Alex de Sherbinin is a senior researcher at Columbia University's Earth Institute and deputy manager of the NASA Socioeconomic Data and Applications Center.

Koko Warner researches climate change, adaptation and environmentally induced migration at the United Nations University Institute for Environment and Human Security.

Charles Ehrhart coordinates global response to climate change at CARE International, a nonprofit organization dedicated to alleviating global poverty.

ENVIRONMENT

Casualties of Climate Change

TOM STODDART *Getty Images*

Shifts in rainfall patterns and shorelines will contribute to mass migrations on a scale never before seen

By Alex de Sherbinin, Koko Warner and Charles Ehrhart

SINCE THE BEGINNING OF RECORDED TIME, CLIMATE-FORCED MIGRATIONS HAVE RESHAPED CIVILIZATION. Four thousand years ago a prolonged drought and the resulting famine in Canaan drove Jacob and his sons to Egypt, setting the stage for the famous exodus led by Moses. Three millennia later a prolonged dry period and lack of grazing lands helped to push Mongol armies out of Central Asia as far west as Europe, where many settled and intermarried. And in the 20th century the American Dust Bowl, an ecological catastrophe precipitated by drought and compounded by bad land-management policies, displaced 3.5 million people from the Midwest.

Today this age-old story has a new twist. We are entering an era marked by rapid changes in climate

IN BRIEF

Climate change caused by global warming will disrupt the livelihoods of millions of people, prompting many to move from their homelands.

Here we examine three regions around the world that have already begun to suffer the effects of climate change, leading many to leave.

Predicting exactly who will move and where they will go to is an impossibility, but leaders can implement policies to help alleviate the inevitable suffering.

Wanderers: A family wades through the streets of Chokwe, Mozambique. Increasingly frequent floods there have caused many families to permanently relocate.

brought on by man-made greenhouse gas emissions. Anticipated changes include higher rainfall variability, greater frequency of extreme events (such as droughts and floods), sea-level rise, ocean acidification, and long-term shifts in temperature and precipitation—any of which can profoundly disrupt the ecosystems that supply our basic needs. In our more densely settled world, people may be forced from their homes in numbers never seen before.

Most attention has centered on the plight of low-lying island states threatened by rising sea levels. Under certain scenarios, many of the world's 38 small island states could disappear by the end of this century. Yet the problem faced by the inhabitants of these states is just the tip of the atoll. In India alone, 40 million people would be displaced by a one-meter sea-level rise. Unfortunately, this coastal flooding is far from the only climate-related challenge in South Asia. Models developed by Arthur M. Greene and Andrew Robertson of Columbia University suggest an increase in total monsoon rainfall but a decrease in the frequency of rain, implying more intense rainfall in fewer days. Shifts in the seasonality of river flows (as winter snowpack declines and glaciers shrink) would affect the agricultural livelihoods of several hundred million rural Asians, as well as the food supplies of an equal number of Asian urbanites.

Although it may take decades to understand the full impacts of glacier melting and sea-level rise, the increase in climate-related catastrophes is already a fact. The frequency of natural disasters has increased by 42 percent since the 1980s, and the percentage of those that are climate-related has risen from 50 to 82 percent. The United Nations Office for the Coordination of Humanitarian Affairs and the Internal Displacement Monitoring Center estimates that in 2008, climate-related calamities drove 20 million people from their homes—more than four times the number displaced by violent conflict.

SEE MORE MAPS
ScientificAmerican.com/jan2011/migrations

Forced migration and displacement prompted by climate change is therefore poised to become the international community's defining—and potentially overwhelming—humanitarian challenge in coming decades. In this article, we offer a sense of what the future holds by looking at the factors that have already begun to instigate such movements in three regions of the world. First we consider Mozambique, where a combination of catastrophic floods and periodic droughts has caught rural populations in a double bind. Next we examine the Mekong Delta. Floods there have long been part of the rhythm of life, yet the scale in recent years has surpassed historic precedent, and the country is facing catastrophic losses of productive land from projected sea-level rise. We close with Mexico and Central America, where tropical storms and cyclones have displaced thousands, and drought looms as a constant danger.

