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Cuba, Puerto Rico, and Climate Change: Shared Challenges in Agriculture, Forestry, and Opportunities for Collaboration

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Abstract

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Cuba and Puerto Rico have much in common and have been referred to in a poem by Lola Rodríguez de Tío as *"…son de un pájaro las dos alas"* (two wings of one bird). Throughout their histories, they have faced similar challenges in maintaining food security and ecosystem health. Global climate change now threatens both islands with parallel challenges to their similar cropping systems, forests, and producer demographics. Rising temperatures and resultant shifts in climate patterns have led to an increased occurrence of drought, punctuated by tropical storms and hurricanes of increasing intensity. Both Puerto Rico and Cuba have historically found innovative ways to harness the ingenuity and resilience of their people. Building new partnerships and frameworks for technology transfer, knowledge sharing, and innovation across the Caribbean islands has the potential to enhance adaptive capacity, food security, and ecosystem services, and to ensure that the islands are prepared for climatic changes in coming decades. This report provides a brief historical overview of the agricultural and forestry sectors in Cuba, outlines regional climate projections and their expected effects on working lands in both Cuba and Puerto Rico, and broadly assesses adaptive capacity and vulnerability, making suggestions for building adaptive and resilient working lands systems.

Keywords: Cuba, Puerto Rico, climate change, agriculture, forestry, adaptive management.

Executive Summary

Climate change is challenging farmers, ranchers, and foresters throughout the world, and particularly those in the working lands systems of the Caribbean. The United Nations Intergovernmental Panel on Climate Change (IPCC) has long recognized the unique vulnerability of what are known as Small Island Developing Nations because of their exposure to extreme weather events and sea level rise, as well as their limited geographic and economic scale. Cuba and the U.S. Caribbean (Puerto Rico and the U.S. Virgin Islands) have experienced the damaging effects of increasing climate variability in recent years, with modeling efforts projecting an intensification of these trends in coming decades. High temperatures, drought, extreme rainfall, and damaging storm events are stressing many small-scale producers, which are often limited in their capacity to respond and adapt. In the U.S. Caribbean, the high costs of imported energy, feed, fuel, fertilizer, and machinery often disadvantage local producers operating on small margins and struggling to compete with large mainland-based agribusinesses. Navigating assistance programs and credit applications can be a significant barrier for many of these producers, resulting in underuse of some federal and local programs aimed at helping farmers recover from and prepare for climatic variability and change.

To help address climate change vulnerability within working lands in the Caribbean, the U.S. Department of Agriculture Caribbean Climate Hub (CCH) was established in Puerto Rico with the mission of developing effective networks, techniques, and tools for the translation and dissemination of climate science information related to agriculture and forestry as well as corresponding best management practices. The CCH is working with its partners to refine and improve climate projections for the region and better understand what types of information and tools are effective in facilitating resilient working lands. Its staff believes that working with farmers, ranchers, and foresters at every stage to incorporate critical local knowledge is vital to developing climate science and support tools that are context specific, relevant, and timely.

Cuba and Puerto Rico have much in common in terms of history, culture, geographic location, and climate, and now face similar challenges associated with climate change. Achieving food security in the Caribbean in an era of increasing droughts, rising temperatures, and market volatility will likely require creative solutions that work to bolster local production in sustainable and climate-resilient ways, as well as open new terms for equitable trade within the region. Opening avenues of information sharing and collaboration between these two islands will enhance their ability to successfully plan, adapt, and respond to the challenges of climate change.

Climate Change: Effects, Projections, and Impacts on Agriculture and Forestry

Many countries throughout Latin America and the Caribbean (LAC) region are facing comparable climate challenges to similar crop assemblages and producer demographics and have much to gain from building collaborative partnerships. From 2014 to 2016, a prolonged drought across Puerto Rico and the U.S. Virgin Islands led to a reduction in crop yields, losses of livestock, and water rationing for hundreds of thousands of people, highlighting vulnerabilities within the region's water management systems and the concomitant effects on the adaptive capacity of producers. Hurricanes Irma and María in September 2017 had significant effects on the communications, power supply, forests, and agriculture in Puerto Rico and the U.S. Virgin Islands. In Cuba, there is evidence that climate change effects are stressing the nation's water supply, increasing erosion rates, decreasing crop yields, and amplifying the proliferation of vectors that cause disease, as well as contributing to a reduction in forest coverage.

Current Regional Climate Change Effects

The following is a list of regional climate change effects occuring in Puerto Rico, Cuba, and the U.S. Virgin Islands:

Increasing temperatures—

- Proliferation of pests and disease
- Heat stress in livestock
- Increased rates of potential and real evapotranspiration
- Increasing human health risks

Rising sea level—

- Salinization of coastal soils and aquifers
- Loss of arable land
- Impacts on critical infrastructure

Shifting rainfall patterns—

- Increasing frequency of prolonged and severe droughts
- Extreme rainfall events and intense storms
- Increasing variability

Regional Projections[1]

Both Puerto Rico and Cuba are projected to experience increasing mean annual temperatures over the course of the 21st century. The projected range of increase varies according to the emission scenario and particular climate model used.

Surface Air Temperatures—

Surface air temperatures are expected to rise between 2 to 9 °C (3.6 to 16.2 °F). Karmalkar et al. (2013) projected a 2 to 5 °C (3.6 to 9 °F) increase for the Latin American and Caribbean region based on the SRES A2 emission scenario. Interpolation of downscaled climate data for Puerto Rico has resulted in a much higher set of projections (7.5 to 9 °C [13.5 to 16.2 °F]) (see fig. 5 on p. 14). Either scenario presents acute challenges to the agricultural sectors of Puerto Rico and Cuba.

Precipitation—

Significant drying trends with regional and seasonal variability is expected. Regional climate models show a drying trend characterized by a decrease in wet season precipitation. The decrease is generally higher for the early wet season (May through July) than the late wet season (August through November) and for the western Caribbean (Cuba) than the eastern Caribbean (Puerto Rico).

Impacts to Agriculture and Forestry

Projected impacts to agriculture and forestry include the following:

- Reduced water availability (heat stress, desiccation, reduced yields and productivity, reduced availability and nutrient content of forage)
- Proliferation of pests and disease
- Increasing losses resulting from storm damage
- Soil loss/degradation
- Increased production costs (energy, water, supplemental feed)
- Reduction in arable land
- Global market volatility

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[1] See appendix for more indepth discussion of regional projections.

Adaptive Capacity and Vulnerabilities

The Cuba and Puerto Rico, along with other Caribbean island territories and nations, recognize the threat that climate change poses to food security and forest productivity, both globally and nationally, and have begun analyzing and addressing various vulnerabilities in their respective agricultural and forestry systems. In 2015, the Cuban government released its *Segunda Comunicación Nacional a la Convención Marco de las Naciones Unidas sobre Cambio Climático* (Second National Communication to the United Nations Framework Convention on Climate Change) (Republic of Cuba 2015). The report inventories climate projections for the country, highlights current impacts and vulnerabilities, inventories greenhouse gas sinks and sources, and discusses impacts and vulnerabilities as well as adaptation and mitigation efforts and strategies.

In Puerto Rico, the Commonwealth government convened the Puerto Rican Council on Climate Change in 2010 to assess the territory's vulnerabilities and recommend strategies to respond to expected changes. The council published the first *Puerto Rico State of the Climate* report in 2013, assessing social and ecological vulnerabilities within the island at large. This report was followed by the CCH's 2015 assessment of vulnerabilities within the U.S. Caribbean's agricultural and forestry sectors. These and other reports conducted by Oxfam International, the IPCC, and other groups highlight some common issues and vulnerabilities that may be more effectively addressed by expanding collaboration and strengthening regional ties (Gould et al. 2018).

Shared vulnerabilities within Cuba and the U.S. Caribbean—
Shared vulnerabilities within Cuba and the U.S. Caribbean include the following:

- Limited water resources
- Soil conditions (degraded, prone to erosion)
- Import dependency
- High production costs
- Limited adaptive capacity
- Geographic and economic scale
- Exposure to tropical storms/hurricanes
- Climate-sensitive crops

Adaptive Capacity—

Cuba, the U.S. Caribbean territories, and other countries throughout the LAC region may be able to alleviate the most severe effects of climate change on working lands by effectively addressing vulnerabilities within water management systems and increasing adaptive capacity among producers. Water resources in both Cuba and the U.S. Caribbean are limited, and improving best practices in water management is an increasingly important strategy for improving adaptation to climate variability and change and reducing risks associated with water shortages.

The ability of individual producers to adapt to climatic challenges depends largely on their ability to access accurate and region-specific information regarding climate projections and adaptive cultivation techniques, as well as access to the capital needed to implement changes. As such, addressing vulnerabilities to build adaptive capacity in working lands systems in the region will likely succeed only as part of more comprehensive, integrated effort that works to address the political, social, and economic environment in which these vulnerabilities have developed.

Next Steps: Strategies for Moving Climate Science to the Field

Responding to the myriad challenges that climate change poses to agriculture and forestry in Cuba and the U.S. Caribbean can be improved by a better understanding of climate processes to improve forecasting accuracy, as well as improved communication strategies to ensure that the right science gets to the right end user at the right time. Recent studies have found that, although improvements in forecast accuracy and specificity are still needed, current climate change support tools can be useful in building adaptive capacity but remain largely underutilized. To improve these tools and increase their usage, information is best when useful, relevant, and context specific. These objectives can be accomplished using collaborative approaches that engage farmers, ranches, and foresters in the planning and development stages, thus ensuring that the end product is tailored to the needs of the end-user group and that they are made aware that such products exist.
Once climate projections and correlating support tools have been developed for a region, they are more effective when disseminated in a way that encourages usage among trusted advisers and producers. Caribbean island territories and nations have much to gain from sharing expertise in the realms of climate science development and dissemination.

Contents

Introduction[1]

The Cuban archipelago is formed by the island of Cuba, the Isle of Youth, and more than 1,600 islands, islets, and cays that have a total surface area of 110 860 square kilometers (42,803 square miles), making Cuba the largest country in the Caribbean (fig. 1). The country is divided into 15 provinces and 168 municipalities, including the special municipality of the Isle of Youth. As of 2016, 31 percent of Cuba was forested and 60 percent was in agricultural uses (FAO 2018).

Most of the territory of Cuba has a tropical climate with a summer rainy season. Many parts of the country experience a mid-summer drought similar to that experienced in much of the Caribbean region. The average annual temperature ranges from 24 to 26 °C (74.2 to 78.8 °F), with the country's two seasons being defined by a slightly warmer rainy season lasting from May to October and a less rainy, slightly cooler "winter" season from November to April. Average rainfall is 1335 millimeters (52.6 inches); however, drought events are not uncommon, and some droughts may last several years (Republic of Cuba 2015).

In 2017, the Cuban population reached 11,484,636 inhabitants (FAO 2018), with a population density of more than 100 inhabitants per square kilometer (~265 inhabitants per square mile), 77 percent of whom lived in urban areas. Although the population grew steadily through much of the 20th century, population growth had slowed significantly by the early 2000s, dropping to near zero in recent years and projected to remain steady over the 2020s (World Factbook 2019). This shift is due in large part to declining birth rates, increasing life expectancy, and increasing emigration. Cuba and Puerto Rico are two of the few Latin American and Caribbean (LAC) countries or commonwealths with aging populations (Republic of Cuba 2015).

