Fifth National Climate Assessment: Chapter 22

Southeast

Chapter 22. Southeast

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Introduction

Patterns of climate risk, social vulnerability, and climate adaptation in the Southeast echo centuries of human history. The region consists of highly diverse communities and landscapes, including one of the most biodiverse areas in the continental United States. The Southeast's ecosystems, stewarded for generations by Indigenous Peoples, are now in a precarious state. Centuries of political and land-use decisions have threatened the landscape and the people, with a few prospering at the expense of many. These decisions, shaped by a long history of systemic and structural racial discrimination and aggression, continue to have lasting harmful effects on the preparedness of Southeast communities for mounting climate change threats. The institutions of slavery and intergenerational ownership of individuals as property, Jim Crow segregation, and housing discrimination have resulted in many BIPOC (Black, Indigenous, and People of Color) communities living in neighborhoods that are disproportionately exposed to environmental risks and with fewer resources to address them when compared to majority White communities (Figure 32.18).[1,2,3,4,5,6,7,8,9,10,11,12,13] Furthermore, these frontline communities—those with higher exposures, greater vulnerability, and less adaptive capacity to climate change impacts—continue to face forms of discrimination that increase their vulnerability to climate risks and reduce their options for resilience (Figure 20.1).[1,14,15] These inequities are further complicated by the Southeast's population changes, economic investments, and rising tax revenues in urban and suburban areas. Wealthier communities are able to seek out external resources needed to implement innovative climate resilience and adaptation projects.[16,17] Meanwhile, smaller and more rural communities often lack the capacity to receive and spend funding, train leadership, and advocate for climate adaptation planning.[18]

With virtually no exceptions, climate change in the Southeast continues to exhibit the trends that were reported in the last National Climate Assessment (NCA).[19] We now better understand the increasing intensity of climate stressors in the Southeast, including extreme heat, extreme precipitation events, drought persistence and strength, sea level change, and tropical cyclones (Table A4.1), as well as decreases in the intensity and frequency of disruptive cold-season events like snowfall and frost days (Ch. 2).[20]

There have been notable advancements in Southeast climate change adaptation in recent years.[19] For example, adaptation plans created by Tribal Nations have contributed to those Nations' cultural continuance in a changing climate—that is, their "capacity to maintain members' cultural integrity, health, economic vitality, and political order into the future and avoid having members experience preventable harms" (KM 16.3).[21,22] Indigenous stewardship continues in the Southeast in many contemporary Indigenous "cultural landscapes," or places where Tribal members have centuries-old connections (Box 22.3). In these places, members continue cultivating cultural practices including hunting, fishing, foraging, and ceremony.[23] The increasing hazards of climate change, pollution, and threats to land and water rights–which may be underestimated by existing environmental justice analyses[24,25]–put a strain on Indigenous Peoples' sovereignty and their ability to have high levels of cultural continuance.[21,22,26]

Moreover, communities throughout the Southeast are exploring how to spur action through communicating about climate change science across both formal (classroom) and informal (outside of classrooms) learning,[27,28,29,30,31,32,33] setting clear climate goals,[34] and responding to the mounting threats and stressors that climate change presents (Figure 31.1).[35] However, there has been an equal, if not a greater, number of failures to adequately prepare the region's homeplaces, infrastructure, economy, and livelihoods for the threats of a warming climate, seen in the poorly coordinated responses to hurricanes over many years, from Hurricanes Katrina[36] to Florence[37] and Ida,[38] especially for frontline communities.[39] Moreover, uncoordinated adaptation efforts across municipal and state boundaries to address climate change may hinder the long-term efficacy of any individual project while delaying the shared goal of securing the vitality of the Southeast.