It would be folly to attempt to predict the precise size, direction and timing of the migrations to come, and so we will refrain from doing so. It is our hope that by presenting these case studies we can spur fuller analyses of where mass migrations are likely to occur and the development of international and regional plans to help those forced to leave their homes.

The evidence we present in the stories that follow comes from the European Commission's Environmental Change and Forced Migration Scenarios project (EACH-FOR), a global study on environmentally induced migration, and from a mapping exercise conducted by the Center for International Earth Science Information Network (CIESIN) at Columbia's Earth Institute. SA

We would like to acknowledge the contributions by Susana Adamo and Tricia Chai-Onn of CIESIN and the EACH-FOR case study authors Mark Stal, Olivia Dun and Stefan Alscher.

MORE TO EXPLORE

In Search of Shelter: Mapping the Effects of Climate Change on Human Migration and Displacement. Koko Warner et al. Available at www.ciesin.columbia.edu/documents/ClimMigr-rpt-june09.pdf

Environmental Change and Forced Migration Scenarios Project. Case studies and final report available at www.each-for.eu

CARE International Climate Change Information Center: www.careclimatechange.org

Low Elevation Coastal Zone Data and Maps: http://sedac.ciesin.columbia.edu/gpw/lecz.jsp

MOZAMBIQUE:

THE DOUBLE BLOW

Mozambique, a country the size of California and Montana put together, lies along Africa's eastern coast between Tanzania in the north and South Africa in the south. It has a history of migration and government-sponsored resettlement stemming from the nation's socialist past and a 16-year civil war that ended in 1992, during which five million people were forced from their homes. During the four years following the end of the war, more than 1.7 million Mozambicans returned from Malawi, Zimbabwe, Swaziland, Zambia, South Africa and Tanzania.

Although the civil war is behind them, a new crisis is now afflicting Mozambique. In 2000, 2001 and 2007 disastrous floods in the Zambezi and Limpopo river basins displaced hundreds of thousands of people. The floods of 2007 alone displaced more than 100,000 people, half of whom were evacuated to temporary "accommodation centers." In 2007, after earlier high waters had subsided, Cyclone Favio caused the Zambezi to overflow its banks again. During that episode, affected people lost their homes and livelihoods, as well access to medical facilities, sanitation and safe drinking water. Such double and triple blows greatly hinder communities' abilities to recover, given that many people's limited assets have been literally swept away.

In the years after the 2001 floods, the government encouraged residents to permanently resettle away from dangerous floodplains by providing incentives such as infrastructure in a work-for-assistance program. In exchange for making bricks, the government promised to pay for other construction materials and to contribute technical construction assistance. In interviews conducted by EACH-FOR's Mark Stal, displaced people living in resettlement centers

MOZAMBIQUE FLOOD EXTENTS (*flooding*): BRADFIELD LYON *(Hi)Earth Institute, Columbia University*; RAINFALL DATA FROM GLOBAL PRECIPITATION CLIMATOLOGY CENTER (GPCC) AND IRI DATA LIBRARY (*drought*)

indicated that before the past decade, communities would periodically move out of the floodplain to avoid floods but that they had never contemplated relocating permanently.