Historical Context

The histories of Puerto Rico and Cuba are intertwined with Spanish and American policies and influence, and have much in common. As the Spanish Empire expanded in the 16th century, both islands were colonized largely to serve as strategic naval outposts to help protect exports of precious metals from Central and South America. Both islands remained largely undeveloped and forested prior to the rise of sugarcane and other export crops in the late 18th and early 19th centuries (Dietz 1986, Rosset and Benjamin 1994). Both remained under Spanish rule for nearly 400 years until

[1] The historical and demographic sections of this report are focused primarily on Cuba. For a discussion of the history of agriculture and forestry within the U.S. territories in the Caribbean, refer to the U.S. Caribbean Climate Hub Regional Vulnerability Assessment at http://www.climatehubs.oce.usda.gov/sites/default/files/Caribbean%20Region%20Vulnerability%20Assessment%20Final.pdf.

Figure 1—The Caribbean region.

In the early 1900s, U.S. corporate interests converted much of the arable land base of both Cuba and Puerto Rico to large sugarcane plantations.

the Cuban War of Independence (1895–1898), which culminated with the Spanish-American War in 1898, after which the United States took possession of both islands. In 1902, Cuba gained limited independence under President Tomas Estrada Palma, but the Platt Amendment kept the island under U.S. protection and gave the United States the right to intervene in Cuban affairs. In the early 1900s, U.S. corporate interests (primarily sugar companies) gained large land holdings and favorable trade agreements in both Cuba and Puerto Rico. As a result, much of the arable land base of both islands was converted to large sugarcane plantations (Dietz 1986). By the middle of the 20th century, sugarcane accounted for half of the total land under cultivation in Cuba and produced around 6 million tons (5.4 million tonnes) of sugar per year, nearly 75 percent of Cuba's total export at the time (Álvarez et al. 2006, Rosset and Benjamin 1994).

By the late 1950s, about 25 percent of the arable land in Cuba was under foreign control. In addition, large Cuban landholders and sugarcane plantations controlled more than 21 percent of the total land area (1.8 million hectares [4.4 million acres]). The rural middle class, lower-middle class, and land-holding peasant farmers owned only about 2.5 million hectares (~6.2 million acres). Consequently, 9 percent of the landowners in Cuba held more than 73 percent of the land (Álvarez et al. 2006). These inequalities in ownership and wealth distribution, along with other political and socioeconomic factors, led to the Cuban Revolution, which culminated in Prime Minister Fidel Castro's rise to power in 1959. Land ownership and agricultural reforms were some of the Castro government's first priorities. A series of reforms began with most of the large, privately held cattle ranches and sugarcane plantations being converted to state-administered farms in 1959 (Rosset and Benjamin 1994). As these reforms were enacted and the socialist movement strengthened, U.S. and other foreign-owned companies were nationalized, eventually prompting the initial U.S. embargo on exports to Cuba (with the exception of food and medicine) in 1960. A second agrarian reform in 1962 led to state control of approximately 68 percent of the arable land base (Álvarez et al. 2006). As tensions mounted between the United States and Cuba in the early 1960s, the United States banned imports of Cuban sugar, and Cuba deliberately began to diversify its agricultural sector to increase domestic food crops and supply. Preferential sugar prices and easing of trade with the Soviet Union diverted this process of diversification, as Cuba found it beneficial to continue exporting sugar and raw materials to the Soviet Union in exchange for petroleum, agricultural machinery, and chemical inputs (Rosset 1997).

The Castro government also instituted a major reforestation initiative in the early 1960s that was intended to increase employment and economic opportunities in rural areas as well as address increasing soil and water concerns after decades of deforestation and intensive agricultural activity (Gebelein 2012). Between 1960 and 1966, nearly 300 tree nurseries were constructed and about 348 million trees were planted, primarily *Eucalyptus*, *Pinus*, and *Casuarina* species (Díaz-Briquets 1996). Later, native species, particularly precious woods like mahogany (*Swietenia* spp.) and Spanish cedar (*Cedrela odorata*), were increasingly incorporated into reforestation efforts. Nevertheless, early reforestation efforts in Cuba had high failure rates, attributed largely to poor seed quality, inadequate species-site selection, and limited post-planting care and management (Álvarez Brito 1999).

Throughout the 1970s and 1980s, trade agreements with the Soviet Union and other communist states in Central and Eastern Europe (the Eastern Bloc) enabled Cuba to pursue a "modern" agricultural system characterized by intensive, industrial production technologies driven largely by external inputs (Funes-Monzote

2008). By the late 1980s, agricultural production in Cuba more closely resembled that of the central valley of California than other countries in the LAC region. Although this production model temporarily boosted yields, it also had profound environmental, political, and socioeconomic ramifications. As soils degraded, yields began to decrease. Mechanization of farm labor contributed to an increasing urban migration of the population (69 percent of Cubans were living in urban areas by 1989) (Funes-Monzote 2008), and Cuban leaders became increasingly disillusioned with the growing level of import dependency (Rosset and Benjamin 1994). To address the situation, the government adopted the National Food Program in 1989 (prior to the collapse of the Soviet Union) with the main goal of increasing production of various fruits and vegetables (Rosset and Benjamin 1994).

In 1989, increasing food insecurity was amplified dramatically by the collapse of the Soviet Union and East Germany and the tightening of trade restrictions by the United States.[2] Prior to dissolution of the Soviet Union, Eastern Bloc states had comprised as much as 85 percent of Cuba's total trade. Cuba had depended on trade with these countries for everything from fuel and food to machinery and spare parts. Subsequently, agricultural activities as well as food imports were severely disrupted. Cuba's gross domestic product fell by almost 50 percent, and total imports were reduced by 75 percent (Rosset 1997). Because the inputs and machinery on which the agricultural sector had come to depend became increasingly scarce, crop production significantly declined, and forests became increasingly important sources of fuel, food, medicine, and building materials, as well as significant for recreation and respite (Álvarez Brito 1999). In 1991, the Cuban government declared a "Special Period in Peacetime" that effectively enacted wartime austerity measures. Food shortages during what became known as simply the "Special Period" from 1991 to 1994 resulted in a sharp drop in the caloric intake of the average Cuban (Franco et al. 2007). Increasing pressures on forests for fuel and wood products during this time ultimately led to a reversal in the island's post-sugar-boom forest recovery.

The substantial reduction in import capabilities compelled Cuba to accelerate an agricultural reinvention process that had already begun in the mid to late 1980s. Likewise, as forests and other environmental conditions declined and global norms on conservation and sustainable development increased, awareness of the need for greater environmental protections grew within Cuba. In comments made to the 5th Congress of the National System of Agriculture and Forestry Technicians in 1991, Fidel Castro said, "We must produce more food without feedstock and without

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[2] In 1992, the U.S. Congress passed the Torricelli Bill, which barred shipments to Cuba of food and medical supplies by overseas subsidiaries of U.S. companies. Later, the Helms-Burton Act (1996) restricted foreign investment in Cuba.

fertilizers. We must plan 1992 as if we had none available. The little fertilizer that has been available has been dedicated to rice, plantains, *viandas* (roots and tubers), and vegetables: those foodstuffs that are produced directly in the countryside" (Rosset and Benjamin 1994: 33). Policies and laws shifted to promote diversified food production and environmental protections. These included the comprehensive "Law of the Environment," which contained chapters on air, water, forests, biodiversity, parks, planning, research, and technology, among other topics, as well as the comprehensive 1998 Forestry Act, which addressed forest use and management, funding and fiscal instruments, and reinvigoration of the reforestation initiative created in the early 1960s (Houck 2000).

The dilemma that Cuba faced after the fall of the Soviet Union was very similar to that which now faces Puerto Rico and much of the Caribbean in light of environmental and economic vulnerabilities posed by climate change and import dependency. That is, how can they reinvent a resilient local food system without relying on costly imported synthetic fertilizers and petroleum?

The dilemma Cuba faced after the fall of the Soviet Union was similar to that now facing much of the Caribbean in light of vulnerabilities posed by climate change and import dependency: to reinvent a resilient local food system.

Cuba's strategy for transitioning the country's food system away from import dependency has been varied, but has resulted in many large state-held farms being returned to various forms of farmer cooperatives (fig. 2), in large part through the creation of the Basic Units of Cooperative Production in 1993 (Funes et al. 2002).

Throughout the 1980s, Cuba invested significantly in human resources and was thus equipped with a robust agricultural research sector when food shortages began to intensify in the latter part of the decade (Rosset and Benjamin 1994).

STATE SECTOR		• State farms • New-type state farms (GENT) • Revolution Armed Forces (FAR) farms, including farms of the Young Workers' Army (EJT) and the Ministry of the Interior (MININT) • Self-provisioning farms at workplaces and public institutions
NON-STATE SECTOR	Non-state sector collective	• Basic Units of Cooperative Production (UBPC) • Agricultural Production Cooperatives (CPA)
	Individual production	• Credit and Service Cooperatives (CCS) • Individual farmers, in usufruct • Individual farmers, private property
MIXED SECTOR		• Joint ventures betwee the state and foreign capital

Figure 2—Post-1993 forms of agricultural organization in Cuba. Adapted from Funes et al. (2002).

Researchers and farmers worked together to implement a number of “new” agricultural technologies such as biofertilizers, as well as reverting to more traditional agroecological techniques such as the use of earthworms, intercropping (which previously had been prohibited), composting, and silvopasture (Álvarez et al. 2006). These strategies were accompanied by new methods of agricultural extension that enhanced the flow of information using new and existing cooperatives as a platform for farmers to share information with each other as well as researchers (Rosset et al. 2011). By 1999, Cuba had become one of the top food producers in Latin America and the Caribbean. The country boasted an annual production growth rate of 4.2 percent per capita from 1996 through 2005, a period in which the regional average was zero percent (Altieri and Funes-Monzote 2012). By 2006, small farmers forming the ranks of the National Association of Small Farmers (ANAP acronym in Spanish), working through various cooperatives, were producing 65 percent of the country’s food supply from only 25 percent of its agricultural land base. These production increases came despite a 72 percent reduction in agrochemical use from 1988 levels (Altieri and Funes-Monzote 2012).

Current Situation: Progress and Challenges

As in Puerto Rico, Cuba’s forests also have been recovering in the post-sugar-boom era, increasing from about 14 percent of total area in 1959 to 28 percent in 2013. This is due in part to natural regeneration of abandoned agricultural areas as well as extensive, long-term reforestation initiatives. More than 30 percent of Cuba’s forest area is reserved as productive forest (70.5 percent natural, 29.5 percent planted), and 69 percent is reserved as “protected forest” for natural reserves, recreation, watershed protection, and other ecosystem services (MINAG 2013). Cuba has the highest proportion of its forest cover designated for protective functions in the LAC region (FAO 2011). Moreover, forest area has continued to increase in the past decade or so, while cultivated agricultural areas are increasing as well (MINAG 2013). Restoration of land affected by open mining in northern Cuba, mangrove reforestation and restoration along the coast, and restoration of endangered native forest species are among the top priorities in the current national reforestation system (MINAG 2013). Forestry programs also promote agroforestry practices that intermix fruit and fast-growth timber species, community tree planting, and urban forestry. Yet, also in a way similar to Puerto Rico, some issues persist in the Cuban forest sector, particularly in terms of limited use of silvicultural treatments in productive forests, low productivity in some areas and forest types, poor species-site selection, and inadequate or insufficient seed sources. Many of these issues are likely to be compounded in the context of climate change (Republic of Cuba 2014).

