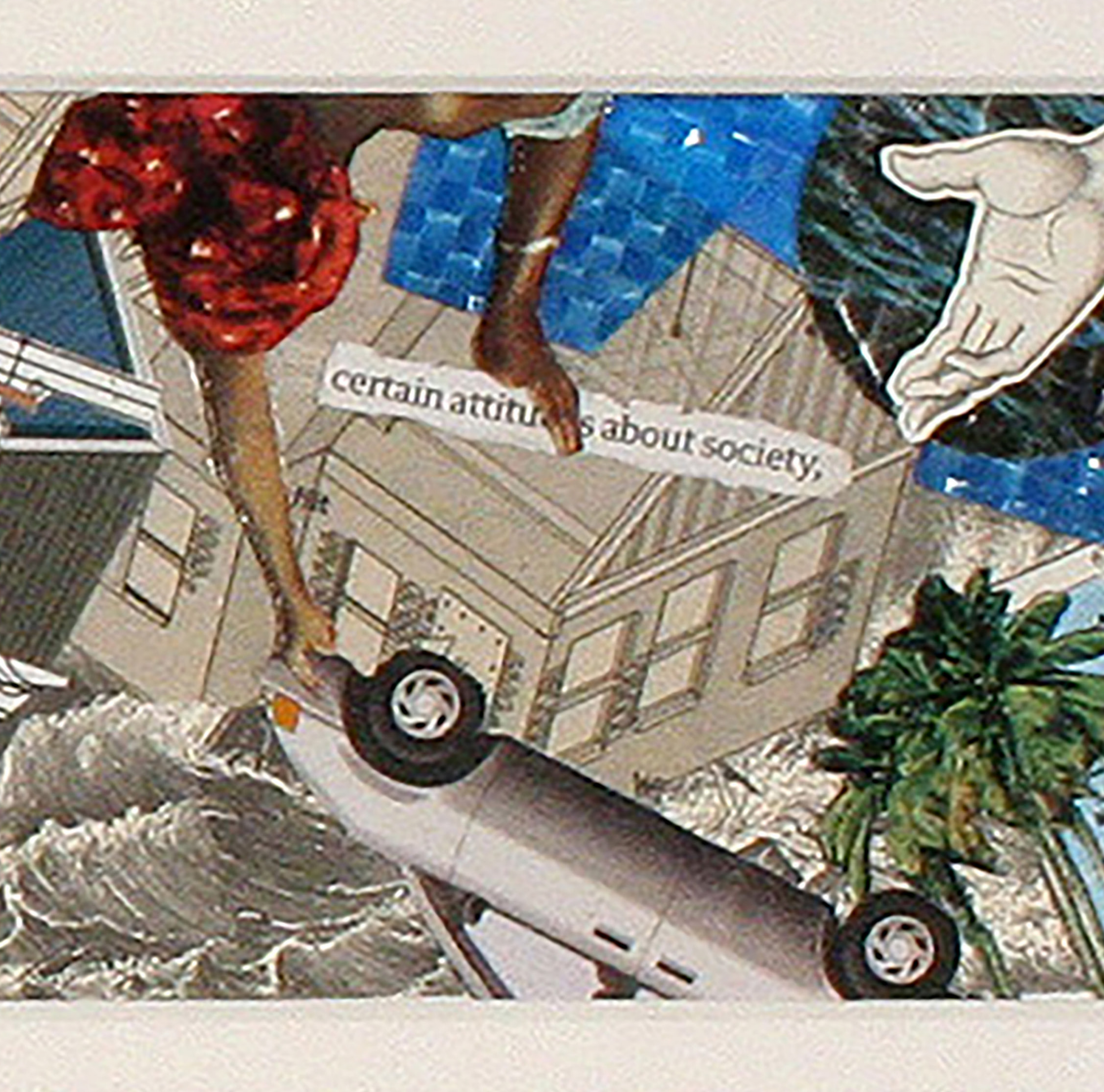
Fifth National Climate Assessment: Chapter 23

US Caribbean



Chapter 23. US Caribbean

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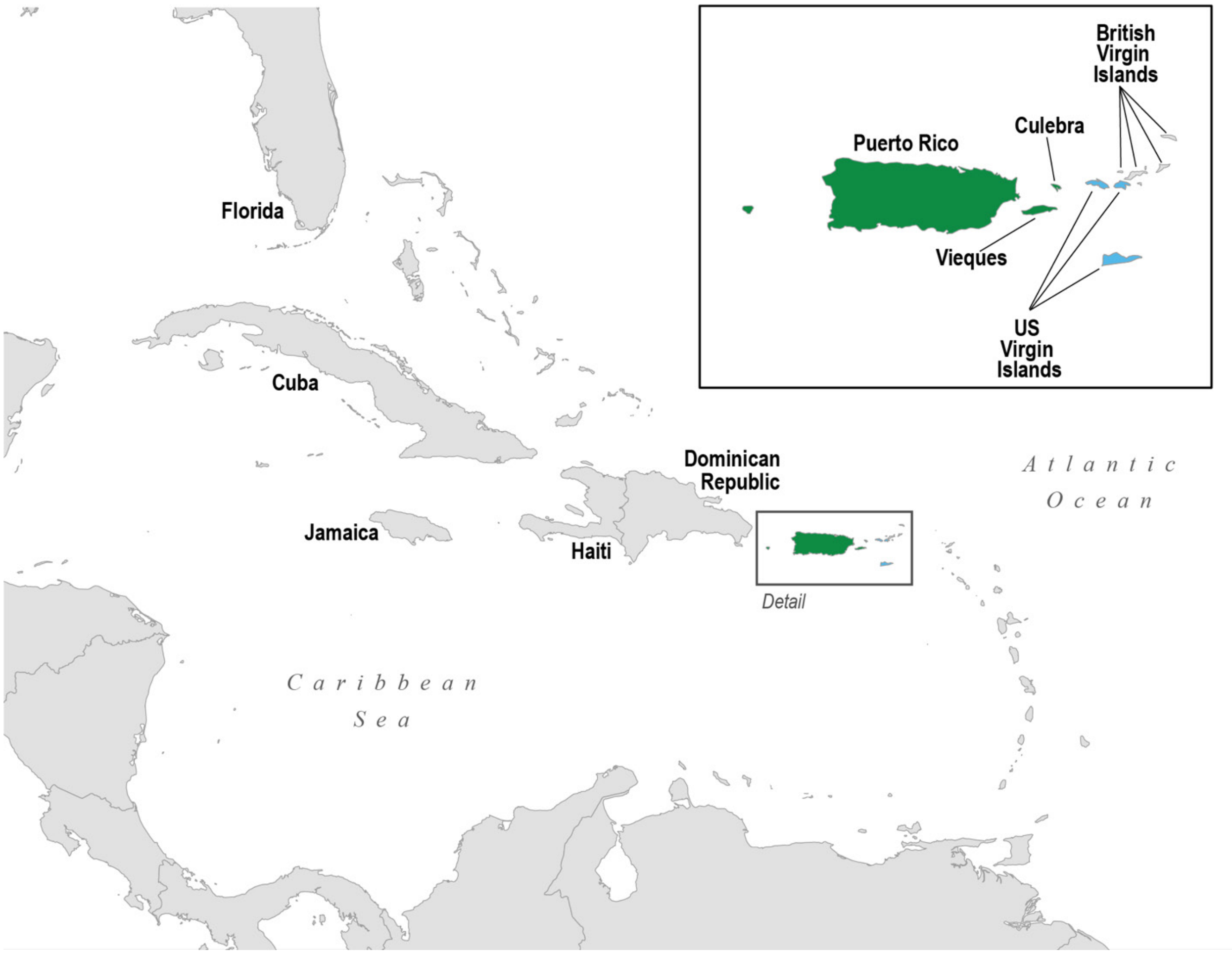
Introduction

The US Caribbean comprises Puerto Rico (PR) and the US Virgin Islands (USVI; Figure 23.1). Both are US territories, and people born there acquire US citizenship by birth. The USVI is home to about 87,000 US citizens (Table 23.1).[1] The USVI has a majority Black population and a mix of English-, Spanish-, and Creole-speaking communities. Puerto Rico (which includes the inhabited islands of Vieques and Culebra) has a population of around 3 million US citizens who are predominantly Hispanic- or Latino-Spanish speakers. Communities in both territories are now the source of significant migration to the US mainland.[2,3,4,5,6]

The US Caribbean



The US Caribbean region in the Fifth National Climate Assessment consists of Puerto Rico and the US Virgin Islands.

Figure 23.1. The map shows the location of Puerto Rico and the US Virgin Islands in the Caribbean Basin. The inset shows the main island of Puerto Rico (green; the two municipal islands of Vieques and Culebra are shown to the east and Mona Island to the west) and the US Virgin Islands (yellow; St. Thomas and St. John to the north and St. Croix to the south). Figure credit: University of Puerto Rico, NOAA NCEI, and CISESS NC.

The USVI and PR share a geographic region. Both are populated by groups that the US government considers minorities, and both face enormous socioeconomic challenges. At the same time, they have different socioeconomic, geopolitical, and climate realities. They are also quite different in scale, governance, and demographics (Table 23.1). Island residents have learned to cope with adversity due to centuries of unfavorable social inequality, colonial policies, and extreme climate events.[7]

Table 23.1. Geography of US Caribbean Territories

The sociodemographic profiles of Puerto Rico and the US Virgin Islands are grounded in long histories of colonization, systemic inequality, and parallel historical backgrounds with deeply rooted Indigenous traditions. These territories are facing similar climate-related hazards that are compounded by shrinking economies, aging populations, and ineffective government structures. Sources: Median household income from US Department of Housing and Urban Development;[8] other data from US Census Bureau.[6]

Category	Puerto Rico	US Virgin Islands
Population Living Below Poverty Level (US average: 11.4%)	43.5%	18.4%
Main Island(s) Surface Area	3,515 square miles	St. Thomas: 32 square miles St. John: 20 square miles St. Croix: 81 square miles
Total Population	3,075,000*	St. Thomas: 42,261 St. John: 3,881 St. Croix: 41,004 Total: 87,146
Principal Language	Spanish	English
Urban Population	93%	96.3%
Rural Population	7%	3.7%
Race and Ethnicity	98.7% Hispanic or Latino** (US: 18.5% Hispanic or Latino)	76% Black (Afro-Caribbean) (US: 13.4% Black or African American)
Median Household Income (in 2020 dollars; US average $67,521)	$20,539	$37,254
Population Change 2010–2020	−17.4%	−18.1%
Government	1 governor 27 senators 51 representatives 78 mayors/municipalities 1 non-voting member of the US House of Representatives	1 governor 15 senators (7 each district, 1 at-large) No representatives No mayors 1 non-voting member of the US House of Representatives

*2020 Post-Enumeration Surveys.[9] **Although "Hispanic or Latino" is the official US Census category, it does not capture the racial and ethnic diversity of PR, the Caribbean, or Latin America. The official US Census definition for "Hispanic or Latino" refers to a person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish cultural origin regardless of race. This definition is meant to cover all Spanish-speaking cultures.

These islands are particularly vulnerable to extreme weather events that are being exacerbated by human-driven climate change, and there is increased potential for impacts because people, cities, and critical infrastructure are often located in the most vulnerable locations.[10,11,12] Extreme weather is triggering cascading, ongoing crises and highlighting political divides, which shape response and recovery efforts. At the same time, these events are revealing grassroots organizational capacities typically ignored by national- or regional-scale discourses regarding vulnerability and resilience.[13,14] A changing climate in the Caribbean highlights the interdependencies of critical infrastructure systems. In addition, climate change threatens the preservation of heritage, particularly tangible heritage both on land and underwater.[15] In addition to catastrophic failures caused by powerful hurricanes, the impacts of extreme events in many places in the Caribbean are exacerbated by intangible factors that undermine the foundations of strong communities and functional ecosystems. Post-disaster recovery is particularly complex in the US Caribbean because of diverse cultural practices, complicated governance structures, and uneven access to information and resources, sometimes referred to as differential social vulnerability (Box 23.1).

The absence of adequate governmental response to climate change and extreme events, coupled with a long history of political marginalization, has catalyzed the rise of community-based organizations that are pursuing sustainable development efforts on their own.[13]

Box 23.1. Differential Vulnerabilities in the US Caribbean

Impacts of climate change on US Caribbean societies must be understood in the context of the social and historical processes that shape identity and exposure (see Chapter 20 for a detailed explanation of these concepts and the links to justice). Not everyone is equally impacted by climate change. Social vulnerability is a multidimensional process affected by social, political, and economic forces interacting from local to international scales.[16] In the US Caribbean, social vulnerability and social determinants of health are best viewed within a systemic risk framework and are at least partially influenced by the following:

- *Culture*: Broad ethnic diversity, different economic backgrounds, and deep historical traumas linked to colonization and struggle characterize the US Caribbean. These backgrounds shape locally relevant worldviews, risk-perception, decision-making, and adaptation and mitigation strategies. Perception of and response to climate risks include local and Traditional Ecological Knowledge and long-term memory of disasters that might or might not be transferable within or between islands (Ch. 20).
- *Access to resources*: High poverty indices and sharp social stratification, together with growing gentrification, migration, displacement, accumulated impacts from past disasters, and concerns linked to human health, influence access to resources—from economic to material objects—that could be used to lessen risks and prepare for adaptation. Aside from economic resources, access to natural resources is affected by the cumulative effects of human activities over time. In the Caribbean, for example, years of Indigenous agricultural practices, colonial plantation systems, and industrialization have contributed to reduced biodiversity, loss of forest cover, soil depletion, unstable slopes, and degraded marine ecosystems, which converge to heighten the severity of risks (Chs. 17, 18).
- *Access to information*: Climate data are often available only on scales that are too large for the needs of relatively small islands with very wide microclimatic diversity. Other barriers to accessing information include language (Spanish and English are the principal languages of PR and the USVI, respectively), educational barriers, poverty, growing indices of illiteracy, and distrust in official entities.
- *Governance*: The political relationship between the US Caribbean territories and the Federal Government affects the ability and capacity for local action. Other formal and informal systems of local governance also affect action, including grassroots leadership, local nongovernmental organizations, and religious organizations.
- *Puerto Rico's fiscal and economic situation:* The prolonged and deep contraction of Puerto Rico's economy since 2006, coupled with the fiscal crisis and the Puerto Rico government's bankruptcy, resulted in significant cutbacks in government institutions, social services, and infrastructure improvements and maintenance.[17,18,19] Such austerity measures, intensified by the escalating intervention of the federally controlled Fiscal Management Board, influence Puerto Rico's ability to address the underlying causes of vulnerability and hinder its capacity to recover and adapt.[20]