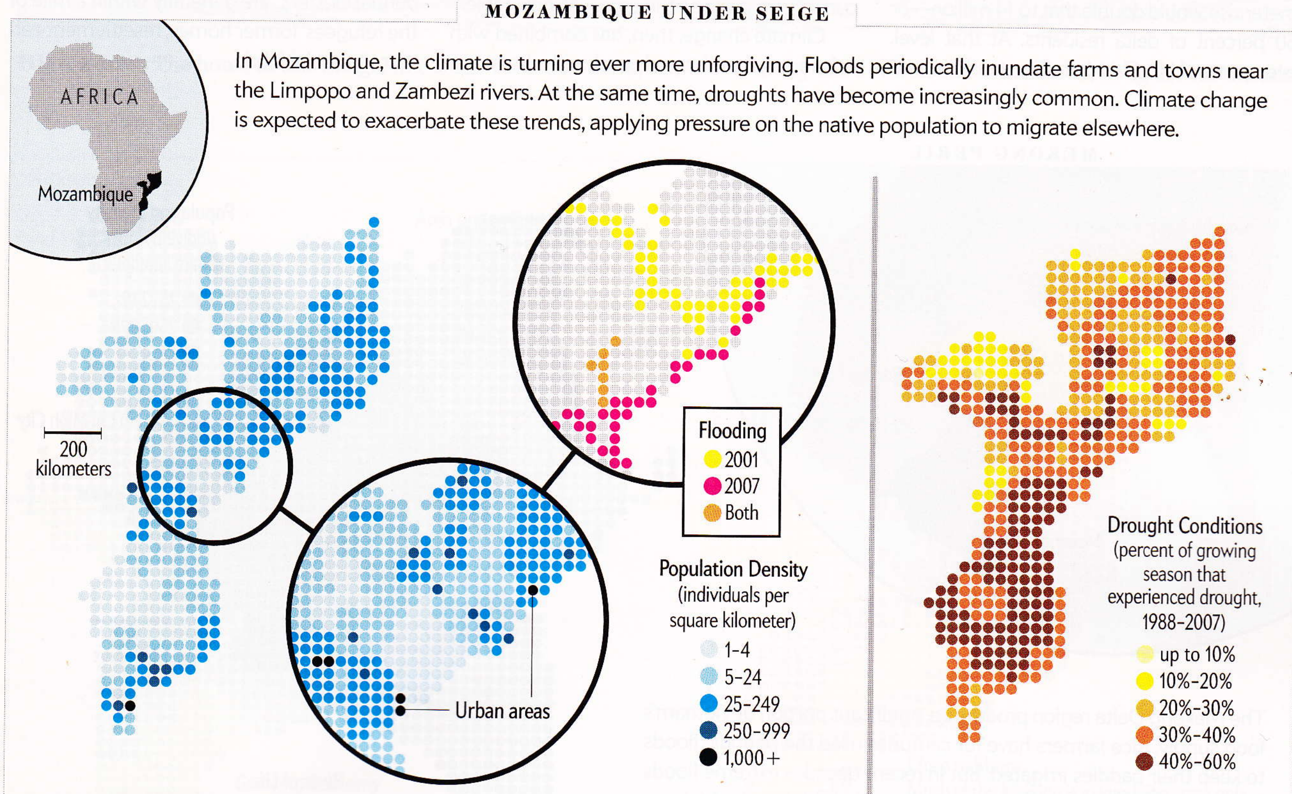
The bitter irony in Mozambique is that the country can be simultaneously hit by drought and flood—as happened in 2007, when the southern part of the country suffered a drought even as the Zambezi farther north was overflowing its banks. Climate models suggest that rainfall levels may increase in the north while decreasing in Mozambique's south. A key element influencing the extent of the trouble will be the spacing and intensity of rainfall; further intensification will only lead to a continuation of the catastrophic flooding that was repeated throughout this decade. Unfortunately, climatologists project even greater variability in this century, with climatic seesawing between extremes of drought and flood, leaving countries such as Mozambique at the mercy of increasingly unpredictable weather patterns.

People who have resettled remain heavily dependent on governmental and international aid because areas to which they have relocated typically lack the infrastructure—schools and health clinics, for example—that would allow for a self-sustaining economy. Frequent crop failure is still the norm. Without outside humanitarian assistance, experts and interviewees suggest that people may need to migrate longer distances or across borders. The main destinations will most likely be Maputo (the capital of Mozambique) and South Africa, given that economic prospects in other cities and neighboring countries are not nearly so bright.

Wishing well: A woman resorts to collecting any water she can scrounge from a nearly dry well in drought-stricken Malange, Mozambique.

MOZAMBIQUE UNDER SEIGE

In Mozambique, the climate is turning ever more unforgiving. Floods periodically inundate farms and towns near the Limpopo and Zambezi rivers. At the same time, droughts have become increasingly common. Climate change is expected to exacerbate these trends, applying pressure on the native population to migrate elsewhere.



The Curse of the Wet
Mozambique's rural population has grappled with increasingly frequent flooding events over the past decade, with some regions suffering from multiple episodes.