Urban agriculture in Cuba also has expanded rapidly since the late 1980s, a great learning opportunity for Puerto Rico and other territories and countries in the region. An estimated 383,000 urban farms in Cuba cover roughly 50 000 hectares (124,000 acres) and produce more than 1.5 million metric tons (1.7 million tons) of vegetables. The highest producing urban farms reach a yield of 20 kilograms per square meter (4.1 pounds per square foot) per year of edible plant material using little to no synthetic chemicals, yields equivalent to 100 metric tons per hectare (112 tons per hectare). Some sources attribute up to 70 percent or more of the fresh vegetable supply in cities such as Havana and Villa Clara to urban sources (Altieri and Funes-Monzote 2012). Cornelius Blanding, executive director of the Federation of Southern Cooperatives/Land Assistance Fund in the United States, has been working with Cuban cooperatives since 1999 and has said that urban agriculture is the Cuban model that holds the most promise for the United States and other countries.[3]

Urban agriculture in Cuba has expanded rapidly since the late 1980s, a great learning opportunity for other territories and countries in the region.

The successes associated with Cuba's agroecological research and productivity, along with innovative farmer organizational schemes, are of increasing interest in the LAC region and around the world. Cuba has achieved a high level of productivity and resilience with various forms of agriculture that harness and enhance ecosystem services like biodiversity, reduce food miles and energy use, and effectively close local production and consumption cycles (Funes-Monzote 2008). By securing these achievements in response to an economic and political crisis, Cuba may have provided Puerto Rico and other nations and territories with a valuable "road map" for transitioning agricultural systems toward models that simultaneously address climate change concerns, while working to improve socioeconomic issues such as food security and import dependency, unemployment, high production costs, and poor public health, as well as addressing many ecological problems like soil degradation and erosion, water pollution, and loss of biodiversity. These issues collectively represent much of what contributes to elevated levels of climate change vulnerability in the socioecological systems of Puerto Rico and throughout the LAC region (Gould et al. 2015).

However, despite Cuba's considerable advances in organic agriculture, challenges remain. Some sources cite high food import statistics as evidence that a lack of access to modern farming technology has led to relatively low productivity in many areas of the country and high postharvest losses resulting from problems with storage, inefficient supply chains, and other issues (WFP 2015). The World Food Programme reports the presence of persistent anemia and other micronutrient deficiencies—particularly in the country's five eastern provinces, where adverse

[3] Blanding's comments were made during a 2016 panel discussion entitled "Cultivating Dialogue: U.S. and Cuban Agricultural Cooperatives," hosted by American University in Washington, DC.

climate conditions can make agricultural production particularly challenging (WFP 2015). Although sources disagree on the total level of Cuban food import dependency, some statistics place the number as high as 70 to 80 percent, while others contend that these statistics apply only to certain staple foods such as rice and oil that the country struggles to produce in sufficient quantity (Altieri and Funes-Monzote 2012). Since resuming restricted agricultural trade with Cuba in 2002, the U.S. share of food imports has grown to around 30 percent. Puerto Rico imports about 80 percent of its food, largely from the U.S. mainland. Because of their proximity (Cuba) and open trade status (Puerto Rico), it can be difficult for local farmers to compete with subsidized and mass-produced agricultural goods imported from the U.S. mainland. Because of their limited geographic and economic scale, both Cuba and Puerto Rico have found it difficult to build and maintain a semiautonomous food system without reliance on imported inputs, machinery, fuel, and processing equipment. Cuba is increasingly becoming part of a highly integrated global food system in which climate change is projected to result in more frequent disruptions of food production and distribution that will lead to increased overall food prices (Brown et al. 2015, Reidmiller et al. 2018). Improving methods of postharvest food storage, transportation, and distribution are likely to be key intervention points in improving food security in Cuba, Puerto Rico, and throughout the world in the face of climate change (Brown et al. 2015). For island nations and territories like Cuba and Puerto Rico, achieving food security is a difficult challenge that requires balancing access to imported food and technology, while empowering optimal levels of local production, innovation, and self-reliance.

Climate Change: Projections and Effects on Agriculture and Forestry

Many countries throughout the LAC region face comparable climate challenges to similar crop assemblages and producer demographics, and have much to learn from the other's successes and failures. The effects of climate change are presenting a myriad of new challenges as well as exacerbating issues that farmers have long dealt with, such as extreme weather events, water shortages, and insect outbreaks (Gould et al. 2015). These challenges are accelerating even as concerns over environmental degradation, import dependency, and food security are increasing the need for more locally based and ecologically aligned food production and distribution systems (FAO, IFAD, and WFP 2014). The U.S. Department of Agriculture (USDA) has joined the United Nations and other international nongovernmental organizations in pursuing strategies that simultaneously mitigate greenhouse gas emissions (GHGs) that are accelerating global climate change, while improving food security worldwide (USDA 2016).

Regional Effects

As in many areas of the world, Cuba and Puerto Rico have already begun experiencing the local effects of global climate change (Gould et al. 2018, Nurse et al. 2014). These trends and events are having an effect on agriculture and forestry in a variety of ways (Gould et al. 2015, Jennings et al. 2014). In Puerto Rico, heavy rainfall events are becoming more common, leading to increases in soil erosion and flooding (Jennings et al. 2014). Average temperatures throughout the Caribbean have increased over the past 40 years, with Puerto Rico experiencing the same number of days at or above 32.2 °C (90 °F) in 2010–2011 as it had per decade from 1900 to 1949 (PRCCC 2013). Higher temperatures, changes in precipitation patterns, and any alteration in cloud cover will begin to increasingly affect the distribution and health of plant communities and ecosystem processes in critical agricultural and forest communities, with increasing nighttime temperatures having the potential to affect tropical tree growth and induce mortality (Gould et al. 2015, Jennings et al. 2014). Intensified extreme weather events and progressively drier summer months in the Caribbean are expected to alter the distribution of tropical forest life zones (Jennings et al. 2014).

In Cuba, there is evidence that the effects of climate change are already stressing the nation's water supply, increasing erosion rates, decreasing crop yields, amplifying the proliferation of vectors that cause disease, and contributing to changes in forest coverage (Oxfam Canada 2011). Both Cuba and Puerto Rico have experienced severe and prolonged droughts in recent years, with profound effects on livestock, crop production, and water availability. Between 1960 and 2000, average precipitation in Cuba decreased between 10 and 20 percent (Oxfam Canada 2011).

A prolonged drought across Puerto Rico and the U.S. Virgin Islands from 2014 to 2016 led to a reduction in crop yields, losses of livestock, and water rationing for hundreds of thousands of residences, highlighting vulnerabilities within the region's water management systems and how they affect the adaptive capacity of producers (Álvarez-Berríos et al. 2018, Gould et al. 2015). Dairy is a very important agroindustry in Puerto Rico and St. Croix in particular, generating millions of dollars in revenue and more than 25,000 direct and indirect jobs (Ortiz-Colón et al. 2018). As intense heat and lack of rain withered grasses in the summer of 2015, producers in the U.S. Virgin Islands were forced to take measures ranging from collecting tree limbs and branches for fodder to relying on imported feed and culling herds. Pastures were so overtaxed that many needed to be resown completely at great cost to farmers. In Puerto Rico, ranchers saw their production costs rise as they were forced to rely ever more heavily on expensive imported feed. On the heels of this devastating drought, Puerto Rico and many other vulnerable island territories or nations in the region experienced a series of damaging storms, culminating in the historic hurricane season of 2017. A preliminary assessment report from the Puerto Rico Department of Agriculture estimated agricultural losses from hurricanes Irma and María to exceed $230 million (PRDA 2018). Particularly hard hit were the economically important but wind-damage-prone coffee and plantain crops. Unfortunately, regional climate models project more of these boom-and-bust rainfall cycles in which prolonged periods of drought are punctuated by intense storm and rainfall events.

Eastern Cuba likewise suffered a prolonged drought from 2003 to 2007 that resulted in extensive livestock mortality, crop yield losses, and the 300,000 inhabitants of Holguín being forced to rely on water trucked in from outside sources (Oxfam Canada 2011). On the heels of this devastating drought, Cuba experienced the most destructive hurricane season in its recorded history. In less than a month in 2008, three major hurricanes and a tropical storm affected the country, wreaking havoc on many of Cuba's primary crops and growing regions and leading to an increase in food imports (Messina 2009). This cycle of extremes has continued into recent years with a damaging drought in 2014–2015, followed by heavy rains associated with a strong El Niño oscillation in 2016 (WFP 2015) and widespread damage from Hurricane Irma in 2017 (Van Beusekom et al. 2018). From 2007 to 2015, climate hazards caused more than $20 billion in damages in Cuba, increasing its import dependency and negatively affecting food security and its ability to build more resilient working land systems (WFP 2015). Estimated damages for Hurricane Maria alone totaled between $27 and $48 billion for the Caribbean region, with estimates in Puerto Rico ranging from $25 to $43 billion (in 2017 dollars) (Gould et al. 2018).

This trend of prolonged droughts punctuated by intense rainfall and storm events is aligned with climate model projections for the region and highlights the vulnerability of water supplies and management systems. Important aquifers on both islands are increasingly exposed to salt water intrusion from rising sea levels, thus compounding threats to water supplies (Gould et al. 2018). Studies conducted by the Cuban government found that, even under a favorable climate scenario regarding water, its potential availability in 2100 could be reduced by 37 percent compared to a 1961 to 1990 baseline (Republic of Cuba 2015).

Regional Projections

In 2015, the Cuban government released the *Segunda Comunicación Nacional a la Convención Marco de las Naciones Unidas sobre Cambio Climático* (Second National Communication to the United Nations Framework Convention on Climate Change) (Republic of Cuba 2015). The report inventoried climate projections for the country and GHG sinks and sources, highlighted current effects and vulnerabilities, and discussed the effects of and vulnerabilities to climate change as well as adaptation and mitigation efforts and strategies. The report reached the following conclusions:

Based on different climate models including regional models, the results were consistent with the trends and climatic features already described; showing a warmer, dryer and extreme climate at the end of the 21st century. The future climate of the country may be characterized by the following changes: a mean air temperature rise of up to 4 °C (72 °F), with a decrease in annual rainfall that, depending on the scenario, would range between 15 and 63 percent, accompanied by an increase in the potential of evapotranspiration and real evaporation. This would lead to a progressive decline in both net primary productivity of terrestrial and agricultural ecosystems as well as potential biomass density. Dry subhumid climates will embrace a wider area from the eastern to the western portion of the island; massifs in the eastern mountainous area of the country will have dry subhumid climates, susceptible to desertification. Under current climate trends and scenarios considered for the next 100 years, there will be a deterioration of the overall environment quality. As a result, there will be a reduction of the water potential on a regional scale, loss of land in low-lying coastal areas, land degradation, a decrease of the agricultural yield in key crops of the national diet, loss of biodiversity mainly in coastal areas, a negative effect on coastal human settlements, an increase in communicable diseases, and the consequent negative impact on all economic activities in general. In a favorable climate scenario regarding water, its potential availability in 2100 could be reduced to 24 km^3 (5.6 mi^3), 37 percent less compared to the 1961–1990 baseline. In any of the climate scenarios, the water balance shows a significant reduction in water potential. (Republic of Cuba 2015: 9).

The report goes on to emphasize that Cuba's "…water resources sector will be one of the most severely affected, which will have major implications on other resources and sectors. In the future, the competition between the availability of water and the increasing human demand will expand" (Republic of Cuba 2015: 10).

In Puerto Rico, recent downscaling of global climate models has revealed steep rates of warming and drying beyond those of expected global averages.

These projections are generally aligned with expected changes throughout the Caribbean, where warming and drying trends are expected to be prominent throughout the next century (fig. 3)

In Puerto Rico, recent downscaling of global climate models has revealed steep rates of warming (fig. 4) and drying beyond those of expected global averages and the potential for shifting life zones (fig. 5) and species distributions (Henareh Khalyani et al. 2016, 2019) (see appendix).