Observed and Projected Climate Change for the US Caribbean

The assessment of observed and projected climate-related trends provides information for evaluating climatic and environmental consequences of future climate changes, risks, and impacts. The following assessment builds on the most recent findings.[1,12,20,21,22,23,24,25]

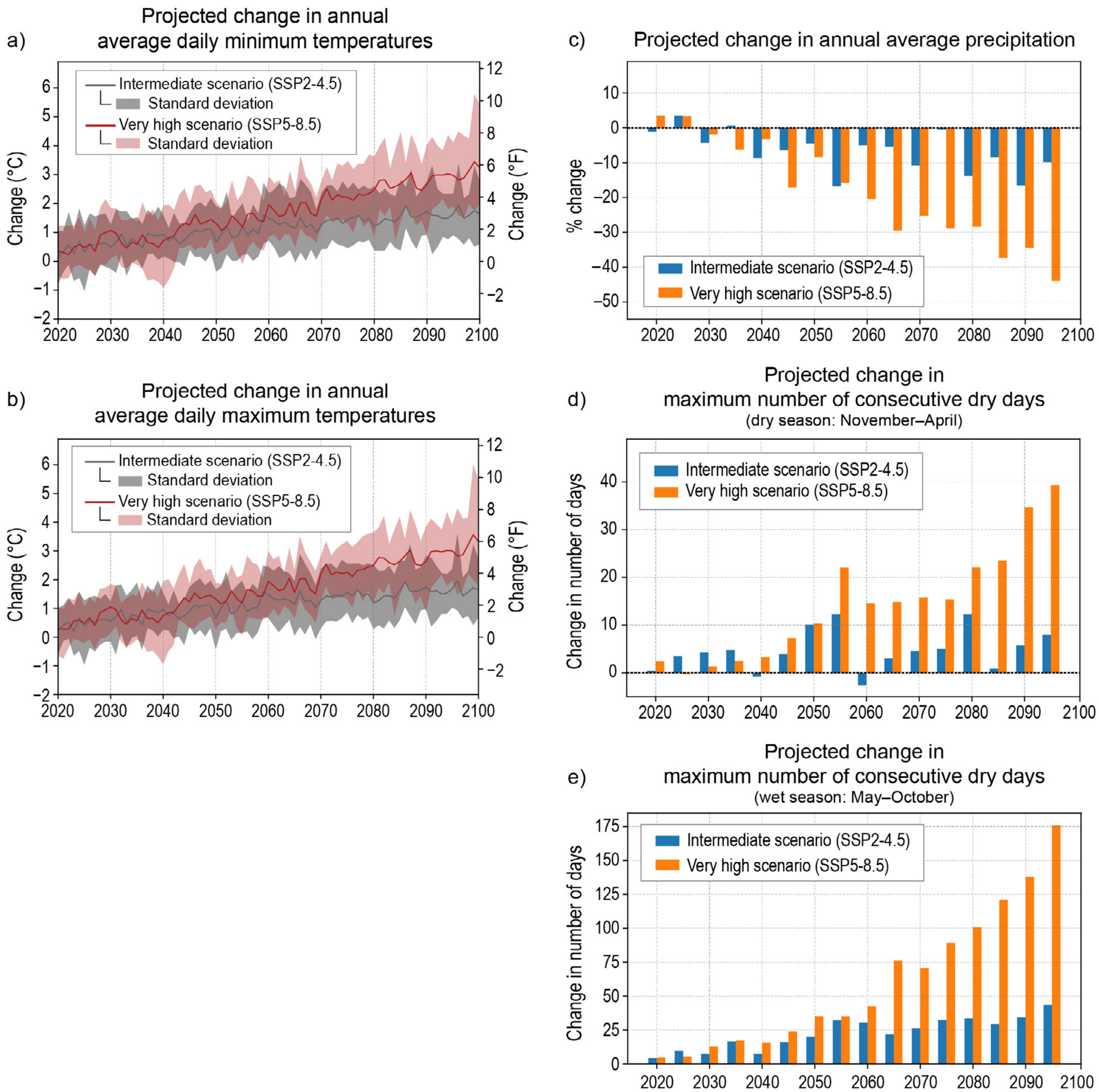
- Natural climate variability (Table 23.2), including the El Niño–Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), and Saharan dust events, has an important role in the subseasonal to interannual (year-to-year) climate within the US Caribbean.
- Daily average temperatures in PR have increased by 2°F since 1950. Minimum temperatures are increasing faster than daily average temperatures, with the largest increase for minimum temperatures at lower elevations. Projections for end-of-century temperatures show additional warming, from as low as 1.1°F under an intermediate scenario (SSP2-4.5) to as high as 7°F under a very high scenario (SSP5-8.5; Figure 23.2).
- No clear long-term trend is detected in seasonal or annual average rainfall over PR, although Figure 2.4 does show a small increase (less than 5%) in Puerto Rico in 2002–2021 compared to the 1901–1960 average. However, climate models project a significant reduction in annual average rainfall by end-century with reductions of 10% for SSP2-4.5 and 33% for SSP5-8.5. The rainfall reductions for SSP5-8.5 compared to SSP2-4.5 become increasingly larger after midcentury. The consequence of reductions in annual average rainfall is a large increase in the number of consecutive dry days, especially for the wet season (Figure 23.2).
- Within the Atlantic basin, the tropical cyclone rain rate is projected to increase by about 15% and the average storm wind intensity around 3% for a global average temperature increase of 3.6°F (2°C) above present-day levels. The number of intense tropical cyclones (Categories 4 and 5) are projected to increase as well (KM 2.2). There is some indication within Puerto Rico that tropical cyclone rainfall rates are increasing over the climatological record, increasing the likelihood of extreme events like Hurricane Maria's rainfall. Sea surface temperatures have warmed, and oceans are becoming more acidic, absorbing increased concentrations of atmospheric carbon dioxide (CO_2).
- Sea level is rising and is expected to continue to rise for centuries (KM 9.1). Long-range sea level scenarios indicate an additional rise of approximately 0.6 feet (0.2 m; Low scenario) to 1.4 feet (0.4 m; High scenario) by 2050 and 1.9 feet (0.4 m; Low scenario) to 6.8 feet (2.1 m; High scenario) by 2100;[25] for connections to Shared Socioeconomic Pathways [SSPs], see the Guide to the Report). The trajectory from tide-gauge observations from within the US Caribbean archipelago from 1970–2020 aligns with the Intermediate scenario out to 2050.

Table 23.2. Large-Scale Circulation and Climate Variability

Changes in the global (large-scale) circulation affect climate variability in the US Caribbean. El Niño–Southern Oscillation (ENSO) is the strongest source of year-to-year climate variability across the globe. An ENSO warm phase is referred to as El Niño and is associated with the warmer water in the eastern equatorial Pacific. The cool phase is referred to as La Niña and is associated with cooler water in that region. These warmer and cooler waters affect the atmosphere and worldwide weather patterns. The different phases of ENSO typically last between 6 and 18 months and recur every 2 to 7 years.[26,27,28] The North Atlantic Oscillation (NAO) is an oscillation in the sea level pressure between the Icelandic Low and North Atlantic Subtropical High.[29,30,31,32] A positive NAO occurs when both the Icelandic low and the Azores high are stronger than average, which creates strong atmospheric pressure differences within the North Atlantic. A negative NAO is associated with a weak Icelandic low and Azores high and weakened pressure differences within the North Atlantic. Saharan dust (consisting of particles containing minerals, organic matter, marine salts, viruses and bacteria, quartz, calcite, hematite, sulfates, and other materials) reaches the Americas from Africa (mainly from the Sahara and the Sahel). Dust season in the Caribbean occurs between May and September (summer), with maximum peaks from June to August.[31,32]

Climate Variability	El Niño	La Niña	North Atlantic Oscillation (positive)	North Atlantic Oscillation (negative)	Saharan Dust
North Atlantic Tropical Cyclone Activity	Suppress activity	Increase activity	Suppress activity	Increase activity	Suppress activity
US Caribbean Rainfall	Weak to negligible impact	Weak to negligible impact	Suppress rainfall	Increase rainfall	Suppress rainfall

Temperature and Rainfall in Puerto Rico



Puerto Rico is projected to become warmer and drier, with increasing uncertainty in the magnitude of change beyond midcentury; just how warm and dry depends on the scenario followed.

Figure 23.2. Projected temperature and precipitation changes for Puerto Rico are shown for an intermediate scenario (SSP2-4.5) and a very high scenario (SSP5-8.5) to demonstrate the range of plausible future changes in the climate. Climate change projections are shown for annual average daily minimum (**a**) and maximum (**b**) temperatures, annual average precipitation (**c**), and maximum number of consecutive dry days during the dry season (**d**) and wet season (**e**). Both scenarios indicate a warmer and drier climate for Puerto Rico, but the magnitude of change for the very high scenario is alarming, especially when considering the availability of fresh water. The average maximum temperature increases for the end of the century (2071–2100) range from 2.8°F (1.5° C) for the intermediate scenario to 4.8°F (2.7° C) for the very high scenario. The increased temperatures, coupled with reductions in annual average precipitation at the end of the century of approximately 10% (intermediate scenario) to greater than 30% (very high scenario), are both indications of a significantly drier climate, with very large impacts anticipated for the very high scenario. A particular concern is the precipitation reduction during the wet season and the large increase in the number of consecutive days without rain, exceeding an increase of 115 days, on average, by the end of the century for the very high scenario. The bar plots in panels (c–e) are averages over five-year periods. All plots are differences relative to the entire period (2021–2100). Figure credit: NOAA NCEI and CISESS NC.

Box 23.2. Missing Data in the US Caribbean and the Pacific Islands

The US Caribbean and Pacific Islands continue to face similar challenges related to climate change (Ch. 30), including geographic constraints (e.g., limited land area, variable topography), reliance on imports, critical dependence on local natural resources (fresh water, fisheries), and differential vulnerabilities to drought, sea level rise, and natural disasters. These territories are home to underserved and underrepresented communities that are systemically excluded from data collection efforts due to administrative structures that are rooted in colonialism.[33,34] These structures, combined with the lack of data, have resulted in capacity issues that continue to promote discrimination, inequity, and inequality in a wide range of sectors (e.g., health, natural resources, education, agriculture, food security, imports, and housing).[35,36,37,38]

Data for the US Caribbean are missing for metrics such as carbon dioxide sources and carbon sinks, municipality-level population projections, and locally relevant downscaled projections for both the changes in average conditions (e.g., temperature, precipitation) and extreme events (e.g., heatwaves, hurricanes, droughts, marine heatwaves, winter storms, dust storms). Even in cases where downscaled data are available for the US Caribbean region, they are not at a fine-enough resolution to distinguish small islands such as the US Virgin Islands, Culebra, and Vieques. Furthermore, Caribbean Traditional Knowledge systems and stewardship have been foundational in responding to climate change, but generations of knowledge have been undervalued, suppressed, and ignored by Western science and have only recently been recognized as valid knowledge sources at the federal level.[39,40] By identifying and addressing the underlying causes for missing information in the US Caribbean, scientific institutions will be able to more equitably develop future research and climate assessments. Doing so would better serve evidence-based decision-making throughout the Caribbean region.

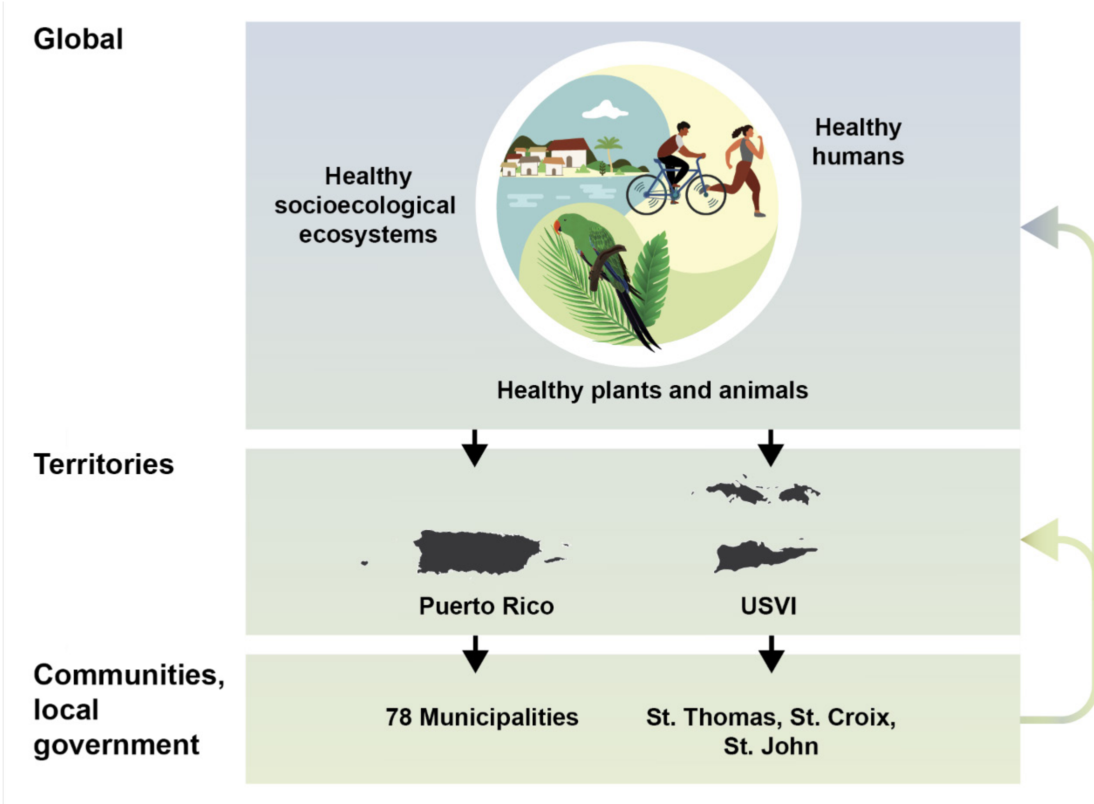
Key Message 23.1

Climate-Driven Extreme Events Exacerbate Inequities and Impact Human Health and Well-Being

Traditionally underserved and disadvantaged communities suffer disproportionate impacts from climate change because they have been systematically excluded from social services, secure livelihoods, quality education, and other social benefits that help sustain health and well-being (*high confidence*). Hurricanes and other climate-related extreme events have been associated with higher rates of disease, mental illness, and overall mortality, as well as loss of cultural heritage that is central to community identity (*high confidence*). As extreme weather events become more intense and more frequent, residents will continue experiencing increasing levels of noncommunicable diseases, excess mortality, behavioral health challenges, and loss of quality of life (*high confidence*). The frequency of heat episodes and the severity of hurricanes are both expected to increase in the region due to human-induced climate change, which will affect public health unless adaptation measures are taken (*high confidence*).