Key Message 22.1

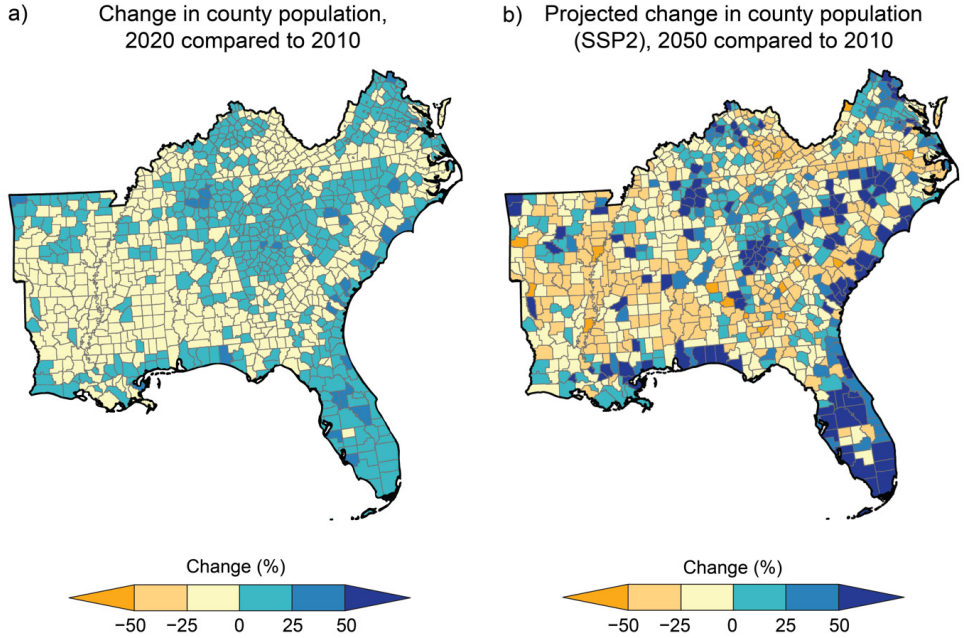
Regional Growth Increases Climate Risks

The Southeast's population has grown and is expected to continue growing, mostly in metropolitan areas and along its coastline (*very likely*, *very high confidence*), putting more communities and their assets into harm's way from increasing risks related to climate and land-use changes (*very likely*, *very high confidence*). Conversely, many rural places are facing declining populations with a growing percentage of older residents (*very high confidence*), making these areas particularly vulnerable to the impacts of a changing climate (*likely*, *high confidence*). At the same time, decision-makers frequently use outdated and/or limited information on climate-related risks to inform adaptation plans, which as a result fail to account for worsening future conditions (*likely*, *high confidence*). These climate adaptation efforts also tend to be concentrated in wealthier communities, leaving under-resourced and more rural populations, communities of color, and Tribal Nations at growing and disproportionate risk (*likely, high confidence*).

A Growing Region Means Increased Climate Risks

All but one of the Southeast's states—Mississippi—experienced population growth over the last decade, and most of the fastest-growing large US cities are located in the region.[40] Even under scenarios with moderate population growth (e.g., Shared Socioeconomic Pathway [SSP] 2), the region's population is expected to increase (Figure 22.1).[41]