The Curse of the Dry
Meanwhile droughts have also hampered food production.

DATA AND APPLICATIONS CENTER (SEDAC), COLUMBIA UNIVERSITY, HTTP://SEDAC.CIESIN.COLUMBIA.EDU/GPW (*population density*); DARTMOUTH FLOOD OBSERVATORY; MOZAMBIQUE FLOOD EXTENTS (*flooding*); BRADFIELD LYON *IRI/Earth Institute, Columbia University*; RAINFALL DATA FROM GLOBAL PRECIPITATION CLIMATOLOGY CENTER (GPCC) AND IRI DATA LIBRARY (*drought*)

Maps by Jen Christiansen

THE MEKONG DELTA:

THE RISING SEA

The Vietnamese portion of the Mekong Delta is home to 18 million people, or 22 percent of Vietnam's population. It accounts for 40 percent of Vietnam's cultivated land surface and more than a quarter of the country's GDP. Its residents grow more than half of Vietnam's rice, produce 60 percent of its fish and shrimp haul and harvest 80 percent of its fruit crop.

All that is threatened. According to the mapping exercise done by Columbia University's Center for International Earth Science Information Network, a one-meter sea-level rise could result in the displacement of more than seven million residents in the delta, and a two-meter rise would double that to 14 million—or 50 percent of delta residents. At that level, even parts of Ho Chi Minh City would be underwater. (We should note that although a two-meter rise in this century is beyond what is generally considered likely, abrupt climate change could create "tipping points" at which the land-based glaciers of Greenland and West Antarctic melt much more quickly than currently anticipated. In this event, a two-meter rise might occur by 2100.)

Flooding has long played an important role in the economy and culture of the area. In the Mekong Delta stretching all the way up into Cambodia, people live with and depend on flood cycles, but within certain bounds. For example, flood depths from half a meter to three meters are considered part of the normal flood regime on which farmers depend. These are referred to as "nice floods" by Vietnamese living in the delta. Higher floods challenge residents' ability to cope and often have harrowing effects on local livelihoods.

In recent decades both the frequency and magnitude of floods exceeding the four-meter mark have increased. EACH-FOR's Olivia Dun conducted interviews with migrants from the delta in Phnom Penh, Cambodia, one of whom noted, "Flooding sometimes threatened our lives. So we came here to find another livelihood." Another said, "My family had crop fields, but in recent years floods occurred very often so the crop was not stable."

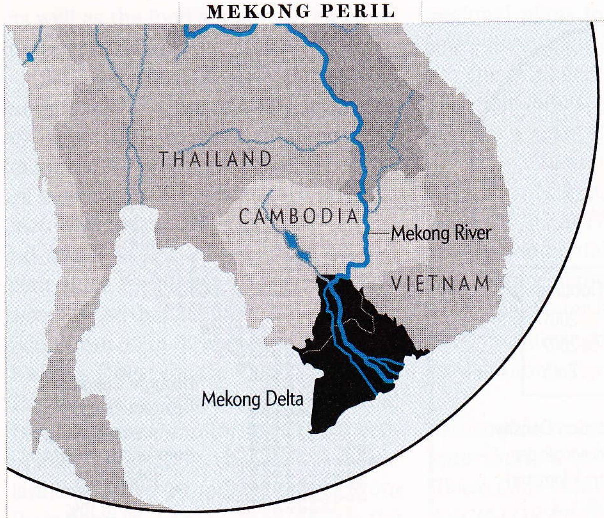
Climate change, then, has combined with existing natural hazards and with the stress placed on the environment by rapid industrialization in Vietnam and upstream countries to put Vietnam's natural resources and those who depend on them in a precarious position. In the face of environmental stressors, people in the Mekong Delta adapt in various ways. Those who have coped by migrating have generally preferred to move to cities, where the economy is growing fastest.