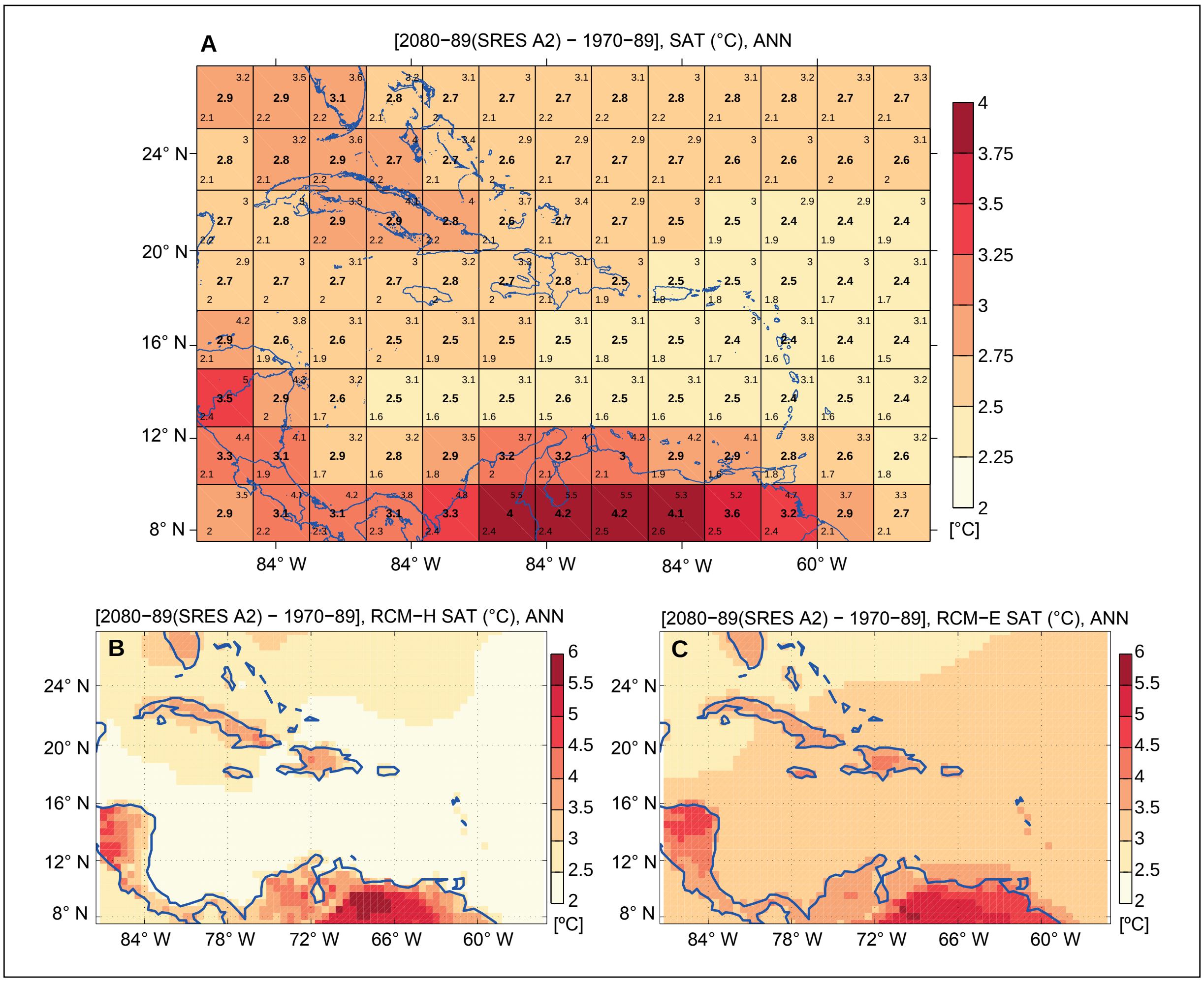

Figure 3—Projected change in mean annual surface air temperature (°C) by the 2080s under the SRES A2 scenario in (A) CMIP3 multimodel ensemble, (B) RCM-H, and (C) RCM-E. Projected change by the 2080s is relative to the mean climate of 1970–1989. In (A), for every grid box, the color indicates ensemble mean projection, the value at the center indicates ensemble median projection, and values at the bottom-left and top-right corners indicate ensemble minimum and maximum projections, respectively. From Karmalkar (2013).

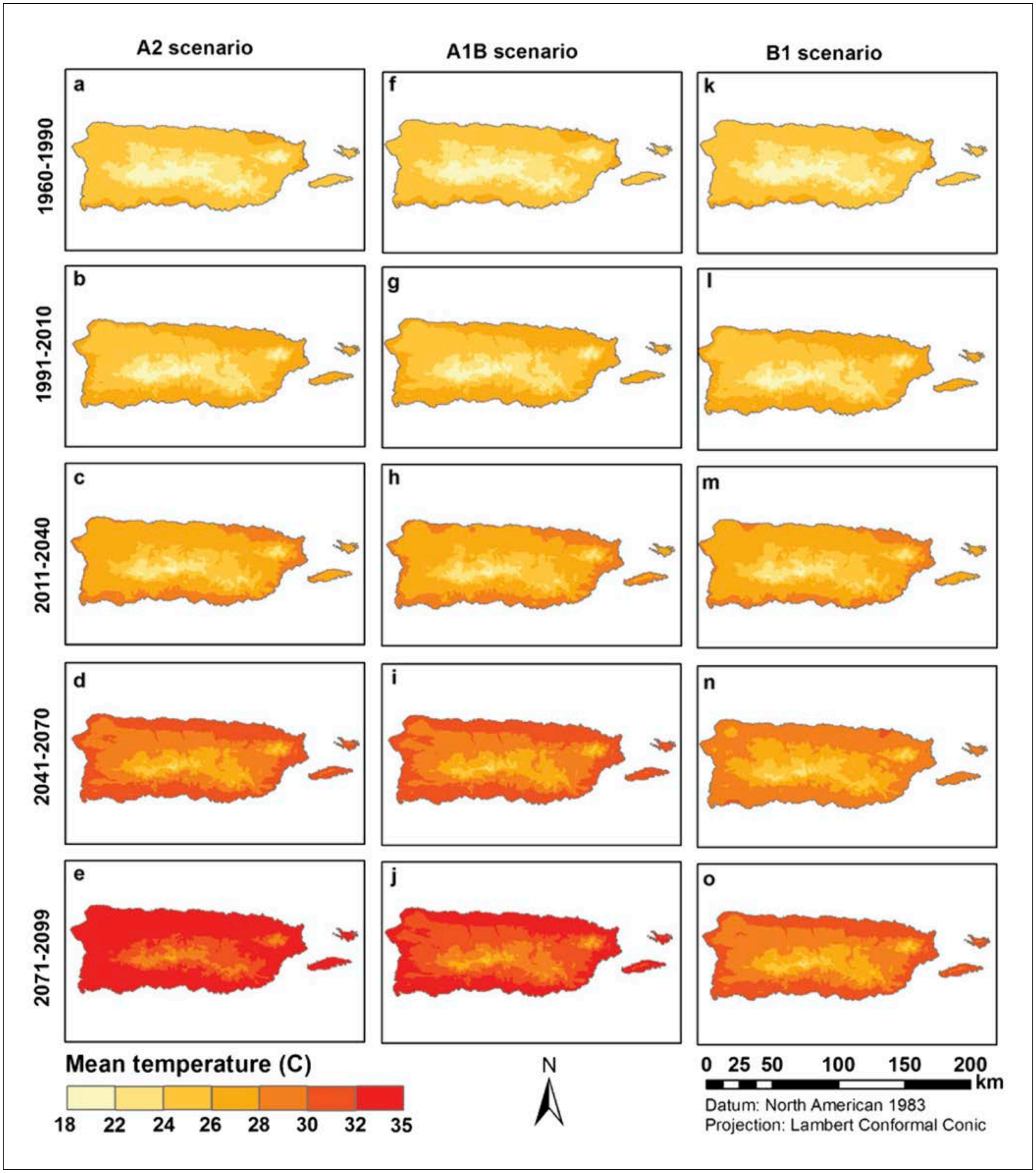

Figure 4—Projected increase in mean temperature for Puerto Rico. From Henareh Khalyani et al. (2016).

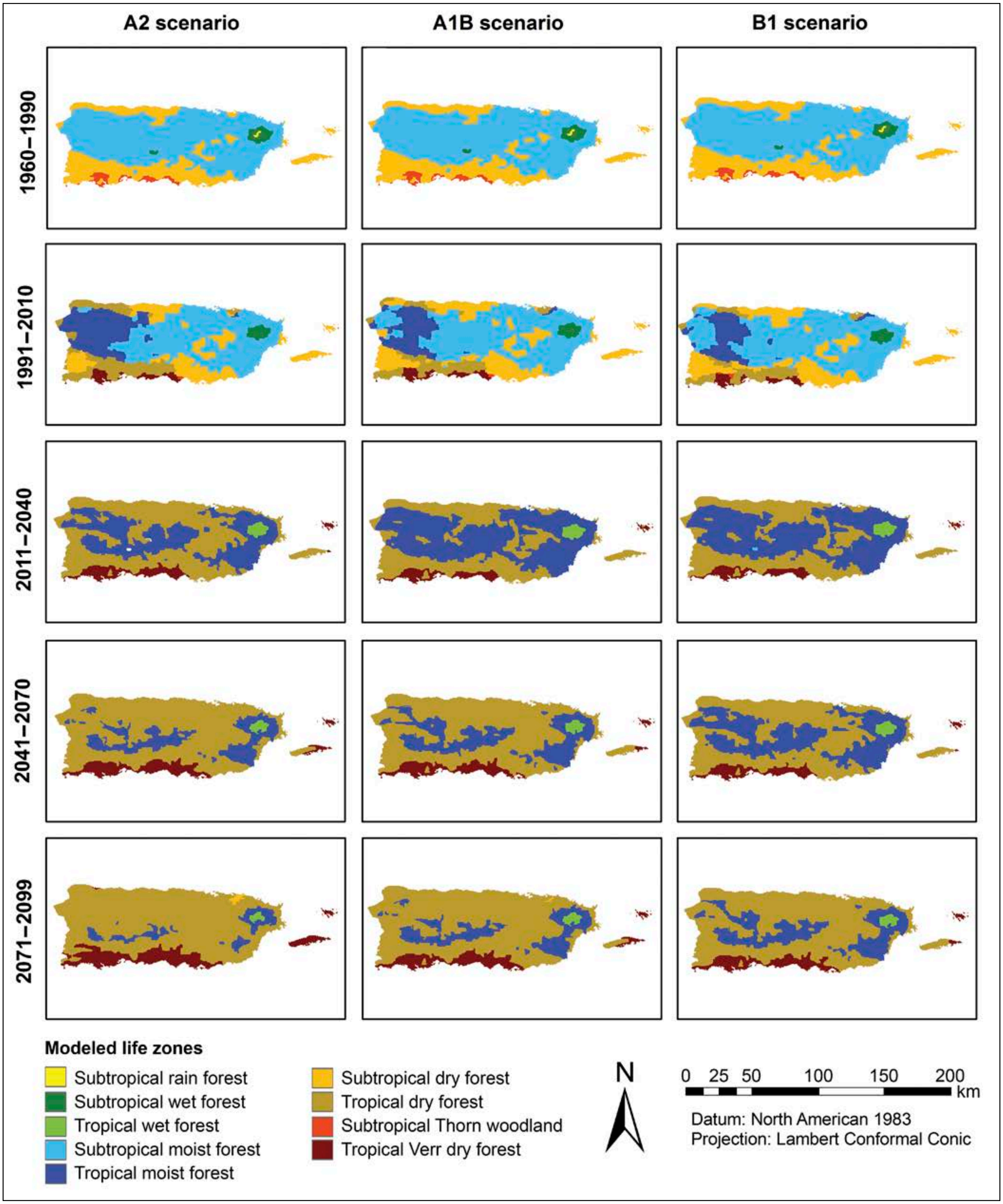

Figure 5—Projected migration of life zones in Puerto Rico. From Henareh Khalyani et al. (2016).

