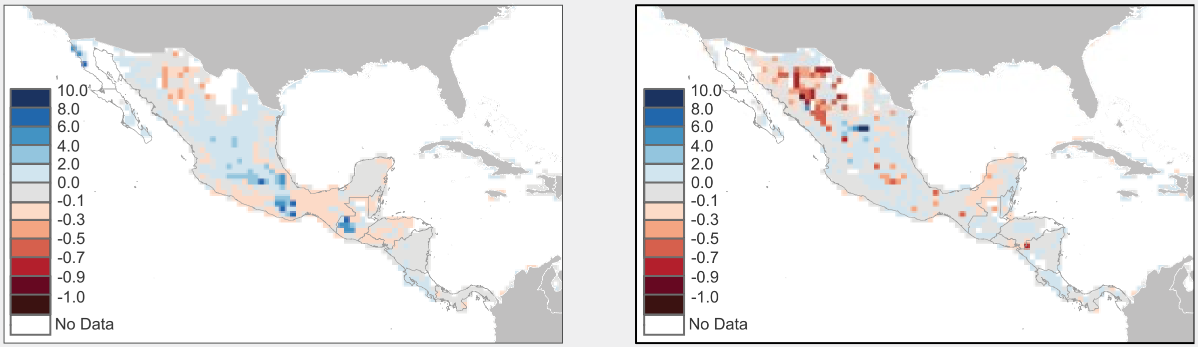
WaterGAP, IPSL-CM5A, RCP8.5

Figure B.6: ISIMIP average index values during 2010-50 against 1970-2010 baseline for crop production, from LPJmL/crop (left) and GEPIC (right), forced with the HadGEM2-ES climate model (top four maps) and IPSL-CM5A (bottom four maps) under RCP2.6 and RCP8.5, Mexico and Central America