For its part, the government in Vietnam has a program known as "living with floods." As part of this program, agencies are encouraging rice farmers to shift to aquaculture—growing seafood such as shrimp and small fish in enclosed ponds. Along the Mekong River's main stem in An Giang province, the program is also moving people away from the river. Almost 20,000 landless and poor households in this province have been targeted for relocation by 2020. Those scheduled for relocation are generally landless, have nowhere else to go if their houses collapse from flooding or landslides, and are too poor to move to urban areas. For these people, social networks—the fabric of relationships with family, friends and employers—provide the essential links to their livelihoods, because most rely on day-to-day employment as laborers. Although the planned "residential clusters" are generally within a mile of the refugees' former homes, resettlement can tear the social fabric.

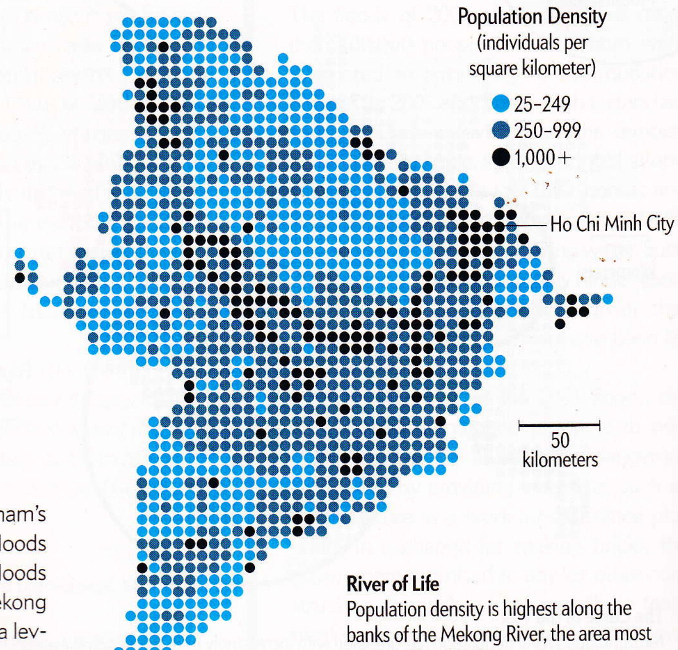
SOURCES: CIESIN; IFPRI; WORLD BANK; CIAT; 2009 GRUMP, BETA VERSION: POPULATION DENSITY GRIDS; SEDAC (*population density*)

HOANG DINH NAM Getty Images (*photograph*); SOURCES: NAVIN RAMANKUTTY ET AL.; 2010, GLOBAL AGRICULTURAL LANDS: CROPLANDS, 2000; SEDAC, HTTP://SEDAC.CIESIN.COLUMBIA.EDU/ES/AGLANDS.HTML (*area under cropland*); ANDREW JARVIS ET AL.; 2008, HOLE-FILLED SRTM FOR THE GLOBE VERSION 4, CGIAR-CSI SRTM 90M DATABASE, HTTP://SRTM.CSI.CGIAR.ORG (*projected flooding area*)