Vulnerabilities and Adaptive Capacity

Much of the Caribbean region is especially vulnerable to the effects of climate change (table 1) because of its exposure to extreme weather events, its geographic and economic scale, and its reliance on tourism and imported goods (Gould et al. 2018, Nurse et al. 2014). The United Nations Intergovernmental Panel on Climate Change (IPCC) has deemed climate change to be a serious threat to agriculture and food security worldwide and has identified the food systems of small island nations within the Caribbean as being particularly vulnerable to its effects (Barker 2012, Nurse et al. 2014). The USDA acknowledges that climate change has the potential to affect the advancement of its mission and core obligation "to provide leadership on food, agriculture, natural resources, rural development, nutrition, and related issues…" (USDA 2014). Likewise, the Cuban government anticipates future agriculture to develop in an "adverse climate environment," negatively affecting the phenology of plants, availability of arable land, water availability, and overall yield (Republic of Cuba 2015). Both governments have released reports in recent years recognizing the need for increased innovation and adaptation both to mitigate GHG emissions from agricultural operations and build resiliency into systems that will be increasingly stressed in years to come (Gowda et al. 2018, Republic of Cuba 2015).[4] Over the next 25 years, a diverse range of effects of climate change on agriculture and forestry in North America are expected, depending on location and cropping systems (Walthall et al. 2013), to result in an overall drop in productivity to pre-1980 levels by 2050 (Gowda et al. 2018). Emerging regional climate models and downscaling of the resultant data are highlighting a decidedly challenging outlook for agriculture in the Caribbean (Henareh Khalyani et al. 2016, Karmalkar et al. 2013). The overall effects, particularly over the long term, may depend largely on the severity of overall warming and the adaptive actions taken by land managers and producers in the near term (Gowda et al. 2018, Walthall et al. 2013). The United Nations Food and Agricultural Organization (FAO) has documented how climate change is expected to adversely affect global food security (FAO 2008, IPCC 2014). Likewise, the USDA holds that "Climate change is very likely to affect global, regional, and local food security by disrupting food availability, decreasing access to food, and making utilization more difficult" (Brown et al. 2015). There is widespread agreement that effective adaptation and mitigation efforts will be necessary at all levels of food production and supply chains to alleviate the most potentially detrimental effects of climate change in the 21st century.

[4] Cuba's Third National Report to the United Nations is slated to be published in 2020.

Table 1—Summary of climate projections and effects on agriculture and forestry for Cuba and Puerto Rico

Climate projection	Temperature	Precipitation	Sea level	Sea-surface temperatures	Climatic disturbances/ extreme events	Effects on agriculture and forestry
Cuba	+2 to +5 °C (projected by 2100—see fig. 2)[a]	-15 to -63 percent[b] (see appendix for seasonal projections)	+9 to +15 cm (0.3 to 0.49 ft) by 2030; +17 to +27 cm (0.56 to 0.89 ft) by 2050[c]; +85 cm (2.79 ft) by 2100	+1.5 °C over 20th century[d]	More coral bleaching events; more drought and extreme rainfall events (>3 inches of rain in 24 hours); greater intensity of hurricanes	Higher cost of production and more heat stress in livestock, crops, and trees; more pests and disease; more exposure to weather extremes
Puerto Rico	+0.8 °C by 2050; +2 to +5 °C by 2100[d] +4.9 to +9 °C by 2100[e]	General drying trend with regional variation[f]	+.07 to +.57 m (.2 to 1.87 ft) by 2060; 0.14 to +1.7 m (.4 to 5.59 ft) by 2110[f]	+1.5 °C over 20th century; +1.17 °C by 2050[d]	More drought and extreme rainfall events; greater intensity of hurricanes; more extreme heat days (>32.2 °C); more coral bleaching events	Less water availability; lower yields per unit of input; less crop suitability; less arable land; less available forage

[a] Campbell (2011).
[b] Decrease in annual average by 2100 relative to 1961–1990 baseline (Republic of Cuba 2015).
[c] Centella et al. (2008).
[d] Puerto Rico Climate Change Council (2013).
[e] Henareh Khalyani et al. (2016).
[f] See Henareh Khalyani et al. (2016) for projections and discussion of uncertainty.

Vulnerabilities

Vulnerability to the effects of climate change and other systemic disturbances has been conceptualized as being composed of a given system's exposure and sensitivity to disturbance, as well as its adaptive capacity (see fig. 6) (Adger 2006). In this way, vulnerability to climate change encompasses biophysical interactions (i.e., how a reduction in rainfall may affect a certain crop), as well as the human dimensions that dictate the will and capacity to adapt (i.e., whether producers possess the resources and information needed to plan for changes and adjust practices).

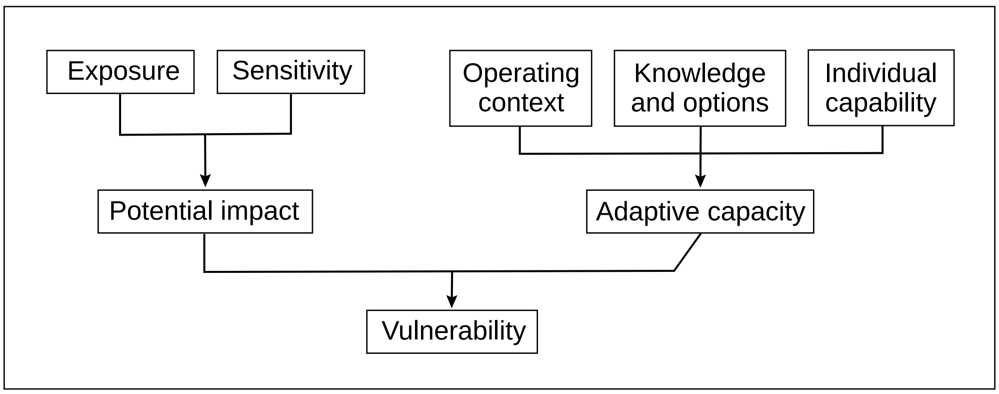

Figure 6—Components of vulnerability (adapted from Marshal 2010).

In both Cuba and Puerto Rico, shifting rainfall patterns have affected many important crops and growing regions with periods of persistent drought being followed by heavy rains, tropical storms, and hurricanes. Adaptation to these changes is particularly challenging given that many areas of the islands have long relied on rainfall, as opposed to river diversions or irrigation from groundwater sources, because of a lack of existing storage and distribution infrastructure. These areas may also be susceptible to damage from extreme weather. A series of destructive hurricanes in 2008 complicated Cuba's efforts to recover from a prolonged drought (2003–2007) and led to an increase in food imports (Altieri and Funes-Monzote 2012, Oxfam Canada 2011). The Puerto Rican agriculture sector suffered a similar chain of events in 2015 when severe drought was followed by years of extreme hurricane and tropical storm activity that culminated with Hurricanes Irma and Maria in 2017. These examples illustrate how the various effects of climate change can exacerbate existing vulnerabilities within a system—creating a negative feedback loop in which each sequential drought, storm, or insect outbreak weakens a producer or sector's ability to adapt and respond to future challenges.

These climatic events have compounding effects on agricultural production, with strong social, cultural, and economic implications that reverberate throughout all aspects of life in the region. If alternative employment opportunities are not available to displaced agricultural workers, fluxes in emigration can be the result (Feng et al. 2010). The patterns of emigration being experienced by some Central American countries are similar to those being experienced by Puerto Rico, which has been losing vital portions of its population for several years. Although immigration and emigration are an integral part of the shifting cultural landscape of any country or territory, large emigrations resulting from crisis or loss of economic opportunity can have profound and lasting effects on internal political and economic realities, as well as on the political stability of an entire geopolitical region. The loss of significant portions of the labor force of any country affects what types of activities may be possible in the future, and also disperses families, which form the fabric of a society. Situations such as this illustrate how of the challenges of climate change transcend traditional disciplinary and geopolitical boundaries to affect every aspect of human life.

Table 2 represents a qualitatively based evaluation regarding levels of exposure, sensitivity, and adaptive capacity to various effects of climate change in Cuba and Puerto Rico. Cuba, Puerto Rico, and other countries and territories throughout

Table 2—Summary of climate change effects and agricultural vulnerability in Puerto Rico and Cuba

Climate effect	Exposure	Sensitivity	Adaptive capacity
Increasing temperatures	High—equal or above global average warming, potentially as high as +9 °C in Puerto Rico	Moderate to high—many tropical crops exhibit a high level of temperature sensitivity	Moderate at lower projected increases Very low at highest projections (+9 °C)
Decreasing precipitation	High—increasing instances of severe drought observed	High—tropical crops are more susceptible to desiccation	Moderate—Cuba is investing heavily in water management
Changing precipitation patterns	Moderate—projected decrease in early wet-season; greater percentage of annual average delivered in extreme events	Moderate to high—can affect phenology of crops as well as pests and disease	Moderate—may be able to invest in infrastructure to collect, store, and distribute rainwater
Seal level rise	Moderate to high—both Cuba and Puerto Rico have key agricultural lands in low-lying coastal areas	High—coastal aquifers and agricultural soils susceptible to salinization	Low—extent of sea level rise largely dependent on global greenhouse gas mitigation efforts
Extreme events	Moderate to high—projected increase in extreme drought, precipitation, and heat events; projected decrease in hurricane frequency; increase in intensity	High—key crops such as coffee and plantains are very susceptible to wind damage; severe drought and heat events have compounding affect	Moderate—certain cultivation practices (agroforestry, contouring, etc.) and infrastructure modifications have the potential to alleviate effects

Note: Ratings are qualitative and based on author analysis of relevant literature. Levels (very low to high) are determined by comparing Puerto Rico and Cuba to other regions such as North America and the European Union.

the LAC region may be able to alleviate the most severe effects of climate change by working to increase the adaptive capacity of producers in the region. Adaptive capacity encompasses all the environmental and socioeconomic factors that enable an individual or organization to effectively plan, adapt, and respond to changing conditions. These factors include the political and cultural context within which an agricultural system is embedded as well as the knowledge, options, and individual capabilities of the producers, advisors, distributors/suppliers, and policymakers who comprise a given food system (Adger 2006, Marshall 2010).

Adaptive capacity encompasses all the environmental and socioeconomic factors that enable an individual or organization to effectively plan, adapt, and respond to changing conditions.

Adaptive Capacity

Both Cuba and Puerto Rico have considerable institutional capacity dedicated to helping build the adaptive capacity of their forestry and agricultural sectors. The USDA Caribbean Climate Hub (CCH) has conducted a vulnerability assessment specific to agriculture and forestry in Puerto Rico and the U.S. Virgin Islands, but perhaps applicable throughout much of the LAC region (Gould et al. 2015). The assessment draws attention to how climatic vulnerabilities within agricultural and forest systems are connected to the broader socioeconomic environment in which they are embedded. As such, addressing vulnerabilities to build adaptive capacity in working lands systems in the region will likely only succeed as part of more comprehensive, integrated efforts that address the political, social, and economic environment in which they arose.