Long histories of colonization and systemic inequality shape the ability of the US Caribbean peoples to maintain health, quality of life, and overall individual and social well-being. Evidence from both PR and the USVI suggests risks from climate impacts to multiple elements of human health, including vector-borne and noncommunicable diseases, mental health, and overall quality of life (Ch. 15).[41] US Caribbean societies, with their multiethnic and multiracial makeup of high proportions of people of African and Indigenous descent, are more vulnerable to climate-related risks due to economic policies and social systems, varying levels of educational attainment, unemployment, poverty, out-migration, older-age demographics, food insecurity, colonialism, and unjust historical treatment.[42] As an effort to address these circumstances and the threat of more frequent extreme events, the One Health approach, similar to the community health concept described in Chapter 15, mobilizes collaborative work among communities, stakeholders, practitioners, sectors, and disciplines to tackle climate change while improving well-being and quality of life for all living organisms (Figure 23.3).

The One Health Approach



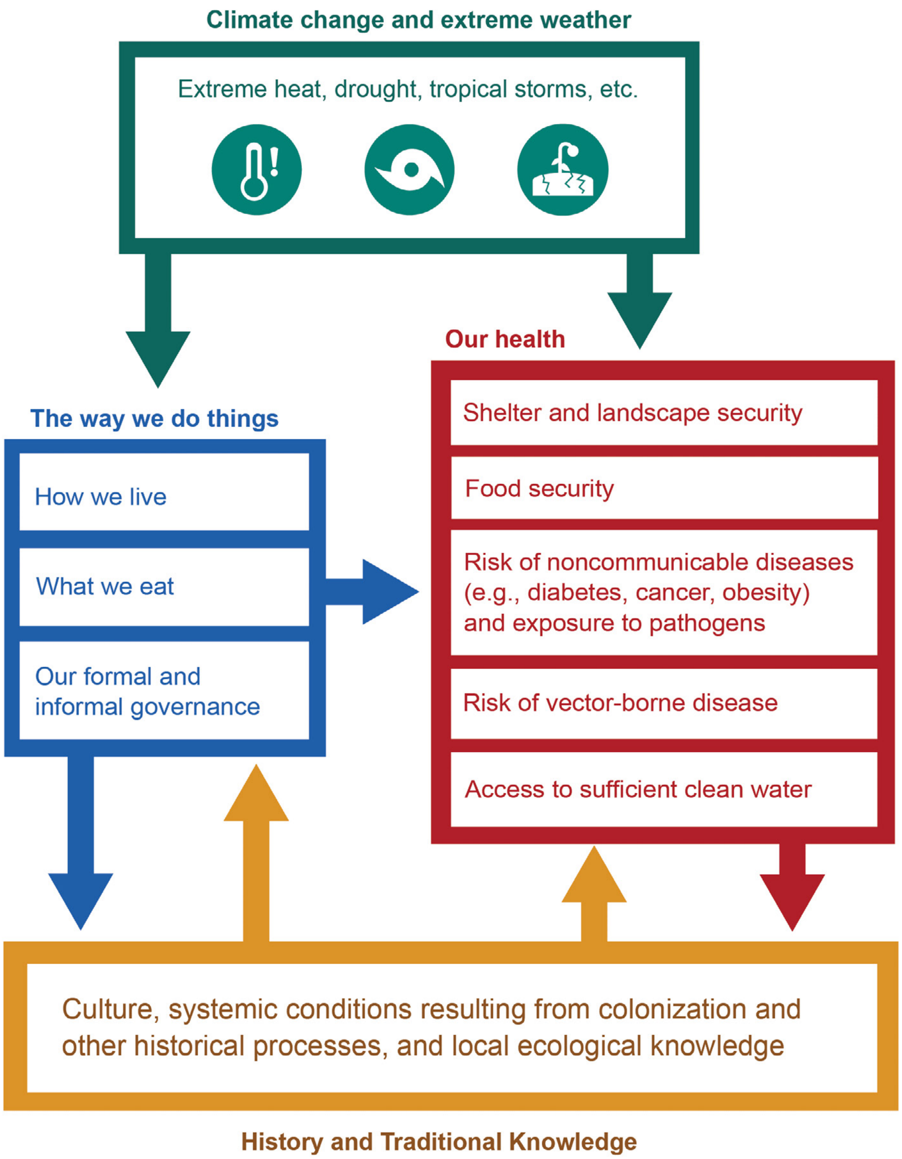
In the face of climate change, the health of Caribbean people, plants, animals, and ecosystems depends on coordination across multiple scales and boundaries.

Figure 23.3. In the US Caribbean, climate change is interacting with the institutional and environmental context of the islands and the social determinants of health. Extreme weather events (e.g., powerful hurricanes, extreme heat, and droughts) are threatening access to clean air, safe drinking water, nutritious food, and safe settlements, as well as damaging infrastructure, reducing tourism, displacing vulnerable communities, promoting migration among islanders, disrupting ecosystem services, and endangering animals. The One Health approach illustrated here promotes collaborative work at local, regional, and global levels to achieve health for humans, ecosystems, and animals alike. Adapted from World Health Organization 2021[43] [CC BY-NC-SA 3.0 IGO].

Community Identity and Heritage Are Necessary for Resilience and Post-disaster Recovery

US Caribbean cultural heritage is under threat due to changing climate conditions (Figure 23.4). Cultural heritage includes tangible elements (such as buildings, artifacts, monuments, and archaeological sites on land and underwater) and intangible elements (such as practices, ideas, representations, knowledge, music, songs, and ceremonies) that are recognizable components of community identity.[15,44] Research from recent hurricane events suggests that the magnitude of loss of heritage is severely underestimated[45,46] and that measures to mitigate climate impacts greatly threaten the preservation of cultural heritage and identity. For example, the traditional ways of life in the US Caribbean placed communities next to riverbanks for thousands of years. Archaeological sites associated with such communities, however, are under threat from flood-control projects,[15] which entail channelizing, dredging, or covering rivers (e.g., USACE 2022[47]). These flood-control projects not only impact archaeological sites but also transform landscapes that are integral to the identity, recreation, and overall well-being of local residents.[15,48] Climate impacts also increase out-migration, which can lead to disintegration of traditional communities and loss of Indigenous and Traditional Knowledge (KM 30.2).[49]

Climate Change and Public Health



Public health is shaped by sociocultural factors and further affected by climate change.

Figure 23.4. The impacts of climate change on human health in the US Caribbean must be considered in the context of the social, cultural, and historical realities of the islands. Shelter and food security, access to clean water, and communicable and noncommunicable diseases are certainly affected by climate, but they are also conditioned by culture, tradition, and historical and colonization processes. Figure credit: University of California, San Diego; University of the Virgin Islands; NOAA NCEI; and CISESS NC.

Impacts of Extreme Events on Health and Essential Services

Extreme events, combined with deteriorating infrastructure and unequal distribution of social determinants of health, are expected to continue to cause interruptions in and insufficient access to healthcare services, as documented after Hurricanes Irma and Maria (KM. 15.2).[14,50,51,52] PR and the USVI have contaminated sites where hazardous waste has been discarded and, in some cases, improperly managed. Some of these sites—26 in PR and 2 in the USVI—are designated as EPA Superfund sites.[53] Extreme flooding has the potential to impact Superfund sites, spreading large amounts of contaminants and carcinogens into the surrounding environment.[54]

In the aftermath of Hurricane Maria, many older adults in PR experienced unmet needs that contributed to declining physical and emotional health, inadequate management of noncommunicable disease (NCD), social isolation, financial strain, environmental health issues, and excess mortality.[14,55,56] High levels of post-traumatic stress disorder (PTSD), depressive symptoms, and disaster-related stressors were also evident (KM 30.2).[42,57] Many hospitals suffered significant damages in both territories.[58] Various healthcare services were greatly affected, including vaccinations, cervical cancer screenings, surgeries, oncologic treatments, and dialysis.[59,60,61,62,63,64] Experts recommend that further disease-specific planning be delineated within the emergency response of each jurisdiction and in collaboration with disease-specific plans for relevant organizations.[65] For instance, region-specific and federal health plans, such as the CDC's comprehensive cancer control plans, would mitigate the impact of extreme weather on specific populations and maintain adequate cancer prevention and treatment care during and after disasters.

Noncommunicable Diseases

The US Caribbean territories have high rates of NCDs, as well as increasing rates of impaired mental health.[42,66] After Hurricane Maria, there were obstacles to providing nutritious, affordable, and culturally acceptable food appropriate for people with NCDs.[42] In PR and the USVI, 67.5% and 65.2% of the population, respectively, are overweight, and 31.4% and 32.5% live with obesity;[67] these conditions are considered predictors of early mortality.[68] Surveys in PR in 2017 and 2019, pre- and post-Hurricane Maria, show an increase over that time span in the prevalence of NCDs and depression in adults.[69] In March 2018, an online survey identified PTSD in 44% of respondents in PR and 66% of those displaced from PR to Florida.[70,71]

Climate-Driven Vector-Borne Diseases

Vector-borne diseases (VBD) in the Caribbean, such as dengue, Zika, and chikungunya, are mostly transmitted by the *Aedes aegypti*, *Aedes albopictus*, and *Culex* mosquitoes (KM 15.1). The abundance of *Ae. aegypti* and *Ae. albopictus* are influenced by temperature and precipitation, and both species have excellent adaptation skills under extreme temperature and precipitation conditions.[72,73,74,75,76] Factors in the US Caribbean that favor VBD outbreaks include climate change, inequality, poverty, serotype profile (virus variation), immunity, deficient water and waste management, and lack of community awareness.[75]

Climate Impacts on Human Zoonotic Diseases

Human leptospirosis is an important zoonotic disease—that is, a disease that transmits from animals to humans—with worldwide distribution. It was first reported in PR in 1942, while the first cases of leptospirosis in the USVI were reported in the aftermaths of Hurricanes Irma and Maria. Recent evidence suggests an excess risk in PR of leptospirosis associated with flood-prone areas, heavy rainfall, and higher temperatures.[77] Extreme weather events such as tropical storms, heavy rainfall, and floods are expected to result in an upsurge in the number and magnitude of leptospirosis outbreaks.[78] Under the above-mentioned climate scenarios, outbreaks in both US territories are *very likely* to occur following extreme weather events.

Excessive Heat and Differential Social Burden of Climate Impacts

Heatwaves are increasing the risk for heat-related illness and death (KMs 6.2, 15.1; Figure 15.1). Conditions of extreme heat in the Caribbean have intensified since 1980. Recent research suggests an increasing trend in the number of days with heat stress (days above 39.9°C [103.8°F]) for the Caribbean region since 1980.[79] Several factors contribute to heat vulnerability and sensitivity, including:

- Populations at the extremities of age (e.g., newborns, children, elders)
- Pregnant women/people
- Individuals who are
    - living in single-person households
    - living below the poverty line
    - working in confined spaces with poor ventilation
    - working outdoors and exposed to risk factors such as direct sunlight or high humidity combined with extremely high air temperature
    - living with disabilities
    - living with chronic health conditions (e.g., obesity, hypertension, diabetes, cardiovascular disease, respiratory illness)
    - without health insurance coverage

With rapid urbanization in the USVI and PR and past population growth, urban heat island effects have become stronger (KM 12.2). San Juan, PR, is already showing evidence of these effects;[80] extreme heat episodes there have been associated with a significant increase in mortality and an increased relative risk for stroke and cardiovascular diseases.[81] Cooling indoor environments help lessen the impact of heatwaves, but energy demands on a crumbling power infrastructure, as well as rising costs of living, create climate risks associated with inequality, as only a section of the society will be able to afford cooling equipment.[82]

Human Health and Natural Sources of Air Pollution

Recent studies suggest that global warming will make dust storms more severe in the Mediterranean and the Atlantic (KM 14.1).[83] In the US Caribbean, dust particles carried across the Atlantic from the Sahara, mostly during summer, affect climate, weather, and ecosystems, including coral reefs, forests, and human populations.[84,85,86,87,88,89,90,91,92] Saharan dust provides nutrients to terrestrial and marine ecosystems. However, in PR, Saharan dust has been associated with increased cardiovascular and respiratory risks;[93] it has also been linked to increased risk of emergency room visits and hospitalizations related to asthma in children in Trinidad and Tobago,[94] Guadeloupe,[95] and Grenada.[96] As humidity and temperatures rise, the abundance of mold and spores in the air also impacts air quality and thus respiratory NCDs.

Sargassum and Health Intersections

Sargassum is a brown seaweed that floats in the Atlantic Ocean and provides an important habitat for migratory organisms that have adapted specifically to it. These algal mats are sometimes pushed by wind and currents into the Caribbean Sea and are frequently reaching the coasts of the region's islands. Evidence suggests that these events threaten coastal ecosystems and social and cultural activities (e.g., fisheries), with negative economic impacts (e.g., reduced tourism and degraded infrastructure; Ch.10; KM 1.2) and adverse human health effects (e.g., heart palpitations, shortness of breath, and skin rashes) due to hydrogen sulfide from decomposing sargassum in the air and direct exposure to algae.[97,98,99,100,101,102,103] While sargassum mats can be harvested for beneficial uses such as fertilizer and animal feed and as an energy source, its use as a fertilizer could transfer heavy metals to crops.[104,105,106] While the impact of this phenomenon has not yet been assessed for the US Caribbean, these conditions are expected to worsen as climate change intensifies.