MEKONG PERIL



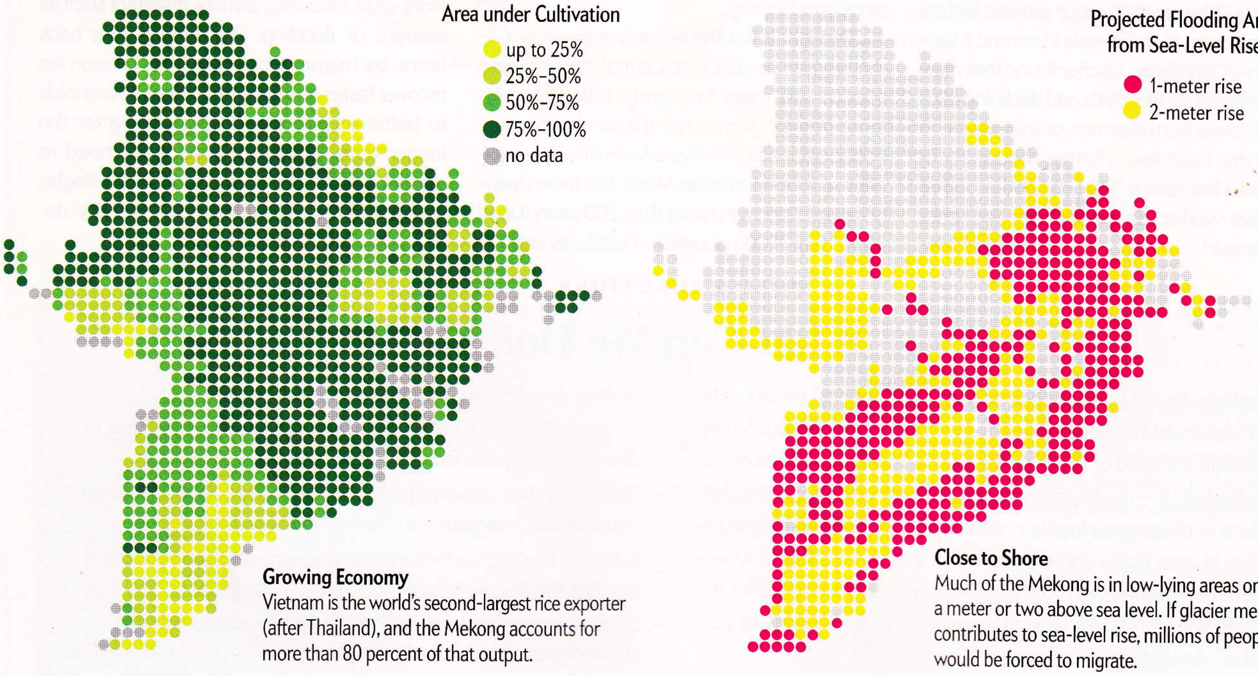
The Mekong Delta region produces a significant portion of Vietnam's food supply. Rice farmers have for centuries used the periodic floods to keep their paddies irrigated. But in recent decades extreme floods have increasingly threatened growing areas. In addition, the Mekong region is vulnerable to sea-level rise. A one-meter increase in sea level would displace more than seven million people from their homes.



River of Life
Population density is highest along the banks of the Mekong River, the area most prone to flooding from excess rains.

High water: The home in this image, like some 400,000 others, was overcome by the worst floods to hit the Mekong in four decades.

HOANG DINH NAM *Getty Images* (*photograph*); SOURCES: NAVIN RAMANKUTTY ET AL.; 2010, GLOBAL AGRICULTURAL LANDS: CROPLANDS, 2000; SEDAC, HTTP://SEDAC.CIESIN.COLUMBIA.EDU/ES/AGLANDS.HTML (*area under cropland*); ANDREW JARVIS ET AL.; 2008, HOLE-FILLED SRTM FOR THE GLOBE VERSION 4, CGIAR-CSI SRTM 90M DATABASE, HTTP://SRTM.CSI.CGIAR.ORG (*projected flooding area*)



Growing Economy
Vietnam is the world's second-largest rice exporter (after Thailand), and the Mekong accounts for more than 80 percent of that output.

Close to Shore
Much of the Mekong is in low-lying areas only a meter or two above sea level. If glacier melt contributes to sea-level rise, millions of people would be forced to migrate.

MEXICO AND CENTRAL AMERICA:

DEADLY STORMS, CRIPPLING DROUGHT

Last drop: A woman walks past a brackish pond in the Tehuacan Valley near Mexico City. Once used for animals, villagers now depend on these ponds for water.

Mexico and Central America are home to almost 10 million farmers, many of whom barely manage to meet their basic needs by growing traditional staples (corn, beans and squash) on steep hillsides. Like farmers anywhere, they depend on moderate rainfall. Too little, and their plants wither and die; too much all at once, and the soil washes down gullies, carrying with it crops and their livelihood.

Sometimes both droughts and storms can hit in the same year. In July 2001, for example, Honduras suffered a drought that affected a quarter of a million people. A few months later a tropical storm flooded the countryside.

Many farmers have already found their livelihoods too precarious and moved north; the great majority of migrants to the U.S. come from poor rural areas in Mexico and Central America. Soil depletion, deforestation and unemployment are among the factors that drive migration—along with the pull of higher wages in El Norte ("the North")—but climatic factors add to the distress. In Tlaxcala in central Mexico, EACH-FOR's Stefan Alscher found that market liberalization in the 1990s and declining rainfall led to lower farm incomes, pushing some to leave. In one interview, a farmer described migration as a last resort: "My grandfather, father and I have worked on these lands. But times have changed.... The rain is coming later now, so that we produce less. The only solution is to go away [to the U.S.], at least for a while."