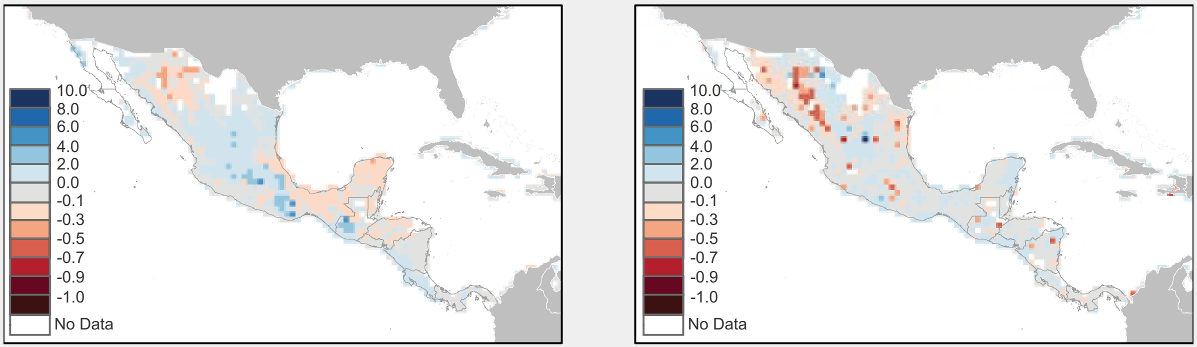
LPJmL, HadGEM2-ES, RCP2.6

GEPIC, HadGEM2-ES, RCP2.6



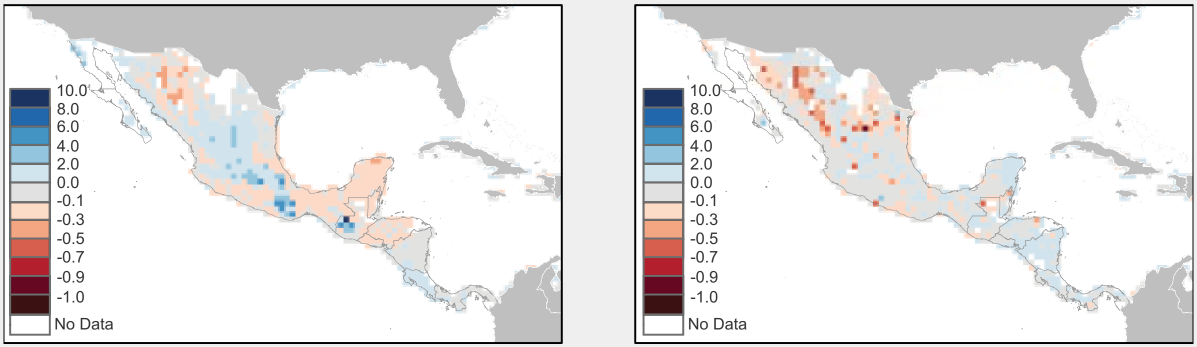
LPJmL, HadGEM2-ES, RCP8.5

GEPIC, HadGEM2-ES, RCP8.5



LPJmL, IPSL-CM5A, RCP2.6

GEPIC, IPSL-CM5A, RCP2.6



LPJmL, IPSL-CM5A, RCP8.5

GEPIC, IPSL-CM5A, RCP8.5

REFERENCES

Biasutti, M. 2013. “Forced Sahel Rainfall Trends in the CMIP5 Archive.” *Journal of Geophysical Research-Atmospheres,* 118 (4): 1613–23. doi:10.1002/jgrd.50206.

Cai, W., S. Borlace, M. Lengaigne, P. van Rensch, M. Collins, G. Vecchi, … F. Jin, . 2014. “Increasing frequency of extreme El Niño events due to greenhouse warming.” *Nature Climate Change,* 5(1): 1–6. http://doi.org/10.1038/nclimate2100

Christensen K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou, J H. 2013. “Climate Phenomena and Their Relevance for Future Regional Climate Change.” In *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change , edited by T F Stocker D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Christenson E., M. Elliot, O. Banerjee, L. Hamrick, and J.E. Bartram. 2014. “Climate-Related Hazards: A Method for Global Assessment of Urban and Rural Population Exposure to Cyclones, Droughts, and Floods.” *International Journal of Environmental Research and Public Health,* 11 (2): 2169–92.

Collins, W. J., N. Bellouin, M. Doutriaux-Boucher, N. Gedney, P. Halloran, T. Hinton, J. Hughes, C.D. Jones, M. Joshi, S. Liddicoat, G. Martin, F. O’Connor, J. Rae, C. Senior, S. Sitch, I. Totterdell, A. Wiltshire, and S. Woodward. 2011. “Development and evaluation of an Earth-system model – HadGEM2” *Geosci. Model Dev. Discuss.* 4: 997–1062. doi:10.5194/gmdd-4-997- 2011

Kirtman, B., S. Power, J. Adedoyin, G. Boer, R. Bojariu, I. Camilloni, F. Doblas-Reyes, A. Fiore, M. Kimoto, G. Meehl, M. Prather, A. Sarr, C. Schär, R. Sutton, G. van Oldenborgh, G. Vecchi, and H. Wang. 2013. “Near-term Climate Change: Projections and Predictability.” In: *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change eds. T. Stocker, D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. Midgley. Cambridge, UK and New York, USA : Cambridge University Press.

Mason, S. J., and L. Goddard. 2001. “Probabilistic Precipitation Anomalies Associated with ENSO.” *Bulletin of the American Meteorological Society*, 82(4), 619–638.

Menon, A., Levermann, A., and Schewe, J. 2013. Enhanced future variability during India’s rainy season. *Geophysical Research Letters*, 40(12), 3242–3247. http://doi.org/10.1002/grl.50583