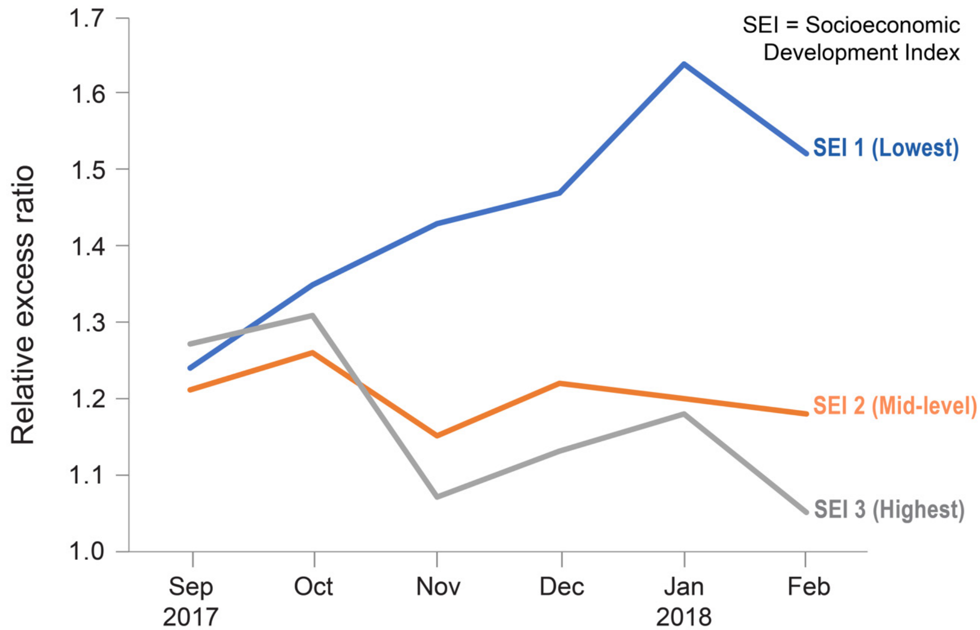
Water Resources and Human Health Interactions

Factors related to environmental health and changing climate (e.g., sea level rise, saltwater intrusion, and pollution) impact water security. Inefficient water management and climate change, including the increasing intensity of storms, have led to growing concerns about water scarcity and water insecurity for both territories.[107] While Traditional Knowledge has been shown to mitigate water scarcity during emergencies—such as individuals and communities activating historic or abandoned water sources during recent disasters[44,108]—these responses might not be enough, as Traditional Knowledge is also threatened, cultural heritage is being lost, and the magnitude of impacts exceeds previous experience (KM 30.1). Older traditional farmers in Puerto Rico have recorded a reduction in freshwater availability in streams and springs that impacts their traditional access to fresh water and their food production, which they consider a heightened risk for their health.[15] Reports on communities in both PR and the USVI that are systematically excluded from welfare, education, and other social services and benefits link inequity to poverty levels and the impact of status on the development and interpretation of laws and programs that address these issues (KM 15.2). Studies after hurricanes in PR and the USVI have shown water pollution, disease vectors, and bacteria in the drinking water supply, all of which are expected to worsen with expected impacts of climate change, thus affecting livelihood security.[109,110,111]

Underestimation of Mortality

Total excess mortality identifies how many more observed deaths happen after a specific event in comparison to the baseline historical trend of expected deaths had the natural event not occurred. After Hurricane Maria in PR, a large excess mortality was noticed by many people but not identified by the official certification of 64 deaths. Six months after Maria, a commissioned independent study identified 21% more deaths in males than expected and a total excess mortality estimate of 2,975 (Figure 23.5),[56] including both direct (related to hurricane injuries) and indirect (related to lack of access to effective care after the storm) deaths. These deaths mostly affected the most vulnerable populations, including those at lower socioeconomic levels.[56] The distribution of causes of excess mortality is predominantly driven by chronic noncommunicable diseases.[112] Further analysis estimated 514 excess deaths in the Puerto Rican population displaced to the US mainland.[113] Evidence shows that considering only direct hurricane injuries greatly underestimates the overall impact on excess mortality. After Hurricane Fiona in 2022, the mortality in Puerto Rico was 1.15 times higher in adults older than 75 years of age, who experienced 226 excess deaths.[114]

Excess Mortality from Hurricane Maria in Puerto Rico



Excess mortality from Hurricane Maria was most common among Puerto Rico's most impoverished residents.

Figure 23.5. Between September 2017 and February 2018, 2,975 excess deaths—that is, above what the mortality rate would have been if the storm had not occurred—were estimated in Puerto Rico due to Hurricane Maria. Mortality was higher for individuals living in low-income municipalities, for those with the lowest scores on the Municipal Socioeconomic Development Index (SEI)—a multidimensional index of poverty developed by the Government of Puerto Rico—and for men aged 65 years or older. These results are useful to health officers, emergency preparedness personnel, and residents, as they help to prepare for and to mitigate the potential effects of hurricanes. Adapted from Santos-Burgoa et al. 2018.[115]

Key Message 23.2

Ecology and Biodiversity Are Unique and Vulnerable

Coastal and terrestrial ecosystems provide a large number of goods and services that are vital to the islands' economies and to the health and well-being of their residents (*high confidence*). These essential systems are degraded by human actions and climate change, thereby reducing the benefits they provide to people, as well as their functionality as habitats for protecting biological diversity (*high confidence*). Climate change is expected to exacerbate the degradation of ecosystems (*very likely*, *high confidence*). The success of climate adaptation strategies will depend on reducing all sources of stress on ecological systems (*medium confidence*).

PR and the USVI are home to diverse aquatic and terrestrial ecosystems and are rich in natural resources and cultural heritage. Residents depend on the region's natural resources and ecosystem services for their well-being and livelihoods. These important ecosystems are being degraded by economic activity, habitat destruction, land conversion, pollution impacts, and overfishing.[116] Climate change impacts on land will have environmental consequences along the coast and beyond. Impacts and consequences will vary by territory, species, and ecosystem type.

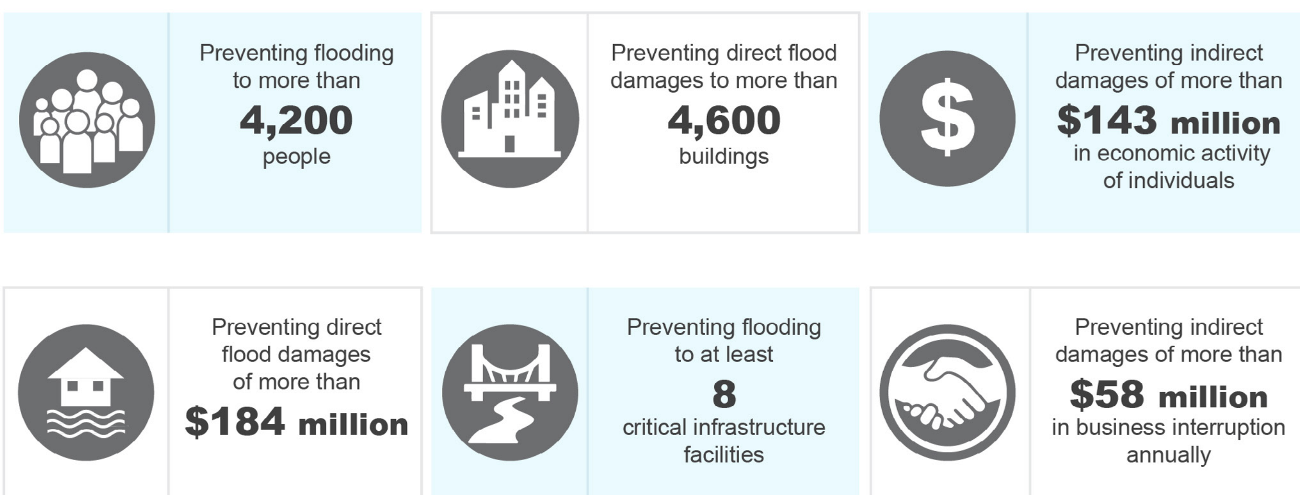
Impacts of a Changing Climate on Ecosystem and Biodiversity Goods and Services

Climate stressors (e.g., extreme precipitation, droughts, frequent and intense tropical cyclones, and steady increases in surface temperatures) and non-climate stressors (e.g., pollution and deforestation) interact to impact ecosystems and the services they provide to people (Ch. 9). Ecosystem services include provisioning services such as food, feed, and fiber; regulating services such as climate regulation, flood control, and air and water purification; cultural services such as recreation and spiritual and aesthetic benefits; and supporting services such as nutrient cycling, primary production, and soil formation.[117] Climate change is increasingly compromising ecosystem goods and services (Ch. 8).

Coastal zones—often highly valued and the focal point for cultural activities, Traditional Knowledge, tourism, and industries essential for economic and social vitality—are at risk from climate change (KM 9.2).[118,119,120] The US Caribbean coastline is roughly 876 miles (1,410 km) in length (PR, 700 miles [1,127 km]; USVI, 175 miles [282 km])[121] and is composed of nested coastal ecosystems such as sandy dunes, beaches, mangroves, salt flats, coral reefs, and seagrass beds. The high population density, concentrated development, and critical infrastructure located within 0.6 miles (1 km) of the coastline are highly vulnerable to coastal hazards and climate stressors.[20] The combined destructive power of wave action and intense rainfall from Hurricanes Irma and Maria alone damaged over 12% of coral reefs,[122,123,124] caused beach loss of 1.2–3.1 miles (2–5 km),[119,125,126] eroded dunes,[118,127] and devastated almost 33% of mangroves.[128] These impacts added to the degradation of ecosystems caused by other climate stressors (KM 8.2).

The loss of recreational benefits from the degradation of coastal reefs is expected to reach $172 billion (in 2022 dollars) by 2100 under a very high scenario (RCP8.5).[129,130,131] In 2019, an assessment quantified the annual coastal flood risk-reduction benefits provided by all US coral reefs, including those in PR and the USVI, as illustrated in Figure 23.6.

Annual Expected Benefits from Coral Reefs in the US Caribbean



Coral reefs provide substantial coastal protection benefits to the US Caribbean each year.

Figure 23.6. Coral reefs are a major component for recreational and commercial fisheries, coastal protection, and the tourism economy. Acting as a natural defense, coral reefs dissipate incident wave energy and protect coasts from erosion and flooding. Arguably, they are one of the most economically valuable ecosystems.[130] Economic estimates are in 2010 dollars. Figure credit: Caribbean Coastal Ocean Observing System.

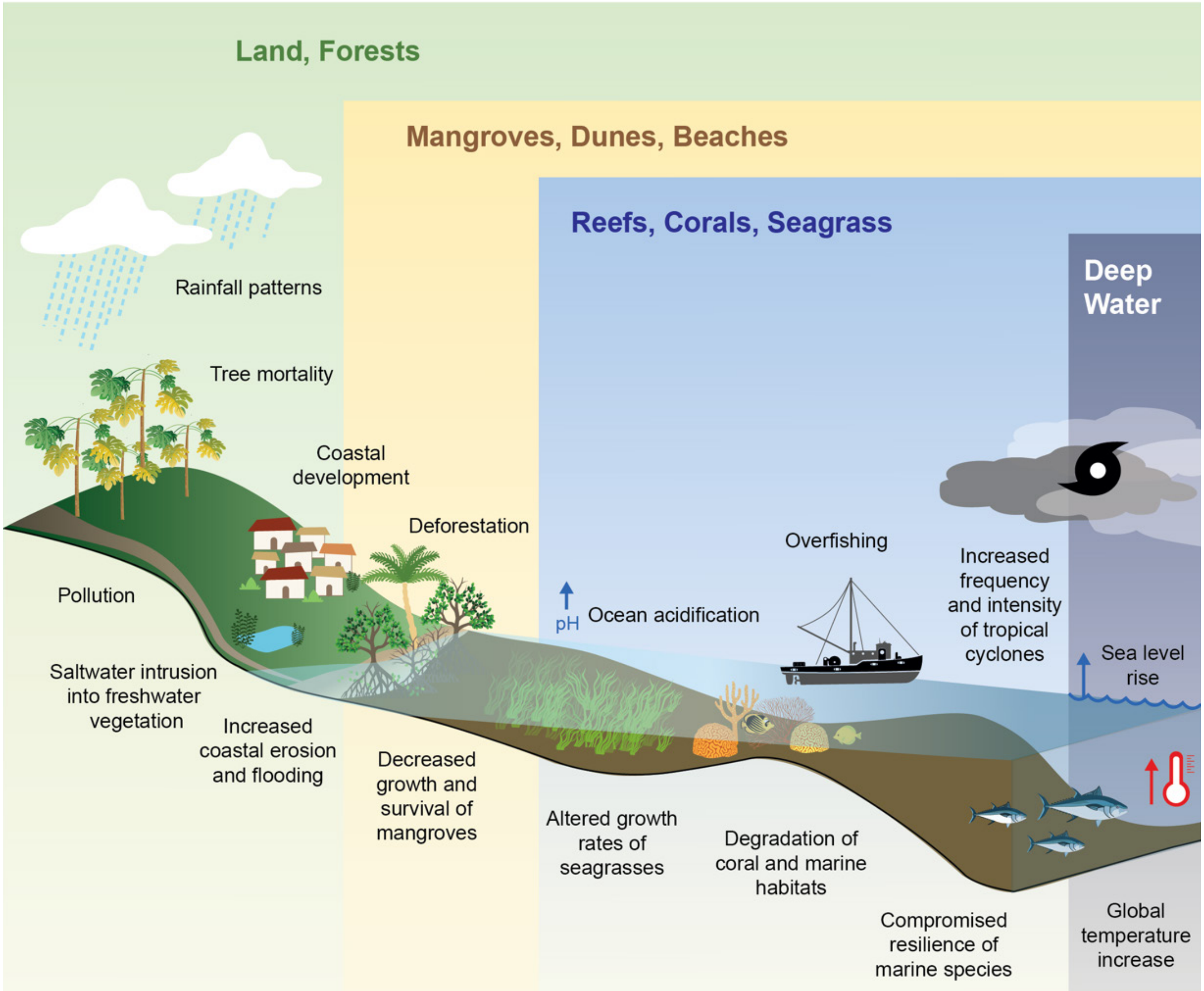
Sediment and contaminant runoff derived from various land-based activities also threaten coastal ecosystems.[125,132] Runoff of land-derived sediment could directly impact coral regeneration capacity, growth, and mortality, as well as the ecosystem services they provide.[93] Cross-jurisdictional strategies and ecosystem-based management principles must be adopted to significantly reduce the adverse impacts of anthropogenic/land-derived pressures on coastal ecosystems.[133] In PR's Guánica Bay watershed, for example, a watershed management plan is being implemented to restore the health of coral reefs damaged by sediment and nutrient runoff.[134]

Caribbean forests are highly diverse, ranging from coastal mangroves to dry forests. These ecosystems provide many services, including habitat, recreation, coastal protection, and improved air and water quality.[135] Although forests are adapted to withstand frequent natural disturbances, projected changes in temperature and rainfall are expected to impact the amount of fruiting and flowering, tree productivity, and nutrient cycling, as well as increase the likelihood of tree mortality, among other impacts (KM 7.2). Furthermore, they can alter the forest ecosystem's biogeochemical processes and affect their composition, structure, and functioning.[136] For example, trees within northeastern PR are already operating above their optimum temperature for photosynthesis; thus, increasing temperatures (which are projected) will lead to the release of more carbon dioxide (a major driver of climate change) into the atmosphere.[137,138,139] Meanwhile, research on tropical forestry, ecology, and conservation in the Luquillo Mountains in PR has reversed the paradigm that tropical ecosystems are fragile, demonstrating instead that they exhibit remarkable resilience to many forms of disturbance.[140]

Emerging Issues and Future Directions

Ecosystems that are already degraded or stressed may have lower adaptive capacity and resilience. Increased stress from climate change may drive ecosystems to tipping points,[141] with potentially irreversible socioeconomic consequences for coastal socioecological systems and community livelihoods.[141] Maintaining, enhancing, and/or restoring ecological connectivity and corridors as conservation strategies are key to helping ecosystems adapt to climate change (Figure 23.7; Ch.1; KM 3.6).