Climate change is projected to lead to a 10 to 20 percent decline in rainfall runoff in Tlaxcala. Compared with the rest of the region, Tlaxcala may have it easy. Most of the region's irrigation occurs on the coastal plains such as those in Jalisco and Sinaloa—major agricultural states that collectively produce almost 18 percent of the country's agricultural GDP. But according to data from the Intergovernmental Panel on Climate Change, these states may see a 25 to 50 percent decline in water availability by 2080, a change that could lay waste the region's productivity.

Drought is not the region's only worry. Climatologists predict that Central America and Mexico will more frequently suffer from intense tropical storms over the coming century. Past experience provides a taste of what to expect. In 1998 Hurricane Mitch, the most deadly Atlantic storm in more than 200 years, killed more than 11,000 people in Honduras and Nicaragua and caused billions of dollars' worth of damage. In 2007 Tropical Storm Noel flooded up to 80 percent of the state of Tabasco, displacing some 500,000 people. In the past, population displacement triggered by natural hazards has generally been local and short term, but more frequent extreme events may well tempt some to give up and move for good.

Solutions are elusive. In agricultural areas people have long used seasonal migration as a coping strategy. Recognizing that most future migration, like that of the past, is likely to flow toward the U.S. and Canada, policy makers there might consider issuing temporary work visas following climate disasters such as drought or flooding. The money sent back home by migrants can help local economies recover faster and help individual households to better endure the devastation. As for the longer term, regional planners will need to develop water-saving irrigation technologies and alternative livelihoods for farmers depending on rain-fed agriculture.

POLICY SOLUTIONS

What Can We Do?

Migrations forced by climate change could very well become the most important humanitarian challenge of the 21st century. When people are impelled to move—whether because of sea-level rise or extreme events—the international community will need to put protections in place, ensuring that movements are orderly and peaceful, that human rights are respected, and that those affected have a voice in their future. We must act now to prepare ourselves for the challenges to come. We urge the international community to pursue the following:

- Reduce greenhouse gas emissions to safe levels.
- Invest in disaster risk management, which has been shown to decrease the likelihood of large-scale migration.
- Recognize that some migration will be inevitable and develop national and international adaptation strategies.
- Establish binding commitments to ensure adaptation funding reaches the people who need it most.
- Strengthen international institutions to protect the rights of those displaced by climate change.