A large group of national sectoral programs in Cuba have a mission to contribute to climate change adaptation. Most prominent are the National Forestry Program (Programa Forestal Nacional); Program for the Rational Use and Saving of Water (Programa de Uso Racional y Ahorro del Agua); Soil Improvement and Conservation Program (Programa de Mejoramiento y Conservación de los Suelos); Program to Combat Desertification and Drought Based on Sustainable Land Management (Programa de Lucha Contra la Desertificación y la Sequía Basado en el Manejo Sostenible de Tierras); and Disease-Transmitting Vector Control Program (Programa de Lucha contra Vectores Trasmisores de Enfermedades), which includes controlling invasive and other species (Republic of Cuba 2015).

In Puerto Rico, the commonwealth government convened the Puerto Rican Council on Climate Change (PRCCC) in 2010 to assess the territory's vulnerabilities and recommend strategies to respond to expected changes. The council published the first *Puerto Rico's State of the Climate* report in 2013 assessing the socioecological vulnerabilities within the island at large (PRCCC 2015). In 2014, the USDA established a network of "climate hubs" to deliver science-based knowledge and practical information to farmers, ranchers, and forest landowners to assist their efforts to adapt to climate change. The CCH was established at the U.S. Forest Service's research facility, the International Institute for Tropical Forestry

(IITF) in Río Piedras, Puerto Rico, to serve working lands in Puerto Rico, the U.S. Virgin Islands, and the LAC region at large.[5] In addition, IITF's research program on climate change consists of experiments, monitoring, and modeling of tropical forests and cities.

Experiments include the following:

- Canopy trimming experiment: anticipating the effects of increased hurricane frequency on tropical forests[6]
- Tropical Responses to Altered Climate Experiment (TRACE),[7] the first warming experiment for tropical forests
- Drought experiments anticipating the effects of drought on tropical forests
- Fire experiments: the effects of fires on pasture dynamics

Monitoring:

- Climate change effects on elevational gradients in the Luquillo Mountains[8]
- More than 50,000 trees tagged and monitored in many types of environments to assess their response to climate change
- Urban plots to assess social and ecological responses to climate change conditions

Modeling:

- Developing future climate scenarios for the Caribbean based on global models
- Modeling tropical forests under the effects of climate change
- Modeling urban systems to integrate green and grey solutions to city resilience

Established in 1939, IITF has a tradition of research and technology transfer with national and international applications based on a platform in Puerto Rico and throughout tropical America. The institute develops and disseminates scientific knowledge that contributes to the conservation of forests, wildlife, and watersheds of the American tropics. The institute strives to be a center for excellence where creativity and accomplishments result in timely products and services that anticipate the needs of society as it is forced to mitigate and adapt to environmental change. Effectively managing tropical ecosystems in the face of multifaceted environmental change requires the understanding of ecological and social mechanisms that drive the function and use of forest systems from wildlands to inner cities.

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[5] Caribbean Climate Hub website: http://caribbeanclimatehub.org/.

[6] http://www.treesearch.fs.fed.us/pubs/47466, http://www.treesearch.fs.fed.us/pubs/49302, http://www.treesearch.fs.fed.us/pubs/47467.

[7] http://www.treesearch.fs.fed.us/pubs/49346.

[8] http://www.treesearch.fs.fed.us/pubs/47285.

Research within IITF is focused on understanding ecosystem dynamics in the face of environmental change across a gradient from wildlands to working lands to cities. The institute also focuses on understanding societal and institutional interactions within the landscape to help inform management, develop effective management options and practices, and predict future states of tropical forests. The IITF and CCH could assist with Cuba's natural resource conservation goals by facilitating technology transfer, training, and two-way knowledge sharing. The goal of these efforts would be to open channels of communication between institutions in Puerto Rico and Cuba tasked with assessing and ameliorating challenges that climate change presents to the continued provision of vital ecosystem services.

In addition to the work of the CCH and IITF, the adaptive capacity of agriculture and forestry in U.S. territories in the Caribbean benefits from a myriad of territorial and federal organizations, including the USDA Natural Resources Conservation Service, USDA Agricultural Research Service, other branches within the U.S. Forest Service, the University of Puerto Rico, the Puerto Rico Department of Natural and Environmental Resources, the U.S. Virgin Islands Department of Planning and Natural Resources, and the Puerto Rico and the U.S. Virgin Islands agriculture departments, among other important partners.

Next Steps in Adaptive Management: Strategies for Moving Climate Science to the Field

Responding to the challenges that climate change poses to the resilience of social-ecological systems in Cuba and Puerto Rico in a timely and effective manner may require new organizational strategies to more efficiently adapt, plan, communicate, and respond. All these actions require an effective information management chain that encompasses how an organization creates or receives knowledge, as well as how they assimilate that knowledge into their policies, programs, and personnel.

Environmental management decisions increasingly require the most up-to-date and comprehensive science available. However, significant gaps among science, policy, and practice persist. This disconnect is increasingly problematic as dramatic GHG emission reductions are needed within the coming decade(s) to stave off the most extreme climate model projections (IPCC 2018).

Changes of the magnitude and pace now being projected for the future demand a new level of effectiveness in planning and implementation in the present. According to USDA Climate Change Program Office Leader William Hohenstein, simply reacting to changes "as they come" is becoming an increasingly insufficient strategy in addressing global climate change.[9] Strategies for accomplishing this elevated level of system functioning are the subject of much research, discussion, and experimentation in the realm of policymaking and governance (Brunner and Lynch 2013, Clark and Clark 2002, Lasswell 1971) as well as business and information management (Easterby-Smith et al. 2008, Osterloh and Frey 2000, Van Wijk et al. 2008). Much of the conversation centers on how knowledge is created, managed, and shared. These are functional aspects that organizations must manage internally as well as externally with the express goal of affecting the attitudes and behaviors of personnel within the organization as well as the various stakeholders interacting with it. The issue posed to managers and policymakers is how to effectively manage and transfer information in a way that prompts and facilitates timely and informed decisions at every organizational level. Although this issue is challenging to organizations on the scale of a single business with a fairly focused mission and goals, it can be profoundly challenging for governmental organizations seeking to promote a range of outcomes over large geographic scales. The ever-increasing pace and complexity of knowledge creation and modification compounds these difficulties.

Communication and Knowledge Sharing

Developing effective networks, techniques, and tools for the translation and dissemination of climate science related to agriculture, forestry, and corresponding best management practices is central to the mission and goals of the USDA climate hubs. This mission is seen as critical in building adaptive capacity in the agriculture and forestry sectors of the United States to ensure adequate and timely adaptations to the effects of global climate change. During Cuba's Special Period food crisis of the early 1990s, the country faced a similar challenge of adapting its food system to rapid change and disruptions as imports of food supplies and agricultural inputs were effectively cut off. As Cuban farmers recovered traditional cultivation methods and augmented them with innovative techniques developed by Cuban researchers, the potential of agroecological methods began to emerge (Rosset et al. 2011). What also became clear was that widespread, systematic transformation would likely not take root without building a social process to accelerate the dissemination and implementation of desirable practices. This need helped drive the adoption of the Campesinoto Campesino (CAC) Movimiento (Farmer to Farmer Movement) strategy of information co-production and

[9] Comments made during a greenhouse gas mitigation workshop hosted by the USDA Caribbean Climate Hub in September 2015.

sharing from Central America (Rosset et al. 2011). The CAC Movement is "based on the horizontal transmission and collective construction of knowledge, practices, and methods. It blends traditional peasant knowledge and farmer innovation together with the science of agroecology. This process has stimulated the rapid generation, diffusion, and adoption of agroecological practices at the farm level" (Rosset et al. 2011).

Recent research in the United States has demonstrated that, while potentially helpful climate science and decision support tools are available, they remain largely underused (Mase and Prokopy 2014). To improve climate support tools and increase their usage, information is most effective when it is useful, relevant, and context specific. These objectives may best be accomplished using collaborative approaches that engage farmers and other end users in the planning and development of decision support tools, making the tools themselves more relevant and giving users a better understanding and sense of ownership (Mase and Prokopy 2014). Facilitating the flow of scientific information to the realm of planning and practice via decision support tools and other methods requires conscious effort, formal institutionalized processes, as well as informal social networks (Folke et al. 2005). These processes represent adaptive organizational practices for agencies in the same way that terracing or cover-cropping represent adaptive cultivation practices for farmers. Advocates contend that this method of knowledge creation and extension is preferable to conventional top-down approaches for a variety of reasons, including the incorporation of local, traditional knowledge and demonstrating respect for farmers' ability to constantly innovate and experiment (Folke et al. 2005).

Experience has demonstrated the increased effectiveness of peer-to-peer educational strategies such as on-farm demonstrations and farmer-led workshops.

Experience and research by CCH staff have also demonstrated the increased effectiveness of peer-to-peer educational strategies such as on-farm demonstrations and farmer-led workshops (Gould et al. 2015).[10] Within this paradigm, researchers and extension agents play a supportive role by providing arenas for information sharing that foster an open dialogue between local scientists and producers rather than a one-way conveyance of generalized knowledge and recommendations. Comparing the effectiveness of communication and knowledge-sharing strategies in Puerto Rico and Cuba could expand the knowledge base of both and represent an area of important collaboration.

[10] Caribbean Climate Hub ADAPTA project: https://caribbeanclimatehub.org/projects/.

Conclusion

Effectively addressing the challenges climate change presents to working lands throughout the Caribbean will likely require new levels of international coordination and cooperation, particularly in the realm of science and technology development and delivery. Connecting Cuba's strategies to combat food shortages in the early 1990s and climate change in the 21st century with CCH, IITF, and other organizations' efforts to build adaptive capacity in Puerto Rico and the U.S. Virgin Islands has great potential to open avenues of collaboration in the region, offer new perspectives, and bolster resilience to the effects of climate change. The challenges of climate change are global, and while projected effects on local food systems in the Caribbean may seem daunting, they also present an opportunity and the impetus to unite the collective creativity and innovative spirit of the people of Cuba and Puerto Rico.

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Appendix

Climate Projections for Cuba and Puerto Rico

Both Puerto Rico and Cuba are projected to experience increasing mean annual temperatures over the course of the 21st century (fig. 7). The range of increase projected varies according to the emission scenario and particular climate model used. Emission scenarios are built on a range of assumptions regarding global economic and technological development, the continued use of fossil fuels, and greenhouse gas (GHG) mitigation policies (IPCC 2000). The scenarios do not take into account implementation of the United Nations Framework Convention on Climate Change (UNFCCC) or the emissions targets of the Kyoto Protocol. In 2000, the Intergovernmental Panel on Climate Change issued a Special Report on Emission Scenarios (SRES) that resulted in four narratives based on scientific literature. These narratives consistently describe the relationships between emission driving forces and their evolution and add context for the scenario quantification (IPCC 2000). For each narrative, several different scenarios were developed by using different modeling approaches to examine the range of outcomes arising from a range of models that use similar assumptions about driving forces. The 40 resulting SRES scenarios together encompassed the best understanding of future GHG emission uncertainties as of 2000.

The range of temperature projections for Puerto Rico are the result of recent modeling efforts by scientists at the U.S. Forest Service International Institute of Tropical Forestry based on the SRES A1B, A2, and B1 emissions scenarios (Henareh Khalyani et al. 2016, 2019). The A2 scenario is representative of a heterogeneous world in which economic development is primarily regionally oriented, and per capita economic growth and technological change are more fragmented and slower, which results in greater temperature increases compared to other scenarios modeled for the region.