Ecosystem Stressors



Both climate and non-climate stressors affect aquatic and terrestrial ecosystems and biodiversity in the US Caribbean.

Figure 23.7. The cumulative effects of these stressors could result in the degradation of aquatic habitats, increases in coastal erosion and flooding, tree mortality, alterations in the growth of mangroves and seagrasses, and diminishment of resilience and adaptive capacity. Adapted with permission from Fitzpatrick and Giovas 2021.[142]

Key Message 23.3

Climate Change Threatens Water and Food Security

US Caribbean food and water systems are becoming increasingly vulnerable to the escalation of climate change, including stronger hurricanes, more severe drought, warmer air temperatures, and other extreme weather (*likely*, *high confidence*). Because the territories are heavily reliant on imported foods, they are affected by climate changes occurring both within and outside of the region (*high confidence*). Reductions in average annual rainfall, increasing air temperatures, and rising sea levels will adversely affect freshwater availability in the future (*medium confidence*). Improved adaptation efforts would benefit from a better understanding of the ways food and water systems interrelate and of the cascading impacts generated by climate change (*medium confidence*).

Food and water security are important for well-being and emerge from complex social and environmental interactions across groups and regions in the Caribbean. About one-third of Puerto Rican adult residents in 2015 lacked consistent access to adequate food, higher than the rate on the US mainland (12%).[143,144,145] Low-income households were more than three times as likely to experience food insecurity as households with higher income.[145] These numbers are influenced by lower governmental expenditures for key economic security programs relative to other US states or territories.[146]

Within this context, climate change can deepen food and water insecurity in the region.

Characteristics of the Island Food Systems

More than 80% of the food consumed in PR comes from the US mainland[147,148,149] on US-flagged ships, as required by law.[150] Most of the food imported by PR arrives at a single port of entry and is transported by only a few maritime companies.[151] In PR, food imports have been increasing since the 1950s.[151,152]

The agricultural sector represents an important source of employment and food security, although production accounts for less than 1% of the GDP in Puerto Rico.[153] Between 2012 and 2018, the total number of Puerto Rican farms declined by 37%, with farms less than 10 acres in size declining by about 57%.[154] The main classes of production are plantains and bananas, coffee, root crops and tubers, fruits and vegetables, nursery crops, and grasses.[154] Cattle and dairy production generate more than 25,000 jobs on the island and occupy more than 50,000 acres.[155,156]

The USVI imports more than 90% of its food, with importation of most food categories increasing over time.[157,158] The main crops grown and sold on the islands are vegetables, nursery crops, and tree crops. Between 2007 and 2018, the sale of these main crops increased by 1.1%, but they still represent less than 1% of GDP.[159,160]

Characteristics of the Island Water Systems

In PR, approximately 82% of water used is derived from surface water sources (reservoirs and streams), with the remaining 18% extracted from groundwater sources.[161] The total storage capacity in reservoirs is decreasing due to sedimentation.[162] Rain harvesting and desalination plants are also sources of potable water, primarily in the USVI. There is a tension between water for consumption and agricultural uses. PR has four irrigation districts around the main island that draw on a network of reservoirs to provide water to farmers for crops via irrigation canals. The Puerto Rico Aqueduct and Sewer Authority (PRASA) also purchases rights to the water in the districts. Water from PRASA is expensive and cannot be used for agriculture.[149] Due to faulty infrastructure, mismanagement, evaporation, and theft, approximately 50% of water purchased by PRASA from the irrigation districts is lost before reaching the public.

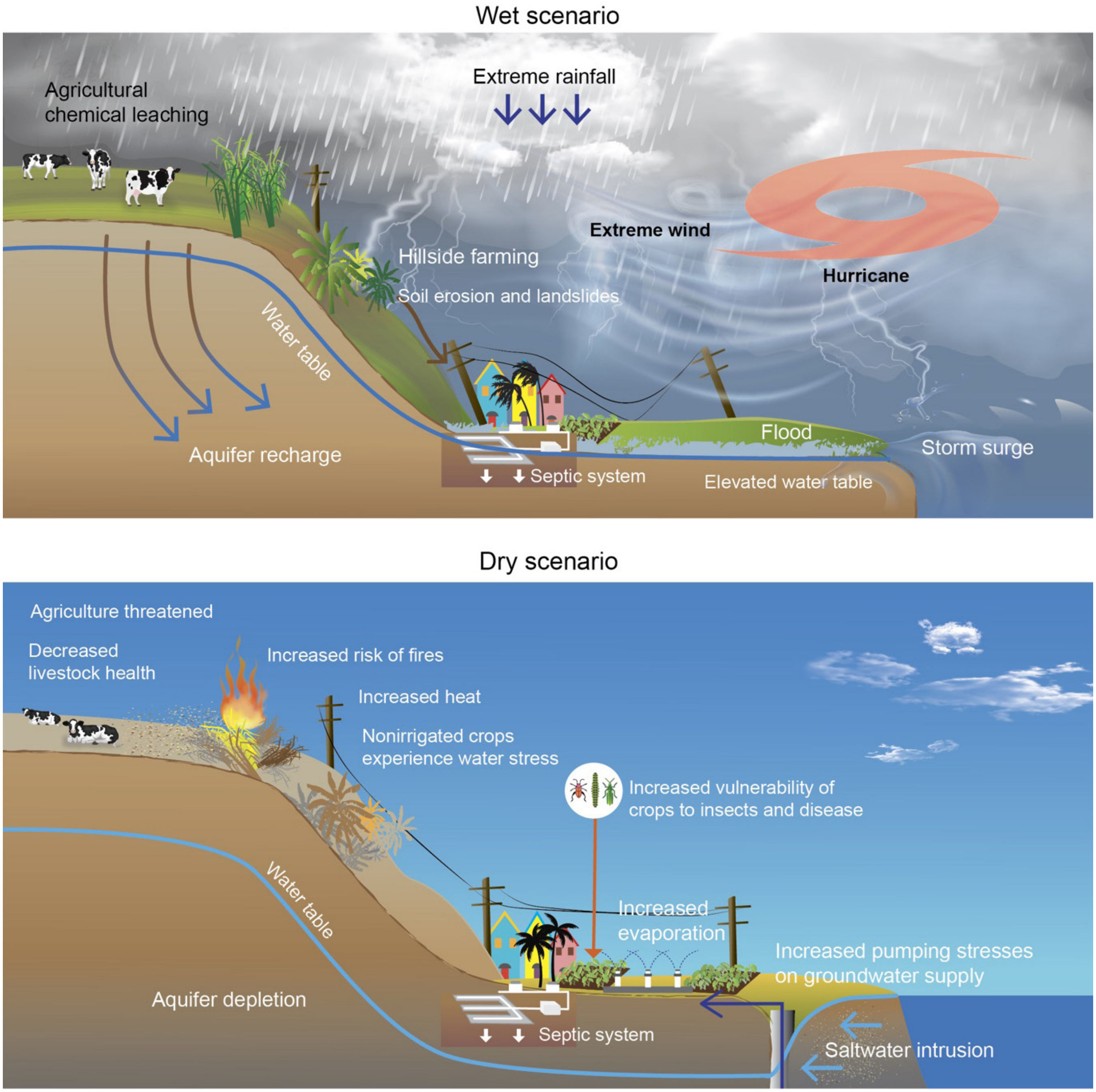
Outside of these four irrigation districts, surface runoff is stored in ponds or pumped from aquifers. The South Coast aquifer (SCA) has declining water levels due to over-pumping, which in some cases has lowered the water levels below sea level, leading to salinification.[163,164,165] The cost of water to farmers is low,[149] which may discourage them from using water efficiently. Irrigation scheduling can be used to optimize irrigation water use;[166] however, limited data exist on the irrigation scheduling methods used by farmers in PR and the USVI. About 10%–20% of the water introduced into the irrigation canals is lost by leakage.[161]

In the USVI, farmers access water from surface ponds and aquifers and from stored rainwater in cisterns. On St. Thomas, the majority of the farming occurs in the drier Estate Bordeaux.[167] Farmers there depend mostly on private and public cisterns and ponds or on wells that are privately managed. On St. Croix, most farmers depend on groundwater from deep wells or water from private cisterns or ponds they own or that are managed by the USVI Department of Agriculture. On St. John, farmers capture water in privately owned ponds. Few farmers depend on the public water system.

Climate Stressors on Food and Water System Components

Climate change is affecting and will continue to affect the region's food and water systems (Figures 23.8, 23.9).[147] In the past, strong winds and heavy rain have destroyed crops and caused livestock mortality. They have also led to landslides, soil erosion and degradation, flooding, and sediment contamination of water.[168] Between 1995 and 2017, agricultural losses attributed to hurricanes in PR accounted for 3%–26% of the total estimated economic damages. Hurricane Maria in 2017 alone caused more than $2.3 billion (in 2022 dollars) in losses and damages to crops and infrastructure,[169] which represented a reduction of about 80% of the main island's total agricultural value.[170] Beyond these direct impacts, a substantial portion of agricultural losses were caused by indirect effects of tropical cyclones, including energy outages, disrupted telecommunication and water supplies, and damaged roads and irrigation systems.[152,168,171] With a projected increase in the intensity of major tropical cyclones, these impacts are expected to worsen without investments to make food and water systems more resilient (KMs 8.3, 11.3, 30.1).

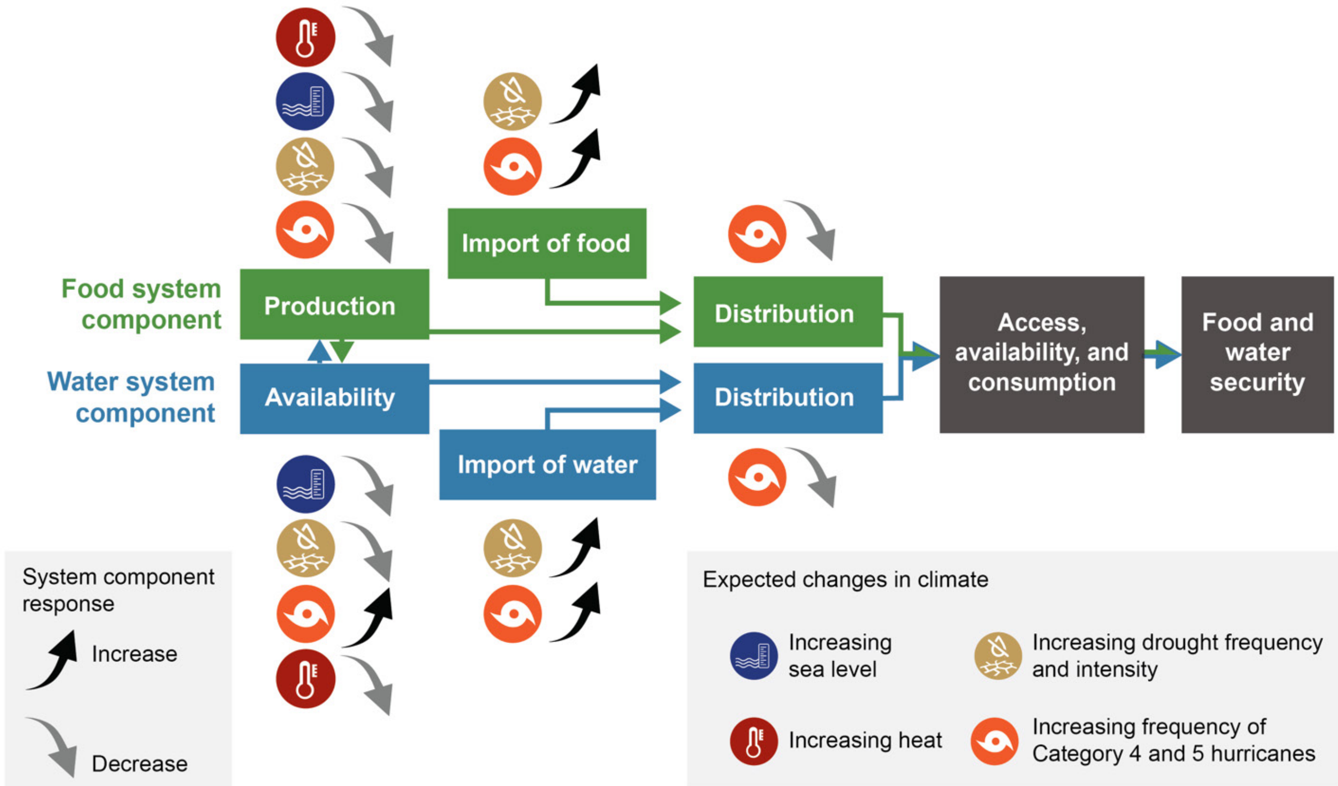
Climate Impacts on Food and Water Systems from Ridge to Reef



Risks to food and water systems differ under wet and dry scenarios.

Figure 23.8. (**top**) In periods of wet conditions, saturated soils coupled with heavy rainfall from hurricanes and storms can lead to flooding and, in turn, soil erosion and vegetation and crop destruction. Strong winds and floods can also damage infrastructure needed for food and water distribution. Excessive rain combined with higher sea levels affects water quality through the leaching of agricultural chemicals and wastewater from septic systems. (**bottom**) Dry conditions, on the other hand, increase groundwater pumping for irrigation. When combined with sea level rise, these conditions can also lead to saltwater intrusion into coastal aquifers. Figure credit: University of Puerto Rico, North Carolina State University, USDA Forest Service, University of Arizona, and University of the Virgin Islands.