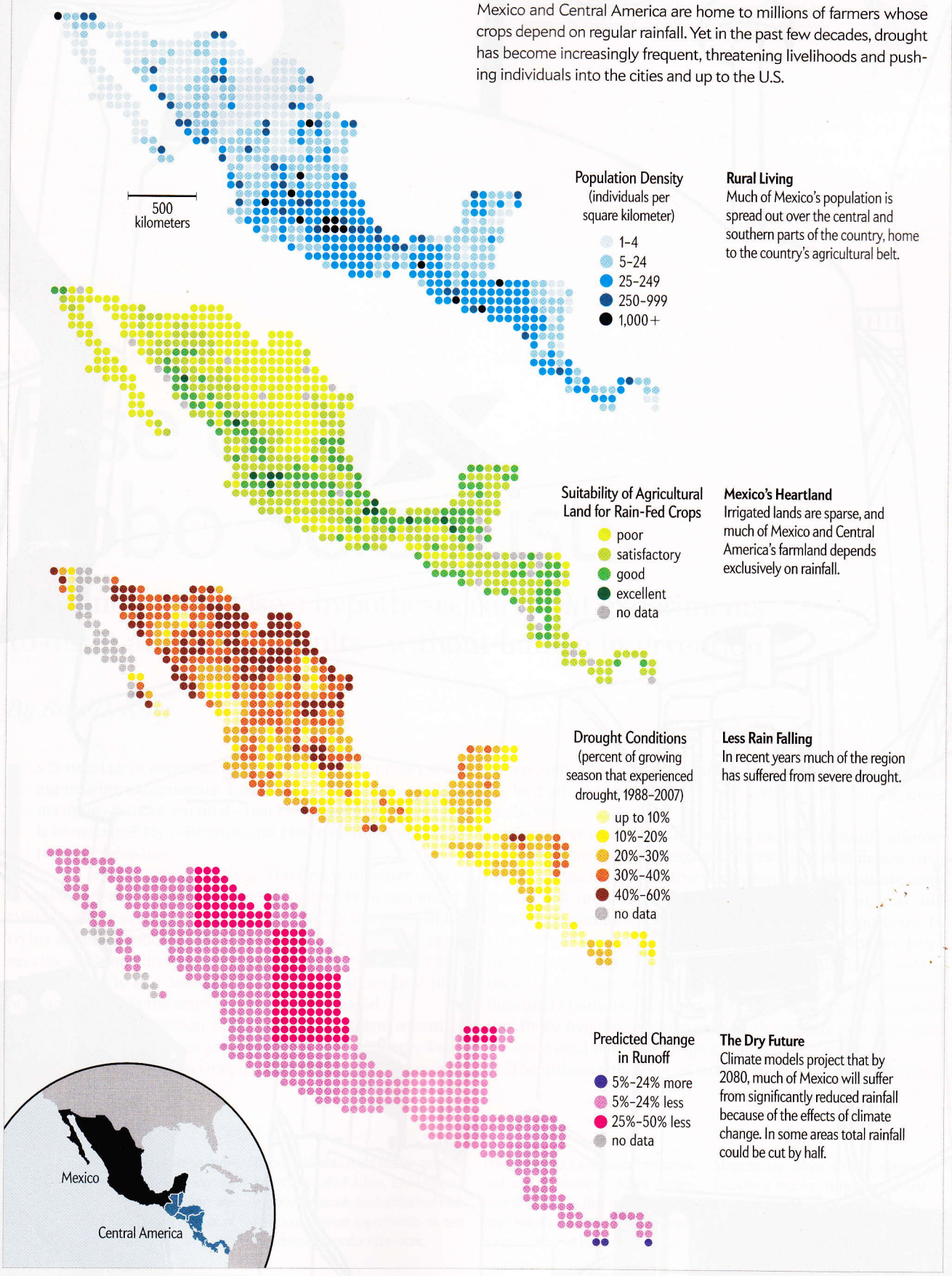
—*A.deS., K.W. and C.E.*

BRENT STIRTON *Getty Images*

(LOW INPUT LEVEL) FROM THE FOOD AND AGRICULTURE ORGANIZATION'S FGDD (*rain-fed agricultural areas*); "IMPACT OF CLIMATE CHANGE ON RIVER RUNOFF," BY DAISUKE NOHARA ET AL., IN *JOURNAL OF HYDROMETEOROLOGY*, VOL. 7, NO. 5, OCTOBER 2006; DATA OBTAINED FROM AUTHORS VIA PERSONAL COMMUNICATION (*rainfall-runoff change*); BRADFIELD LYON *IRI/Earth Institute, Columbia University*; RAINFALL DATA FROM GPCC AND IRI DATA LIBRARY (*drought*)

MEXICO'S DROUGHT FORECAST

Mexico and Central America are home to millions of farmers whose crops depend on regular rainfall. Yet in the past few decades, drought has become increasingly frequent, threatening livelihoods and pushing individuals into the cities and up to the U.S.



(FLOW INPUT LEVELS FROM THE FOOD AND AGRICULTURE ORGANIZATION'S FGDD *(rain-fed agricultural areas)*; "IMPACT OF CLIMATE CHANGE ON RIVER RUNOFF," BY DAISUKE NOHARA ET AL., IN *JOURNAL OF HYDROMETEOROLOGY*, VOL. 7, NO. 5, OCTOBER 2006; DATA OBTAINED FROM AUTHORS VIA PERSONAL COMMUNICATION *(rainfall-runoff change)*; BRADFIELD LYON *IRI/Earth Institute, Columbia University*; RAINFALL DATA FROM GPCC AND IRI DATA LIBRARY *(drought)*