Karmalkar et al. (2013) used general circulation model (GCM) data included in the Coupled Model Intercomparison Project phase 3 (CMIP3), and the UK Hadley Centre regional climate model (RCM) data, to provide both present-day and scenario-based future information on precipitation and temperature for individual island states within the Caribbean (figs. 7 and 8). They found that models used in the Caribbean to date have struggled to accurately reproduce observed rainfall patterns because of the complex interactions between sea surface temperatures, sea level pressure, and predominant wind patterns. These difficulties have resulted in a generally dry bias when comparing observed and modeled precipitation, which should be noted when studying precipitation projections. Modeled temperature patterns are more closely aligned with observations, thus projections are considered more certain although some uncertainty still exists. The end-of-century picture of Caribbean climate, as deduced from the CMIP3 models, is one characterized by a

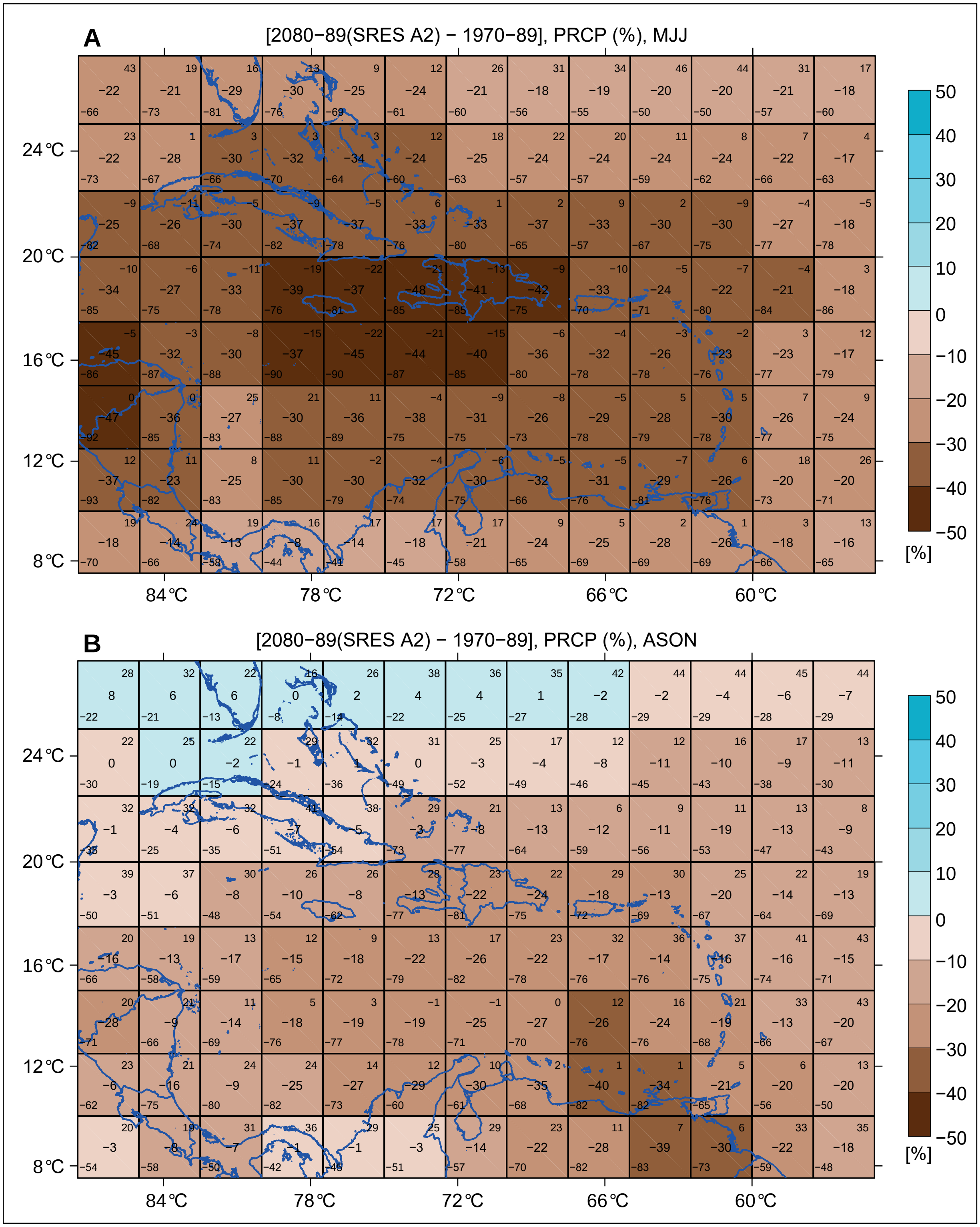

Figure 7—Projected change in precipitation (percent) by the 2080s under the SRES A2 scenario based on the CMIP3 multi-model ensemble for the following seasons: (A) MJJ (early wet season) and (B) ASON (late wet season). Projected change is relative to the mean from 1970 to 1989. From Karmalkar (2013). MJJ = May, June, July. ASON = August, September, October, November.

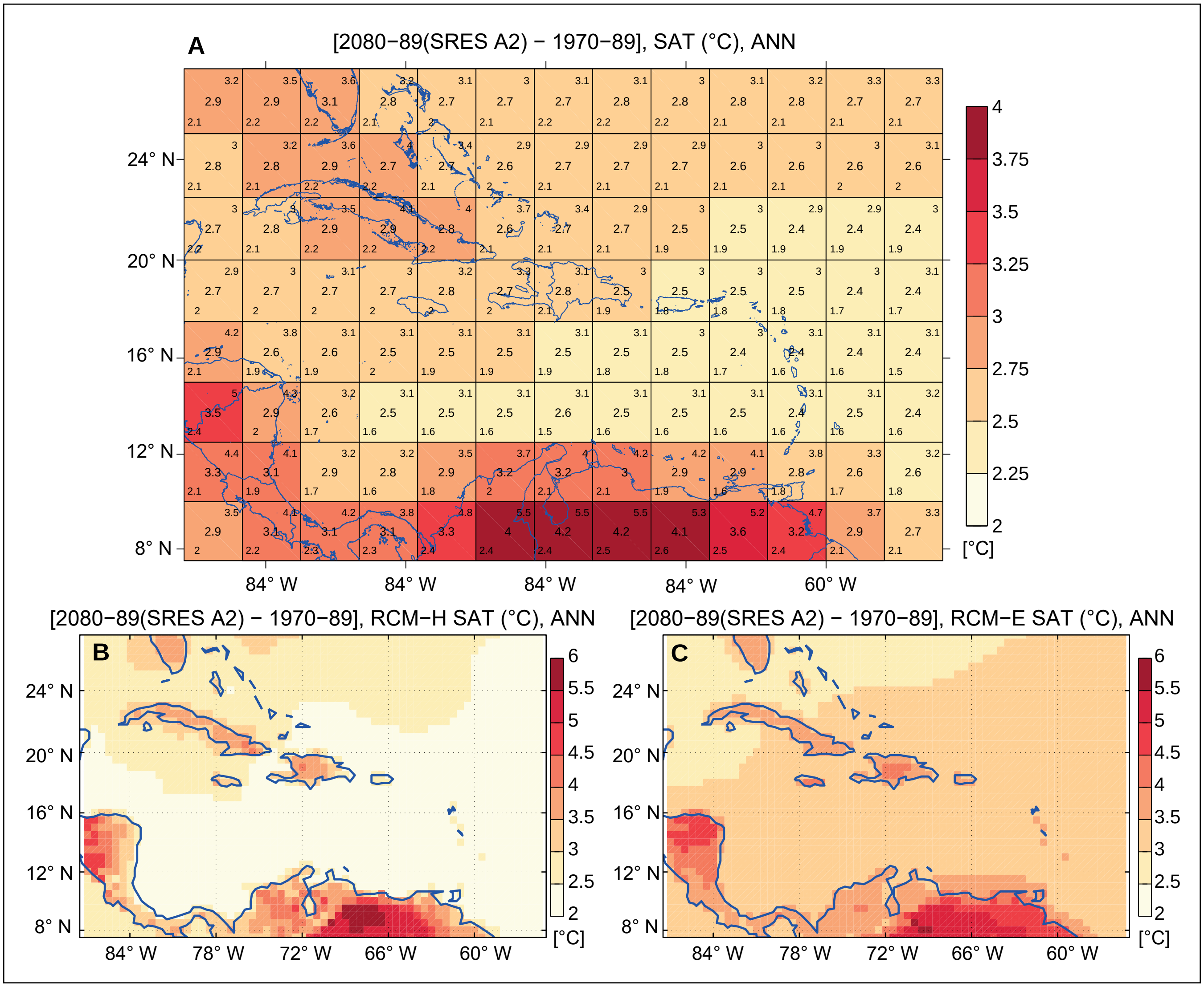

Figure 8—Projected change in mean annual surface air temperature (°C) by the 2080s under the SRES A2 scenario in (A) CMIP3 multi-model ensemble, (B) RCM-H, and (C) RCM-E. Projected change by the 2080s is relative to the mean climate of 1970–1989. In (A), for every grid box, the color indicates ensemble mean projection, the value at the center indicates ensemble median projection, and values at the bottom left and top right corners indicate ensemble minimum and maximum projections, respectively. From Karmalkar (2013).

decrease in wet season precipitation. The dry season is largely unaltered except for a small increase in precipitation in November in the Bahamas. The RCM simulations similarly project a drying trend (though more intense) for the wet season, but the agreement between the two RCM projections is generally poor with respect to which portion (early or late) will be driest. Both the GCMs and the RCMs project higher warming of surface air temperatures over the northwestern Caribbean and relatively lower warming in the southeastern Caribbean. The RCMs, however, have higher warming values in general, especially over the eastern Caribbean where the landmasses are better resolved.

Surface Air Temperatures

Both Puerto Rico and Cuba are projected to experience increasing mean annual temperatures over the course of the 21st century. The range of increase projected varies according to the emission scenario and climate model. Karmalkar et al. (2013) projected a 2 to 5 °C (3.6 to 9 °F) increase[11] for the Latin American and Caribbean (LAC) based on the SRES A2 emission scenario (see fig. 7). Interpolation of downscaled climate data for Puerto Rico has resulted in a much higher set of projections (7.5 to 9 °C [13.5 to 16.2 °F]) (see fig. 9) (Henareh Khalyani et al. 2016).[12] Either scenario presents acute challenges to the agricultural sectors of Puerto Rico and Cuba. Under "worst case scenario" projections, climate-controlled environments would almost assuredly be required for any viable agricultural operation. Such operations would necessitate massive investments in energy and water management infrastructure. If global efforts are successful in limiting average global warming to 1.5 °C, as was ratified at the Paris UNFCCC Conference of the Parties, downscaled models indicate that Puerto Rico may still experience a dramatic increase in total dry days and in days that exceed historical temperature maximums (particularly in the wet season) (Hayhoe 2013). Prolonged dry periods are expected to become more frequent with even 1 °C of average global warming (Hayhoe 2013). Modeling indicates that much of the mean temperature increase projected for Puerto Rico and Cuba will be the result of increases in mean minimum temperatures, indicating a narrower range of temperature variation (both annual and diurnal) and sustained higher temperatures (Hayhoe 2013, Karmalkar et al. 2013).

Increasing temperature trends can affect crops in a variety of ways. An important aspect of increasing minimum temperatures is the affect that such increases have on the pollination stage of crops and other plants. The pollination stage is a critical period in which exposure to high temperatures can be particularly damaging to crops. Pollen release is related to development of fruit, grain, or fiber. Exposure to high temperatures during this period can greatly reduce crop yields and increase the risk of total crop failure. Plants exposed to high nighttime temperatures during the grain, fiber, or fruit production periods experience lower productivity and reduced overall quality (Walthall et al. 2013).