Food and Water Systems



Cascading impacts of climate change affect food and water systems and security.

Figure 23.9. The figure displays the effects of the main climate changes that directly affect the islands on each of the system's components. The up and down arrows show the increasing or decreasing effect of a given climate change stressor on the food or water system components. For example, the increasing frequency of Category 4 and 5 hurricanes will cause a decrease in the distribution of food and water. The effects of climate changes are moderated by external influences such as socioeconomic changes that precondition the islands to be more or less susceptible to climate changes. Figure credit: University of Puerto Rico, USDA Forest Service, University of Arizona, North Carolina State University, and University of the Virgin Islands.

Drought has been common to PR and the USVI. Between 1950 and 2016, periods of severe drought occurred across the Caribbean (1974–77, 1997–98, 2009–10, and 2013–16). Regions of PR in 2020 and the USVI in 2021–2022 were declared by the USDA to be natural disaster areas because of drought conditions. The 2014–2016 drought was characterized as the most severe on record.[172] Livestock losses in 2015 accounted for about 62% of all reported economic losses, and plantain losses accounted for 22%. The combination of periodically dry conditions with a warming trend leads to aridification and compounding impacts (KM 4.1).[173] Aridification leads to increased demand for irrigation. Higher demand for irrigation, coupled with salinification of aquifers from sea level rise, suggests that groundwater aquifers like the SCA will be under increasing pressure in the future. Following 2015, the government of Puerto Rico created the Scientific Drought Committee. The USDA Caribbean Climate Hub created the Caribbean Drought Learning Network in 2021 to integrate drought-related information, initiatives, and programs in PR and the USVI.[174] These initiatives can help preparation and response to future droughts.

Increasing average and intermittent extreme temperatures are expected to reduce crop yields,[175] especially in tropical regions.[176] Expected impacts on crops include reduced seed yield,[177] reduced pollen production, and increased rate of senescence (i.e., shortening of a crop's life cycle).[178] The negative effects of increasing temperature worsen under water deficit conditions.[178] Higher temperatures also increase the potential for wildfires;[179] can affect the range of weeds, diseases, and insects;[180] and can cause heat stress in farmworkers (KM 4.2).[181] Increased atmospheric CO_2 levels may counteract the negative impacts of higher temperatures; however, adequate water is required to take advantage of CO_2 fertilization.[182] Crop water use may increase[183,184,185] or decrease[186] under climate change conditions, depending on site-specific changes in the meteorological parameters.

Both drought and elevated temperature have negatively impacted livestock producers in PR and the USVI.[152,156] High temperatures lead to heat stress, which reduces animal productivity, increases the proliferation and survival of parasites and disease pathogens, reduces the ability of dairy cattle to produce milk and gain weight, and lowers conception rates. Furthermore, bovine breeds in PR and the USVI are more susceptible to heat because they were largely introduced from temperate regions, such as from within the US mainland.[155,156]

Soil health has direct effects on the ability to maintain agricultural production in the future and to adapt to climate change. Soil organic carbon is affected by increasing temperatures. Both mineralization and the loss of organic carbon and nitrogen increase under elevated temperatures.[187] Extreme variation in rainfall can promote carbon loss via soil drying and soil erosion. Certain conservation practices—such as no-till farming and the use of cover crops—can promote soil health and enable the sequestration of larger amounts of carbon in the soil.[187,188,189] The USDA Natural Resources Conservation Service is promoting methods to increase soil health in PR and the USVI.[190]

Social Protection

Crop insurance plays an important role in reducing climate impacts. In PR, about 50% of farmers participate in the Puerto Rico Crop Insurance Corporation (PRCIC; a similar program is currently unavailable in the USVI). Between 2010 and 2019, the PRCIC paid compensation for agricultural losses for 25 events, all but one—a wildfire—related to rainfall (hurricanes, tropical storms, tropical depression floods, and extreme rains). Ninety-eight percent of the total insurance payouts for the 2010–2019 period was for losses caused by hurricanes. The insurance program, however, does not cover drought.[152]

Emerging Issues

Areas receiving increased attention essential to managing extreme weather include plant and animal breeding,[156,191] crop production within controlled environments,[192] precision agriculture,[193] irrigation scheduling,[194,195] and flood and drought early warning systems.[196,197] Increased local food production and the need to balance water use among sectors will become increasingly important issues.[149] In the USVI, the lack of information to quantify economic losses associated with climate impacts, such as the effects of drought on food and agriculture, is also an issue. Superimposing climate change on top of other compounding issues (internal and external) will create additional stressors and have cascading impacts on food and water systems within the region. Understanding the complexity of the islands and their food and water systems will aid in the creation of contingency planning for problems that may arise.

Key Message 23.4

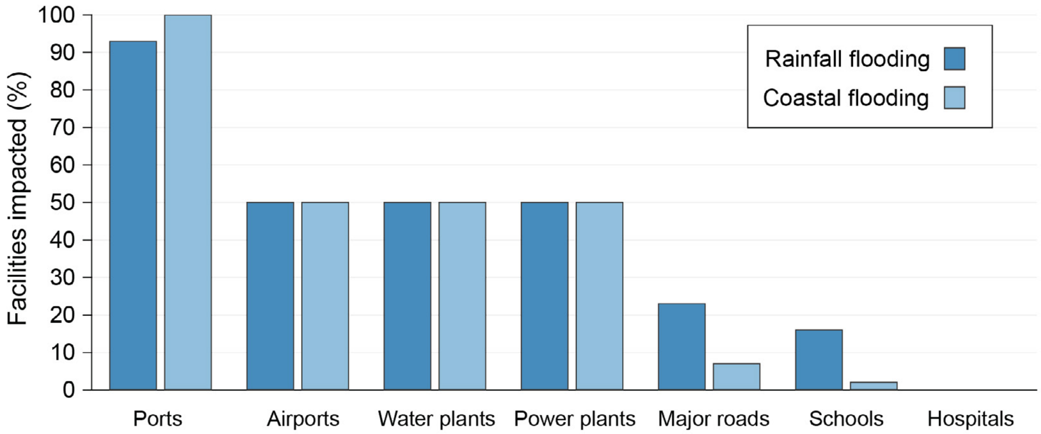
Infrastructure and Energy Are Vulnerable, but Decentralization Could Improve Resilience

Climate change has created profound risks for the US Caribbean's critical infrastructure, already weakened from years of disinvestment and deferred maintenance (*high confidence*). Increasingly powerful storms, along with rising sea levels, are severely impairing infrastructure systems, with increasing damage projected in future years (*likely*, *high confidence*). Dependence on fossil fuel imports increases energy insecurity (*high confidence*). Infrastructure improvements, coupled with a new paradigm focused on decentralization, adoption of distributed solar, and shared governance, could help limit residents' vulnerability to health and other risks associated with loss of essential services (*likely*, *medium confidence*).

The 2017 and 2022 hurricane seasons in the Caribbean demonstrated the vulnerability of critical infrastructure (e.g., energy, water, healthcare, transportation, telecommunications, wastewater, stormwater, and solid waste) in Puerto Rico and the USVI to natural hazards.[23,24,198] This vulnerability is mainly caused by years of deferred maintenance, the recurrence of powerful tropical storms,[199,200] and a centralized mode of production and governance that limits redundancy, flexibility, and, therefore, the ability to anticipate and adapt to future scenarios that climate change will create.[201,202,203,204,205]

Powerful tropical storm impacts are exacerbated by higher sea levels, which increase storm surge and prevent proper drainage of higher stormwater volumes.[12,21,25,206,207,208,209] As a consequence, critical infrastructure systems, which tend to be concentrated near the coasts and floodplains, will experience compounded effects of different hazards and disrupt the movement of people, goods, and services (Figure 23.10; KM 9.2).[204,210] Climate change is also causing higher temperatures and drier conditions,[12,21,211] thereby reducing water availability, increasing water demand, and intensifying saltwater intrusion into aquifers.[212,213] And, because infrastructure systems are interconnected and interdependent, the disruption of any single system will affect the operation of other systems. Currently, even outside of droughts, water for human needs competes against demand for power production (KMs 4.2, 5.1).[214] Similarly, even without hurricanes, sea level rise affects the operation of marine, air, and surface transportation systems,[204] and stormwater flows overwhelm wastewater systems.[200,204]

Infrastructure at Risk of Flooding in the US Virgin Islands



Many types of facilities in the US Virgin Islands and Puerto Rico are threatened by storm-induced flooding.

Figure 23.10. The figure shows the percentage of critical infrastructure currently located in flood zones (rainfall flooding caused by rainstorms and coastal flooding caused by storm surges and waves) in the US Virgin Islands. Many similar facilities are at risk in Puerto Rico,[215,216] but data are missing to represent the information in this report. Facilities at risk of flooding or that are flooded might not be able to provide critical services to communities when flooded, and there might not be another alternative available. The figure shows vulnerabilities under current climate conditions; additional flooding caused by sea level rise or potential future increases in intensity and duration of rainstorms is not included. Figure credit: University of the Virgin Islands, NOAA NCEI, and CISESS NC.

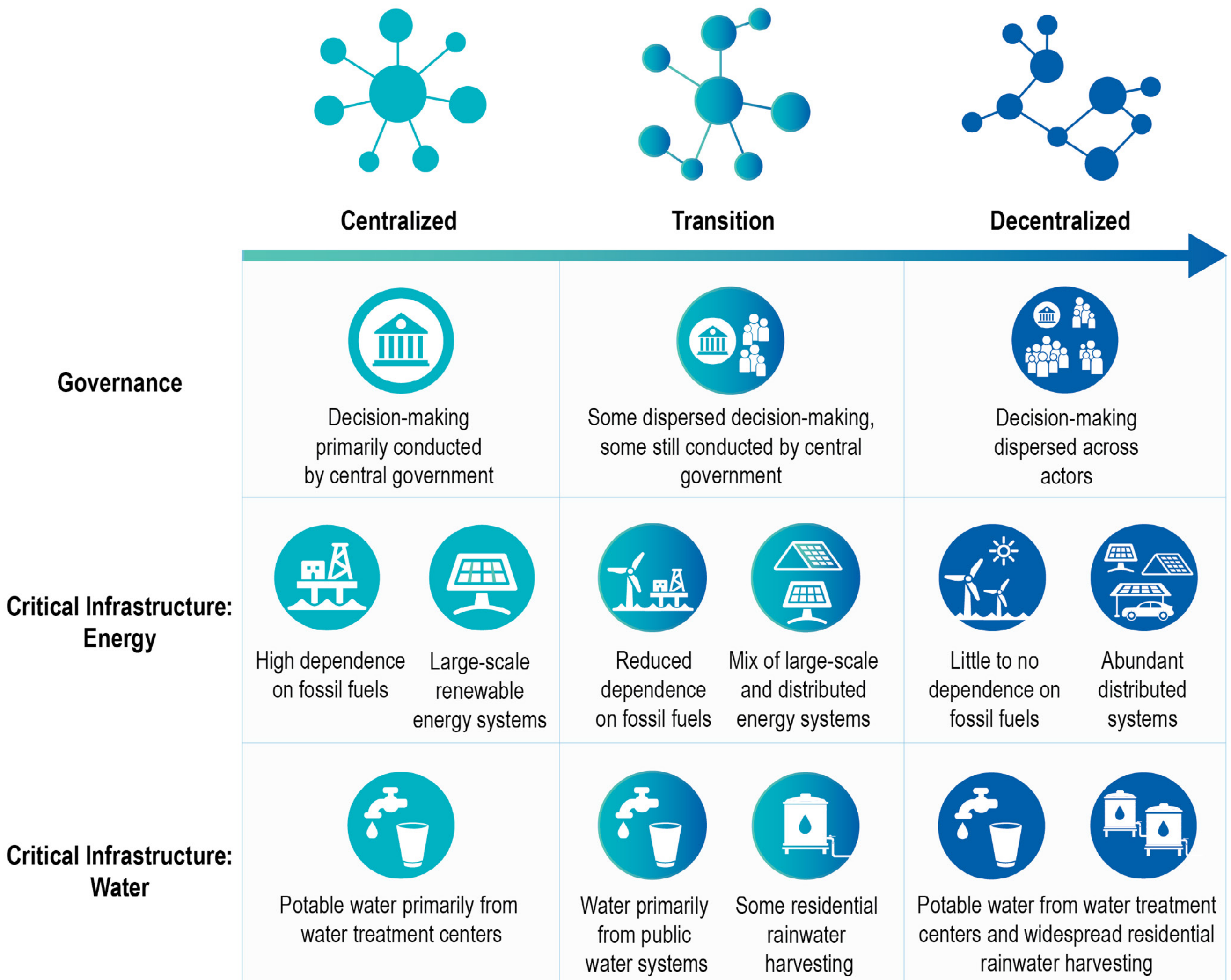
Increasing temperature and heatwaves will drive power and water demand, and wetter storms will increase demand on wastewater and stormwater pumps.[217,218] Damage from increased rainfall rates from hurricanes and increased hurricane intensities are projected to increase solid-waste flows, and response and recovery activities may intensify the use of single-use items such as utensils or water bottles.[24,219,220] Demand for healthcare is also expected to increase as communities experience higher temperatures or greater exposure to stormwater or wastewater and associated waterborne pathogens.[221]

The effects of climate change on infrastructure systems are compounded by human impacts on ecosystems. Ecosystem degradation (e.g., beach erosion, loss of coral reefs or mangroves) is also increasing hazard impacts on infrastructure.[222,223,224,225] Similarly, increased sargassum seaweed[226] can impair infrastructure and render it inoperative, as well as affect the health of the people operating these systems.[227,228,229]

Finally, climate change compounds the stress on already-strained infrastructure systems. Legacy challenges, including systemic lack of investment, mismanagement, and fiscal limitations, undermine the capacity to invest in adaptation activities or to maintain a competitive edge in retaining talent and updating technical capacity.[199,230,231]

Dealing with climate hazards while mitigating other risks will require new thinking about the pitfalls of existing approaches and the potential for a path that allows for better management of resources and service delivery. Highly interdependent infrastructure systems with centralized operation and management structures might be unable to anticipate and adapt to disruptions caused by future climate conditions.[202,232,233] Successful infrastructure adaptation strategies may require restoring natural infrastructure systems (e.g., aquifers, mangrove wetlands, nearshore coral reefs, etc.) for provision of services.[234,235,236] It also may require the adoption of a new paradigm, such as more decentralized infrastructure systems and different models of governance (KM 18.4). For example, household rainwater harvesting protects against prolonged public water system interruptions;[237] sustainable material management reduces pressure on landfills;[238] and microgrids and community solar and household solar systems provide power during interruptions from the centralized utility (Figure 23.11). These types of decentralized systems can help achieve mitigation targets[239,240,241,242] while also reducing negative health impacts of fossil fuel plants.[243] However, it is important to consider whether or how the adoption of these new systems could exacerbate existing inequities of access to services or to these technologies,[203,244,245] or compete against other land-use opportunities such as farming and housing.[246]

Decentralizing Infrastructure and Governance



Strengthening the resilience of infrastructure will require a transition to decentralized systems as well as decentralized modes of governance.