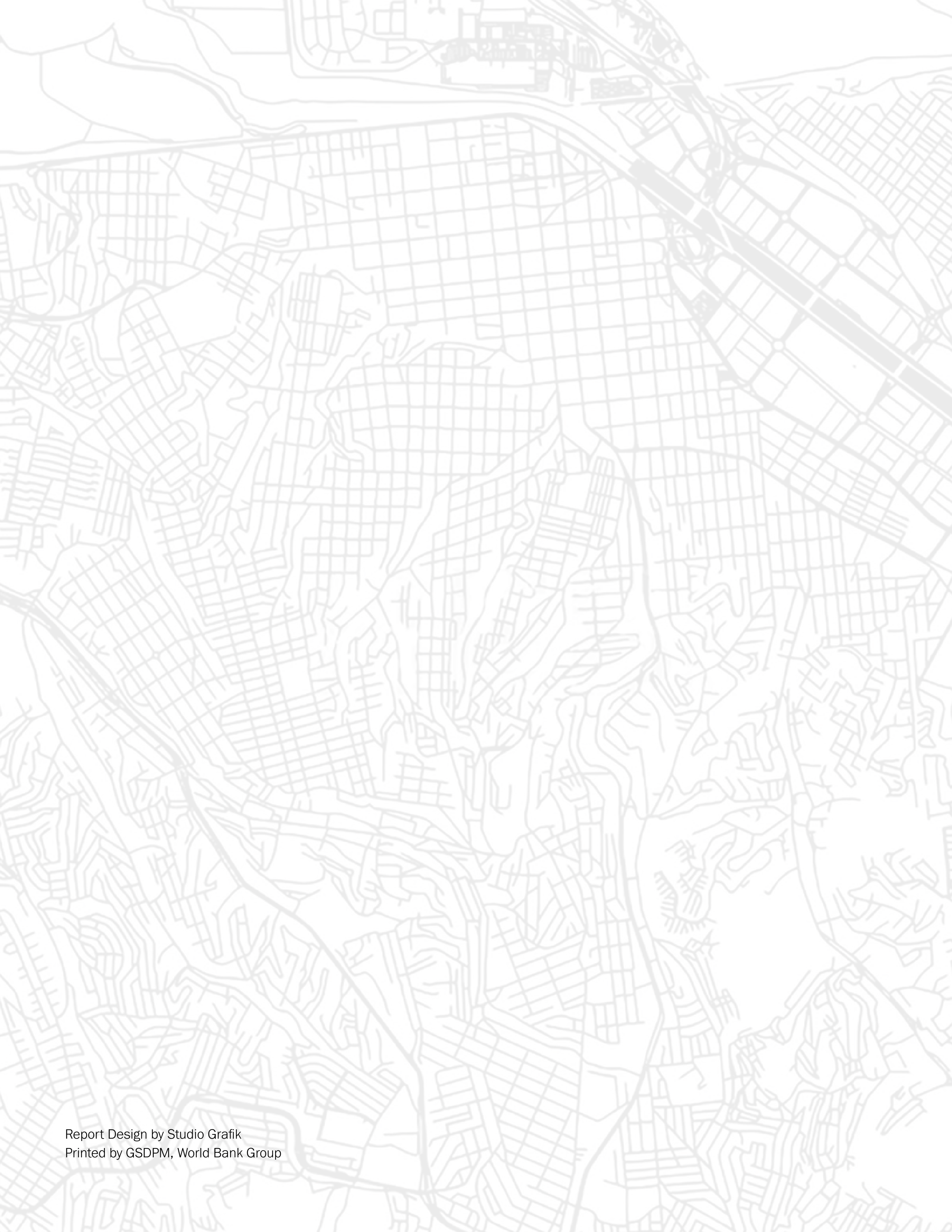
Menon, A., Levermann, A., Schewe, J., Lehmann, J., and Frieler, K. 2013. Consistent increase in Indian monsoon rainfall and its variability across CMIP-5 models. *Earth System Dynamics*, 4(2), 287–300. http://doi.org/10.5194/esd-4-287-2013.

Singh, D., Tsiang, M., Rajaratnam, B., and Diffenbaugh, N. S. 2014. Observed changes in extreme wet and dry spells during the South Asian summer monsoon season. *Nature Climate Change*, 4(6), 456–461. http://doi.org/10.1038/nclimate2208

Williams, A P, and C Funk. 2011. “A Westward Extension of the Warm Pool Leads to a Westward Extension of the Walker Circulation, Drying Eastern Africa.” *Climate Dynamics,* 37 (11–12): 2417–35. doi:10.1007/s00382-010-0984-y.

Yang, W C, R Seager, M A Cane, and B Lyon. 2015a. “The Annual Cycle of East African Precipitation.” *Journal of Climate,* 28 (6): 2385–2404. doi:10.1175/Jcli-D-14-00484.1.

Yang, W C, R Seager, M A Cane, and B Lyon. 2015b. “The Rainfall Annual Cycle Bias over East Africa in CMIP5 Coupled Climate Models.” *Journal of Climate,* 28 (24): 9789–9802. doi:10.1175/Jcli-D-15-0323.1.



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