Rising temperatures will also likely lead to increasing pressure from pests and disease, heat stress in animals, and unpredictable changes in the phenology of many

[11] Increase for years 2080–2089 vs. 1970–1989. Puerto Rico and Cuba are projected to increase by <3 °C.

[12] 2071–2099 vs. 1960–1990. Source: Henareh Khalyani et al. (2016) using data from Hayhoe (2013).

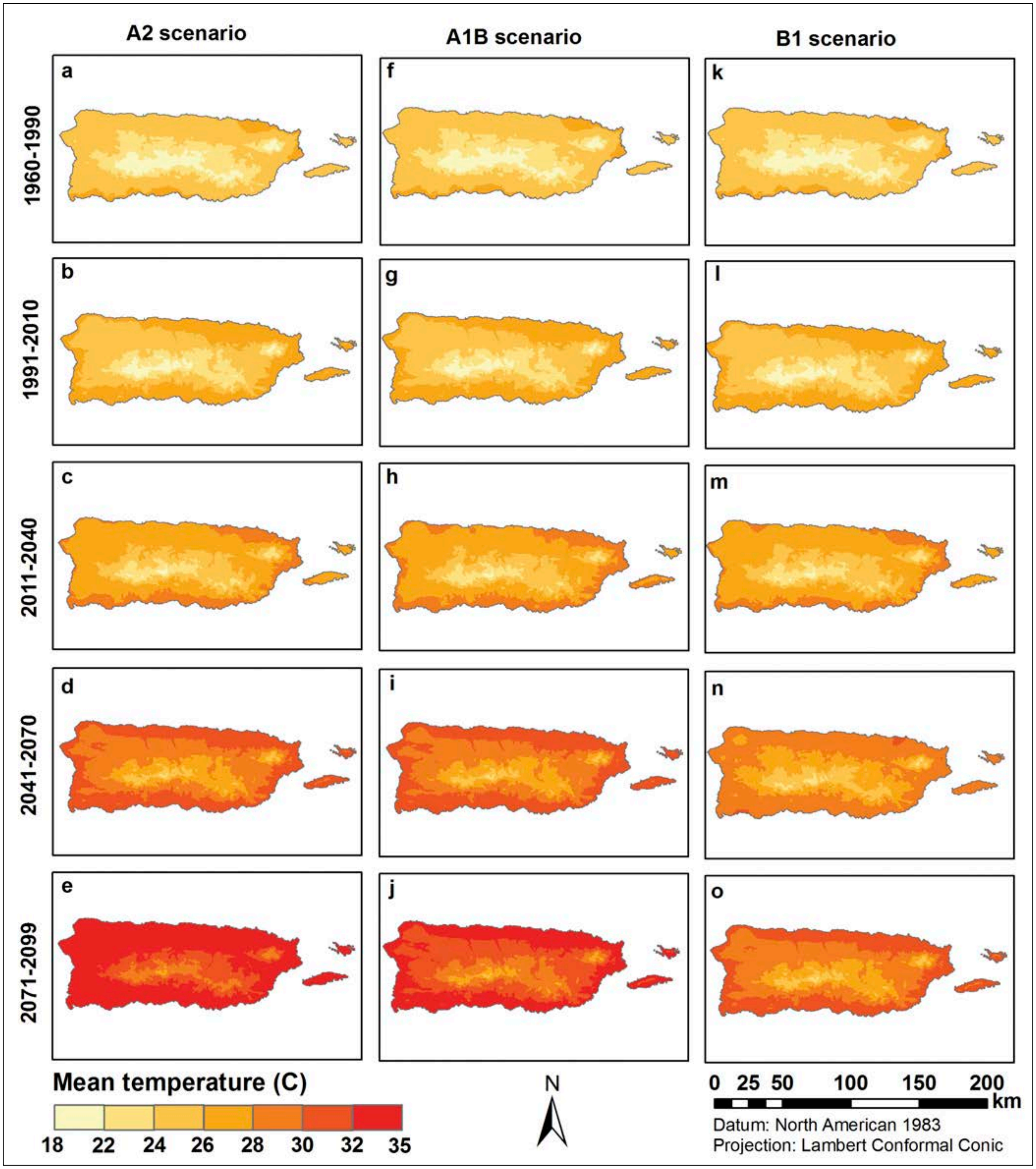

Figure 9—Projected increase in mean temperature for Puerto Rico. From Henareh Khalyani et al. (2016).

plants. Water shortages and heat stress among livestock have already been cited as a growing concern among many farmers in the U.S. Caribbean and throughout the LAC region (Gould et al. 2015). Higher temperatures can result in increased respiration rates in plants that in turn will require greater soil moisture to maintain vitality and yields. Maintaining necessary moisture levels in light of increased temperatures and evapotranspiration rates will likely require a range of adaptation strategies, including investment in water management infrastructure (irrigation, water storage, etc.) as well as a shift toward agroforestry and other agroecological practices that work to maintain soil moisture by increasing shade and decreasing ambient air temperatures. Rising temperatures are also likely to affect forest ecosystems throughout the Caribbean. In Cuba, expected effects include modifications to phenological patterns in mountain and coastal tree species; losses to biodiversity in high-altitude systems; accelerated reproductive cycles of forest pests, and altered phenology among forest diseases (Planos et al. 2013). Rising temperatures and other changes in climate are also expected to alter the distribution, population, and effects of existing forest pests and diseases and may lead to additional vulnerabilities to new insects and diseases or introduced invasive species.

Precipitation

Increasing mean surface air and sea-surface temperatures are tied to changes in larger global circulation patterns that correlate to rainfall patterns within the Caribbean (Karmalkar et al. 2013). As discussed previously, models exhibit greater uncertainty in projecting future precipitation trends than temperature. That aside, regional models show a drying trend characterized by a decrease in wet season precipitation (fig. 6). The decrease is generally higher for the early wet season (May through July) than the late wet season (August through November) and for the western Caribbean (Cuba) than the eastern Caribbean (Puerto Rico) (Karmalkar et al. 2013). Those trends stand in contrast to study findings published in 2009 for Puerto Rico that show a decrease in dry season precipitation but an increase during the wet season (Harmsen et al. 2009). Recent efforts to interpolate downscaled climate data for Puerto Rico show greater variability in precipitation trends over time, but a linear increase in important indicators such as total dry days and maximum consecutive dry days (an important drought indicator) over the next century (fig. 10) (Henareh Khalyani et al. 2016).

The impact of drying trends and reduced water availability on agricultural systems in Cuba and Puerto Rico could be profound (Van Beusekom et al. 2014). Both islands have experienced critical water shortages in recent years associated with prolonged droughts. A 2011 report by Oxfam listed water availability as a

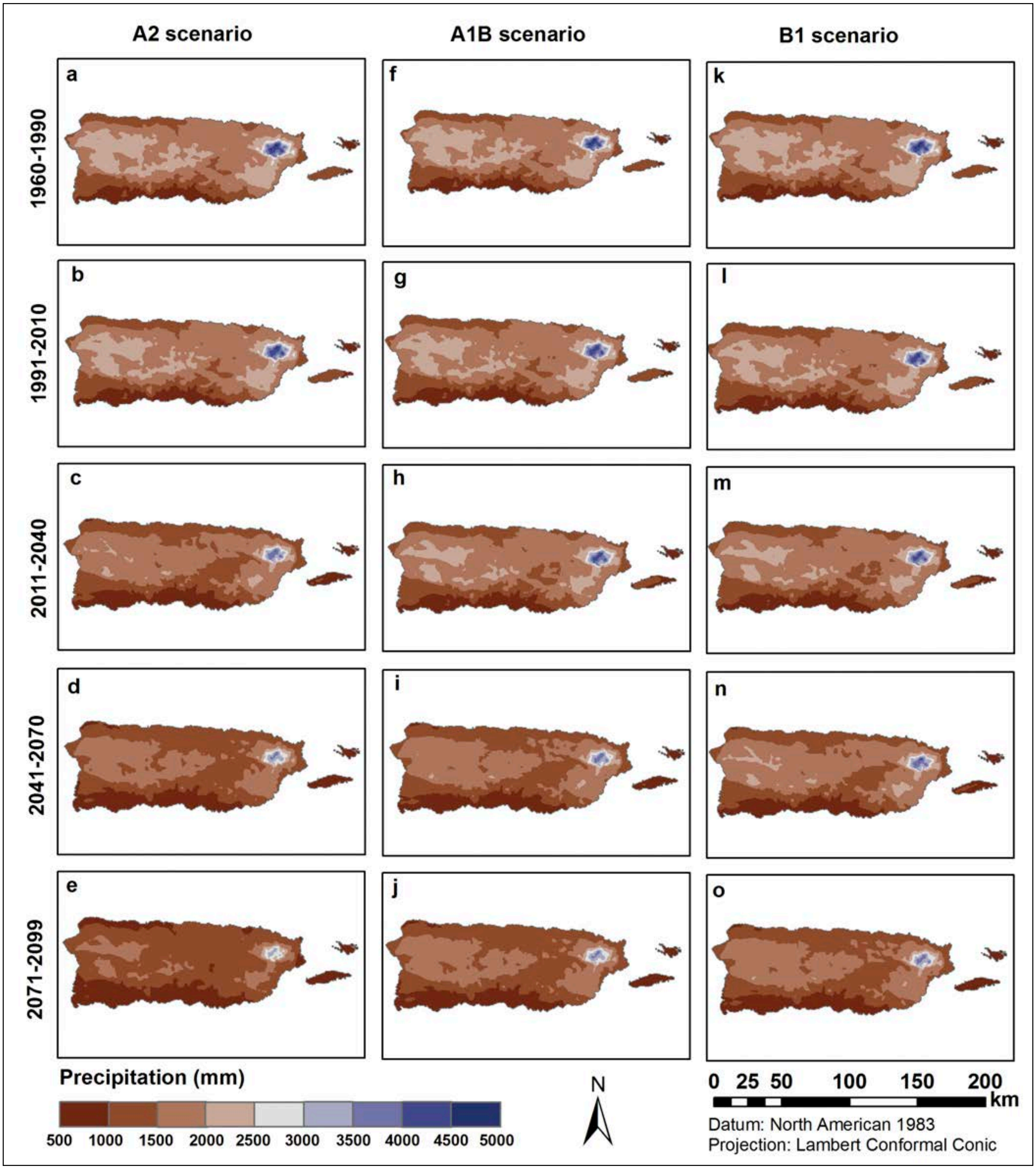

Figure 10—Projected changes in annual precipitation for Puerto Rico. From Henareh Khalyani et al. (2015).

major challenge facing Cuban agriculture in coming years (Oxfam Canada 2011). Increasing temperatures and reduced rainfall could require significant investments in irrigation and water management infrastructure to ensure ample future agricultural water supply (Harmsen et al. 2009).

Cuba has already begun this investment process by increasing public spending on environmental protection from 390.8 million Cuban pesos in 2009 to 517.3 million Cuban pesos in 2013, 230.4 million of which were allocated to water management (the exchange rate with U.S. dollars is 1 to 1) (Alonso and Clark 2015). Further investments by either country will need to be secured in an environment of increased competition for fiscal resources and stressed water supplies. Even if water supplies remain available in sufficient quantity, constructing needed storage and distribution infrastructure will likely be a challenge for local governments and many small-scale, limited-resource farmers.

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