Figure 23.11. For power systems, decentralization means not only investing in more renewable energy systems managed by utilities but also increasing investments in systems managed by communities and households. For water systems, decentralization means increasing investments in water harvesting infrastructure to serve as an alternative. The improvement of governance models, by decentralizing decision-making and resource allocation, will better address climate change threats and current system frailties and problems. Figure credit: University of the Virgin Islands, NOAA NCEI, and CISESS NC.

Infrastructure systems in the Caribbean are at risk of future climate events, but current operation and management approaches increase their vulnerability.[199,200,230] Further research on infrastructure systems, including community-based solutions to climate challenges, could help identify appropriate paths for adaptation.

Key Message 23.5

Adaptation Effectiveness Increases When Coupled with Strategic Governance and Planning

Climate adaptation in the US Caribbean is challenging because of multiple interacting factors, including high risk exposure, limited or misaligned funding, insufficient institutional and organizational capacity, and siloed approaches to risk reduction and resilience (*high confidence*). Effective adaptation to support resilience in the US Caribbean could be enhanced through co-development and integration of robust global, regional, and local climate science and risk-based knowledge into planning and implementation, as well as improved governance arrangements (*high confidence*). US Caribbean capabilities in planning and adaptation could be enhanced by strengthening partnerships across the wider Caribbean region and the US mainland (*medium confidence*).

Small islands provide a special case for development and adaptation due to their geographic isolation, complex geographies, diverse cultures, and unique natural resources, compounded by challenges such as their small economies, limited human resources, and costs of utility provision and services.[247,248] Sound policies and institutional capacity are fundamental to effective risk-reduction and disaster response and recovery, as well as the ability to seize current and emerging opportunities for adaptation planning and implementation.

For PR and the USVI, significant financial resources could be made accessible for climate adaptation and comprehensive disaster management, such as through disaster recovery funds, the Community Development Block Grant Mitigation (CDBG-MIT) program, and other federal and nongovernmental organization donors. However, effective adaptation planning is impeded by limited uptake of climate change information in decision-making,[249] weak linkages between programs,[250,251] and insufficient institutional capacity for prioritizing initiatives and designing linked operational systems across multiple organizations.[168,252,253] In addition, adaptation and recovery could be made more efficient and effective by allocating funds that account for social vulnerability metrics.[254]

Policy for climate change planning and adaptation in the US Caribbean has advanced slowly in recent years, as evidenced by the Puerto Rico Climate Change Mitigation, Adaptation, and Resilience Act[255] and Executive Order No. 474-2015: Preparing the Virgin Islands of the United States for Adapting to the Impacts of Climate Change.[256] The Puerto Rico law that created the Expert Advisory Committee on Climate Change mandates that the government allocate funds for its operation and develop a climate change mitigation, adaptation, and resilience plan. Many community-based organizations have also taken action to advance social transformation, climate adaptation, and sustainable development.[257,258,259,260] Organizations in PR include Casa Pueblo (energy); Vieques Love (disaster preparedness, resilience, and capacity building); Mujeres de Islas (sustainable development); Vida Marina (dune restoration); Protectores de Cuenca (watershed restoration); Corporación de Servicios de Salud Primaria y Desarrollo Socioeconómico El Otoao (socioeconomic development and public health); and El Josco Bravo (agriculture). Organizations in the USVI that have taken action on climate change include the University of the Virgin Islands Caribbean Exploratory Research Center (climate change and health), St. Thomas East End Medical Center Corporation (education program on climate change and health), and Foundation for Development Planning Inc. (advocacy on climate change and disaster risk-reduction and participation in public policy process on climate change). Self-organization has also enhanced community trust and cohesiveness.[13]

In the USVI, the US Department of the Interior funded a climate change initiative in 2016 that produced a vulnerability and risk assessment report.[261] The Caribbean Climate Hub and a limited number of civil society organizations supported the initiative. However, there is currently no climate change adaptation program in the USVI, and the inadequate uptake of climate change information for decision-making identified in 2016[249] is still reflected in current public sector policies and programs in both the USVI and PR.[262]

Challenges and Opportunities

Advances in climate adaptation planning and implementation by individuals, communities, and public, private, and civil society organizations are constrained by shifts in demographics, fiscal and socioeconomic conditions and capacities, and high levels of risk exposure in the region (KM 31.2).

In PR and the USVI, vulnerable populations are located in sites exposed to high climatic risk.[20,263] Social determinants of vulnerability include economic instability and limited access to education and healthcare services.[254,264,265,266] This vulnerability amplifies the effects of disasters and undermines the ability to prepare, respond, recover, and adapt.[168,254,267,268]

Between 2000 and 2019, PR was among the territories and countries most affected by extreme weather–related events, and between 2010 and 2020, it registered the highest number of new displacements in the Caribbean,[269,270] largely because its residents are US citizens and can move to the continental US without restrictions.[271]

The US Caribbean experiences both in- and out-migration, which should be considered in planning and adaptation, as migrants require permanent or temporary shelter and essential services.[272] Progress in policy, programs, and implementation has been made, but the dynamics of intraregional migration are not fully understood or addressed.[270]

Decision-making processes and program delivery mechanisms typically involve multiple institutions, including civil society organizations. However, these public and private organizations often work in silos or with limited coordination or collaboration. The effectiveness of these mixed-delivery systems would be significantly improved through enhancements to coordination mechanisms, improved institutional processes, and increased investment in human resources to understand and manage the connected processes and systems (Ch. 31).[42,251,262,273,274] Similarly, overcoming the limitations in the institutional capacity to develop and manage federal grants will help advance adaptation actions in PR and the USVI.[275]

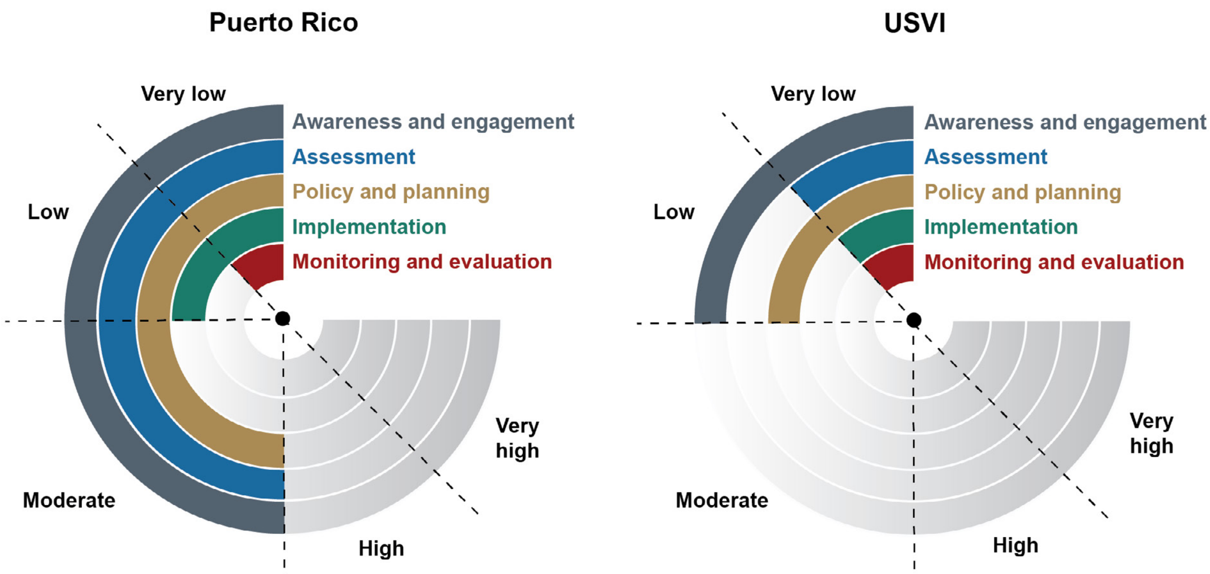
The physical separation of the US Caribbean from the mainland makes disaster response more complex and difficult.[253] Recent reports on the response to Hurricanes Irma and Maria highlight the need for improved planning processes and delivery systems in the relevant federal agencies.[276,277] Ensuring that federal policies and programs are appropriate to local physical conditions and institutional environments and include flexibility to account for future shocks and disturbances could improve disaster response and recovery, as well as climate adaptation action. Policies and program designs that incorporate sustainable land management approaches could reduce vulnerabilities associated with the location of infrastructure and housing in coastal areas and flood zones, water and food insecurity, and degradation of ecological systems. Enhanced alignment of federal and local programs could improve project, program, and development outcomes in the two territories. The government has a fundamental role in creating an appropriate enabling environment for sustainable development—that is, the social ecosystem created by the interplay of policies, laws, institutions, and processes that influence the development of a country. Therefore, ongoing investment in the capacity of government could help ensure that it has the competence to formulate and deliver public policy, maintain significant decision-making capabilities, maintain appropriate and effective governing systems, and develop resilience to shocks.[199,252,278,279,280,281,282]

Current risk-mitigation and emergency response programs focus predominantly on preparedness, response, and recovery—only three of the four phases of a comprehensive disaster management program. The fourth phase is prevention and mitigation, and it is in this phase that economic, legal, sociopolitical, institutional, and other measures are integrated to reduce vulnerability and strengthen resilience.[283,284] In this context, building resilience to disasters and climate change could be enhanced by improving institutional capacity for risk assessment and management.

Both PR Act 33-2019 and USVI Executive Order 474-2015 provide governance frameworks that facilitate coordinated planning and participatory decision-making that involve the public, private, and civil society sectors and the general public. Current federal funding streams available to the territories under the CDBG-MIT program also present an opportunity to advance disaster risk-reduction strategies by focusing more on mitigation and prevention. Modification of the current plans for the USVI and Puerto Rico would make better use of this opportunity.[285]

In the USVI and PR, varying levels of progress have been made across the key elements of climate adaptation (Figure 23.12). This progress reflects the reality that adaptation is an ongoing process that requires evolving governance arrangements to facilitate engagement by all of society.

Status of Adaptation Action



Adaptation action in Puerto Rico and the US Virgin Islands reflects different starting times and available capacity.

Figure 23.12. The figure illustrates progress in adaptation action in Puerto Rico and the US Virgin Islands. The colored bars in the charts show the level of progress for each key element of climate adaptation. Adaptation is presented as a continuous process in which multiple elements may overlap or advance simultaneously. Accelerating adaptation action in both territories would reduce risk and enhance resilience. Figure credit: NOAA/Lynker and Foundation for Development Planning Inc. See figure metadata for additional contributors.

Monitoring, research, and action on regional changes to weather systems, ocean health, and terrestrial and coastal ecosystems may be beyond the financial means of individual island states and territories, underscoring the need for pooling of resources and experiences across the region. Many formal and nonformal relationships exist between institutions, governments, and professional associations in the US Caribbean and other Caribbean countries, which provide opportunities for improving climate adaptation actions through stronger regional collaboration.

Traceable Accounts

Process Description

This chapter was written by a multidisciplinary team of 22 authors that was built in August and September 2021 according to inclusive criteria that sought a diversity of voices by gender, ethnicity, discipline, career stage, knowledge, and geography. Approximately half of the authors work mainly in Puerto Rico (PR), 35% in both US territories, and 15% in the US Virgin Islands (USVI). Sixty percent of authors represent academia, followed by the public sector (about 20%), nongovernmental organizations, and the private sector. The authors are Hispanic- or Latino-Spanish speakers, Afro-Caribbean Black English speakers, and White alone or combined with other races.

Starting in September 2021, the team held weekly all-author meetings to build relationships and capacity. The authors worked in distributed writing teams, each responsible for leading the narrative in each topic and providing evidence supported with literature. On January 19, 2022, the Caribbean chapter hosted a public engagement workshop with 90 participants. Since January 2022, the team continued holding weekly meetings where programmatic and technical issues were discussed. Each Key Message writing team and the chapter lead held weekly meetings to discuss thematic issues, figure development, and more in-depth discussions related to each Key Message.

Key Message 23.1

Climate-Driven Extreme Events Exacerbate Inequities and Impact Human Health and Well-Being

Description of Evidence Base

This topic combines the most recent peer-reviewed information and gray literature on assessment of climate change impacts on the health of people in the US Caribbean. The peer-reviewed literature came from a range of sources.[14,42,50,52,56,59,60,61,62,63,64,80,81,210] The gray literature and reports sourced information from local databases in US Caribbean government agencies and surveys, as well as from databases and other reports.[53,54,67,286] US Census reports lay the foundation for the challenges with descriptions of high levels of poverty and incomes below the US median in both Puerto Rico and the USVI. The literature describing the background information regarding the history of US Caribbean populations being disadvantaged and underserved is documented for the USVI in the needs assessment conducted by Michael et al. (2019)[42] following the 2017 hurricanes; it also provides a combination of local and federal data and information indicating challenges with access to and the extent of services to significant portions of the population before and after the hurricanes. Similar assessments for Puerto Rico have been done by Maldonado et al. (2021)[287] (residential security and community relocation), Seara et al. (2020)[288] (fishing community perception of climate impacts), and Boger et al. (2019)[44] (cultural heritage and traditional knowledge). The relevance of the links between cultural and traditional resources and well-being of people are reported in Boger et al. (2019);[44] Dawson (2013);[289] Finneran (2017);[290] Kohler and Rockman (2020);[291] Perdikaris et al. (2021);[292] and Rockman and Hritz (2020).[293]

There is strong evidence[23,81] in Puerto Rico that extreme heat episodes and extreme rainfall events are increasing in frequency, intensity, and duration, posing the threat of increased incidence of heat-related illness and death, but such evidence is more limited for the USVI at this time. Data on underestimation of mortality was presented for Puerto Rico specifically in Santos-Burgoa et al. (2018)[56] and in NCHS (2019)[294] in the context of the COVID-19 pandemic. The quantification for USVI is not available for the period after Hurricane Maria.

Major Uncertainties and Research Gaps

Post-disaster settings present opportunities for researchers and for developers, often to the detriment of local or impacted communities.[292,295] Louis-Charles et al. (2020)[36] call for the need to pay closer attention to the ethics of engagement between, on the one hand, external researchers, agencies, and investment interests, and, on the other, local communities in the Caribbean. Although there have been popular claims calling out the damages of post-disaster gentrification in the media, social media, and popular music, not much research has been conducted on how disaster capitalism exacerbates injustices and cultural erasure in Puerto Rico and the USVI. Elders and Traditional Knowledge highlight concerns with rates of migration of youth and disarticulation of traditional communities that still would benefit from further research.[296]

While research on aerosol and aeroallergen distribution and health impacts has been conducted in Puerto Rico, this association has not yet been quantified in the USVI.

Reports[42,51] and peer-reviewed literature describe impacts of extreme weather and the efforts or needs to mitigate or adapt activities in both Puerto Rico and the USVI.[297] Strengthened education and adaptation outreach efforts could help address issues with behavioral health, noncommunicable disease burdens, and other challenges.

The impact of sargassum algal mats reaching the coasts of the US territories is uncertain. Evidence from other Caribbean islands suggests that this phenomenon will contribute to worsening air quality, ecosystem health, and public health in coastal areas. There are some initial initiatives on an early warning system for Saharan dust, extreme heat, and public health, yet preparedness of the public health sector to mitigate illnesses is still low (and lower in the USVI than in PR). There are uncertainties related to Saharan dust clouds and how climate change will affect seasonality, patterns, concentration, and dust distribution. There are still uncertainties as to why excess mortality happens for extended periods after a natural event; the understanding of these mechanisms requires the identification of the cause-specific mortality and the different conditions leading to death, including infrastructure, critical building capacity, housing, and living conditions. Such an approach is currently being advanced in a project led by the National Institute of Standards and Technology.[298]

Description of Confidence and Likelihood

There is *high confidence* that climate-related extreme weather events contribute to loss of quality of life and well-being in the US Caribbean. Long histories of colonization, generational trauma, and systemic inequality shape the ability of the US Caribbean peoples to maintain health, quality of life, and overall individual and social well-being (*high confidence*). The level of local and federal research and reports following Hurricanes Irma and Maria in 2017 included information on trends and also identified significant changes and challenges with general health, support services, mental health and well-being in general. In addition, it was noted that the conditions that supported the poor outcomes are major challenges for communities in both PR and the USVI. More frequent heat episodes and powerful hurricanes are expected to increase in the region due to human-induced climate change, affecting public health unless clear and urgent adaptation measures take place (*high confidence*). Climate conditions are favorable for vector-borne diseases (e.g., dengue, Zika, and chikungunya) and human zoonotic diseases (e.g., leptospirosis) in the US Caribbean (*high confidence*). However, many behavioral factors play a confounding and important role (e.g., life-concurrent events, social distancing, age, exposure) in the spread of these diseases. There is *high confidence* in the data and methods in the estimation of the excess mortality in Puerto Rico from Hurricane Maria, and such estimates are now in the official NOAA reports.[299]

Key Message 23.2

Ecology and Biodiversity Are Unique and Vulnerable

Description of Evidence Base

This topic reviews and synthesizes the most up-to-date assessments of climate change impacts on biodiversity, ecosystems, and ecosystem services in the US Caribbean region. The review included gray literature alongside peer-reviewed literature. The peer-reviewed literature considered strong resources from academic and scholarly journals such as the *Journal of Ecology*; *Biological Conservation*; *American Journal of Marine Science*; *Sustainability Science*; *Ecological Indicators*; *Estuarine, Coastal and Shelf Science*; and *Ecosystem Consequences of Soil Warming*. The gray literature included reports, documents, and white papers from federal and local agencies (USDA, USGS, FEMA, US Global Change Research Program, Puerto Rico Department of Natural and Environmental Resources), government entities (Puerto Rico and US Virgin Islands Taskforce), academia (University of Puerto Rico, University of the Virgin Islands), and nonprofit organizations.

The preliminary literature review established and confirmed the observed ecosystem- and biodiversity-level changes in response to climate change due to direct impacts from climate drivers[20,118,123,125,130,136] and the lack of effective adaptation strategies, policies, and measures.[141] Most of the comprehensive assessments reviewed illustrated the rapid changes of habitats, species, and abundance.[131]

Major Uncertainties and Research Gaps

Both territories experience weather- and climate change–related hazards such as drought, sea level rise, coastal flooding, and erosion. However, the amount of climate research, observations, assessments, and modeling (prediction) are greater in PR than in the USVI. It would be necessary to gather knowledge and information from local agencies, institutions, community-based organizations, and even unpublished information to address existing and pressing gaps in the understanding of climate impacts on biodiversity and ecosystems in the USVI.

Description of Confidence and Likelihood

There is *high confidence* that the synergistic effects of climate and non-climate stressors are impacting ecosystem goods and services, given the expanding literature with regional examples of these changes. As documented in federal, regional, and local climate change assessment reports, climate and non-climate stressors are *very likely* to persist and become more severe, further accelerating ecosystem degradation and aggravating their service efficiency. These assessment reports also highlight the dependence of the US Caribbean residents on ecosystem services for their well-being and livelihood (*high confidence*), hence the need to safeguard these services. Based on a broad range of evidence, there is *high confidence* that maintaining ecosystem functionality will require integrating effective local-level adaptation and mitigation strategies. However, given the lack of literature on implemented adaptation strategies, there is *medium confidence* that local-level adaptation and mitigation strategies could reduce and manage the risks of climate change on coastal and terrestrial ecosystems.

Key Message 23.3

Climate Change Threatens Water and Food Security

Description of Evidence Base

The discussion of the vulnerability of the US Caribbean food and water systems to climate change is based on observations within the islands and projected changes in the regional and global climate.[10,12,20,21,23,24,25] Localized threats to water and food security include changes in drought intensity, frequency, or duration[20,21] and tropical cyclone rainfall rates and intensity.[24] There is mounting evidence of the impact of climate-related extreme events on the food and water system based on measurements, local knowledge, and published and gray literature.[149,152,168,200,300] There is strong evidence that both hurricanes and drought are major issues for island food and water systems, as illustrated by the impacts of Hurricanes Irma, Maria, and Fiona[168] and the 2014–2016 drought.[300] The direct and cascading impacts of these climate stressors with additional compounding problems, especially sea level rise, are a concern for food and water systems.[165] The literature on direct climate impacts to certain sectors such as crops and livestock is widely available[156,185] for Puerto Rico but is limited for the USVI. The evidence is limited when specifically considering island freshwater and food availability and is mostly available through evidence captured by the drought information system reports.[301] There are no systematic studies that quantify the cascading and compounding impacts of these hazards.

Major Uncertainties and Research Gaps

The lack of availability of high-resolution climate change projections that better resolve the island climates is a major research gap for understanding plausible future changes in the island climates. Major uncertainties exist with respect to the role of the island terrain and land-use and land-cover change as the climate warms.[21] This research gap is larger for the USVI than for PR. Another modeling challenge and research gap is how future tropical cyclones may interact with small islands like PR and the USVI, especially as rainfall intensity increases in a warmer climate, with cascading impacts on food and water systems. The association between natural hazards and decreased food security or diet diversity in PR and the USVI is another research gap.[302] For the USVI, there is a noted gap of statistics and scientific impact studies on food production and water use. An area of research not discussed is the impact of climate change and major storms on Puerto Rico and the USVI. While there are some reports that document the impact of climate change on fisheries within the Caribbean basin, there are fewer studies that assess the impacts for Puerto Rico and the USVI.[303,304] The role of community-based efforts for mitigating food and water insecurity, as well as the importance of local and Indigenous knowledge to these ends (KMs 30.1, 30.5), has been poorly researched in the US Caribbean and deserves further attention. More information is needed to better assess the impact and response to extreme climate events.[305] Finally, there are research gaps in the compounding and cascading impacts generated by climate change in both Puerto Rico and the USVI.[168]

Description of Confidence and Likelihood

In the first statement of the Key Message, there is *high confidence* that the US Caribbean food and water systems will become more vulnerable as the climate warms, in part because extreme meteorological events like hurricanes and droughts are *likely* to become stronger and more severe in the future. There is *high confidence* that climate change at both global and regional scales is important because the islands are heavily reliant on imported foods. However, climate change projections at the scale of the islands are limited to a few studies, allowing *medium confidence* in predictions of local direct impacts of climate change on freshwater availability for the region. While improved knowledge will enhance adaptation, the authors have *medium confidence* because the adaptation process also relies on social and economic changes. The evidence base was not sufficient to determine quantitative probabilities for the second through the fourth statements in this Key Message; thus, no likelihood is specified.

Key Message 23.4

Infrastructure and Energy Are Vulnerable, but Decentralization Could Improve Resilience

Description of Evidence Base

The vulnerability of US Caribbean infrastructure systems to climate change is based on observations of impacts of recent climatic events within the islands and projected changes in the regional and global climate. The evidence to support current vulnerability of systems and future climate vulnerability is mostly based on documents from the gray literature, including reports from federal agencies and/or sponsored by federal or territorial agencies[199,200,204,230] following Hurricanes Irma and Maria. The published literature and reports are not as rich as for locations in the continental US. The description of the need for a paradigm change in the governance of infrastructure systems is based on a number of peer-reviewed journal articles describing observations of the limits of current governance systems, as well as more academic journal articles addressing best practices for building resilient infrastructure systems. There is very little published literature on the effects of governance on the ability to adapt, especially in the US Caribbean.

Major Uncertainties and Research Gaps

The availability of more structural and system operation assessments of the vulnerability of infrastructure systems to flood and wind events is a major research gap, because most assessments are made by looking at the presence or absence of a system component in a flood zone. Often it is unclear whether the system component can be accessed or operated, or even whether it may have been rendered unsafe by previous mitigation activities that took place. Another gap is the lack of availability of public geodatabases of infrastructure systems. The region is also missing flood maps that take into account future climates. Furthermore, understanding the effectiveness and feasibility of decentralized governance systems for critical infrastructure is a major research gap and need, as much of the current literature demonstrates the limits of centralized systems in the Caribbean. Finally, the lack of easily accessible data on water and power consumption, traffic patterns, and other ways that humans use infrastructure systems is a major data gap that needs to be filled so that adaptation strategies can be developed to mitigate against any disruption in the delivery of services.

Description of Confidence and Likelihood

Based on the level of damage incurred during Hurricanes Irma and Maria (2017) and Hurricane Fiona (2022), as well as the post-2017 hurricane reports published by the government and federal agencies, there is *high confidence* that infrastructure systems in the US Caribbean are suffering from a lack of maintenance and investment and that climate change has created profound risks for the US Caribbean's critical infrastructure, especially as extreme meteorological events become more *likely* in the future. There is *high confidence* that dependence on fossil fuel imports increases energy insecurity, based on numerous reports from the gray literature and the recent fiscal difficulties experienced by the public utilities in both Puerto Rico and the USVI.

Given the lack of stability of the public utilities, as described in government and federal agency reports, and given the relative lack of long-term data on the effectiveness of solar electric systems as an alternative to centralized systems to provide power to communities during and outside of disasters, there is *medium confidence* that decentralization of system production and distribution, and *medium confidence* that decarbonization and shared governance, will *likely* help limit residents' vulnerability to health and other risks associated with the loss of essential services programs.

Key Message 23.5

Adaptation Effectiveness Increases When Coupled with Strategic Governance and Planning

Description of Evidence Base

The evidence to support the Key Message consists of articles in peer-reviewed journals, research publications by universities, technical papers, assessment reports produced by or on behalf of the federal and territorial governments, executive orders and legislation passed by the territorial governments, and technical reports by Caribbean and global intergovernmental organizations.

The peer-reviewed journals were classified with impact factors that range from 3.20 to 9.5, indicating that the journals are trustworthy. The documents prepared or funded by federal and territorial governments underpin the conclusions regarding challenges of various levels of government for effective planning and adaptation.[148,249,252,253,276,277,279] Literature that supports the conclusions regarding effective adaptation action through improved governance arrangements and coproduction with community organizations includes McGinley et al (2022),[168] Filantropia Puerto Rico Inc. (2022),[258] and Towe et al. (2020).[262] The gray literature also includes publications by research institutions such as the National Institute of Building Sciences, the International Council for Local Environmental Initiatives–Local Governments for Sustainability USA, the University of the Virgin Islands, and the University of Colorado.

Since the publication of the Fourth National Climate Assessment in 2018, climate adaptation action is increasingly being informed by high-quality data, policies, laws, white papers, and technical reports prepared by the governments of the two territories, Puerto Rico's Expert Advisory Committee on Climate Change, the Puerto Rico Climate Change Council, the Governors' Institute on Community Design, academia, scientists, and community-based organizations.

Major Uncertainties and Research Gaps

A large body of literature is available globally and for the wider Caribbean on the benefits of local adaptation through coproduction. For the US Caribbean, although there are participatory efforts, mostly from the nonprofit sector and many supported by academia, the published literature is sparse. As such, additional research and evaluation on the capacity requirements and design for collective action would enhance implementation.

Description of Confidence and Likelihood

Statements about the challenges of climate adaptation in the US Caribbean due to multiple interacting factors—including high risk exposure, limited or misaligned funding, insufficient institutional and organizational capacity, and siloed approaches to risk reduction and resilience—are based on extensive analysis of peer-reviewed papers; federal, regional, and local technical reports; and the onsite experience of the multidisciplinary, multisectoral team of 22 authors of this chapter. Authors had the opportunity to deal with, study, and/or assess these diverse interacting factors that are related to climate adaptation in the US Caribbean from diverse points of view. As a result, authors have *high confidence* in the first statement of the Key Message.

On-site experience, data, and numerous studies with consistent findings support the idea that US Caribbean adaptation could be enhanced through co-development and integration of robust global, regional, and local climate science and risk-based knowledge into planning and implementation, as well as improved governance, resulting in *high confidence* in the second part of the Key Message.

Based on a smaller number of studies but further deliberation among our author team, the statements about how US Caribbean capabilities in planning and adaptation can be enhanced by strengthening partnerships across the wider Caribbean region and the US mainland is assigned *medium confidence*.

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