Population Change in the Southeast

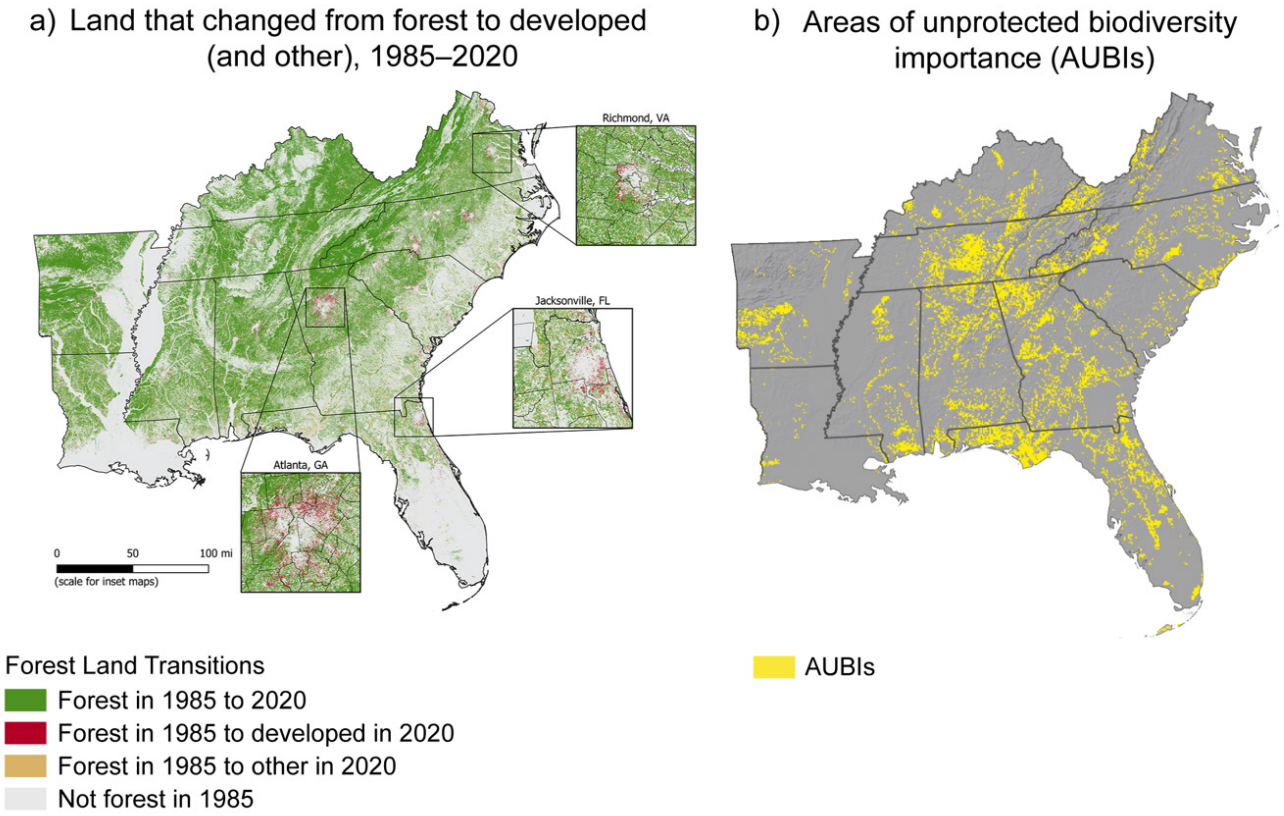


Population change in the Southeast exposes more people to climate threats along the coast and in cities while leaving rural areas with limited capacity.

Figure 22.1. (**a**) Between 2010 and 2020, unequal population change occurred in the Southeast, with coastal and metropolitan counties growing while many rural counties' populations declined. (**b**) This pattern is expected to continue through 2050 (under SSP2) and will expose more people to climate threats. Diminishing populations reduce the capacity of rural counties to adapt to climate threats by reducing critical financial and social resources, such as tax bases and community care organizations. Figure credit: Groundwork USA, NOAA NCEI, and CISESS NC.

Southeast land cover equal to about 1.7 million football fields changed from forested to developed between 1985 and 2019, more than in any other NCA region (Figure 22.2a; Ch. 6). Urbanized land cover is estimated to increase by more than 9% throughout the region by 2060, based on urban area growth trends during 1990–2010,[42] further threatening the region's unique terrestrial and aquatic biodiversity (Figure 22.2b; KM 8.1).

Land-Cover Change and Biodiversity

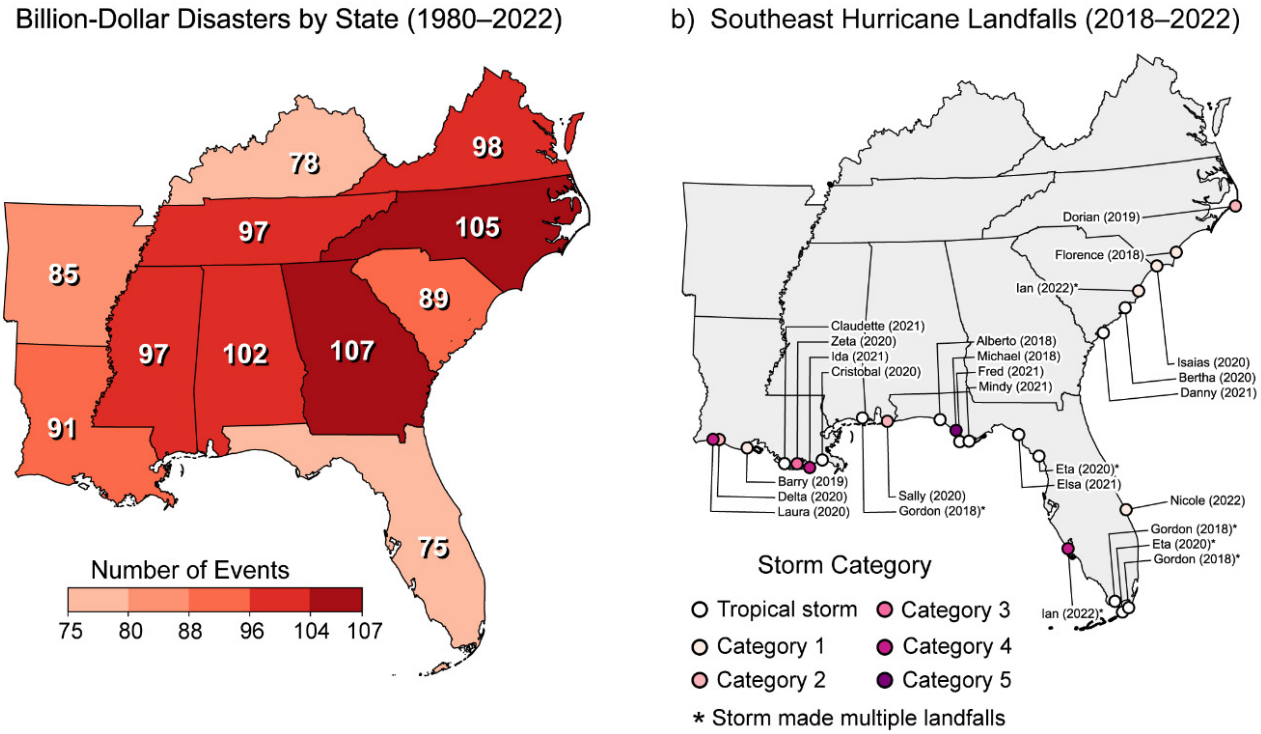


Land cover change and sprawling development threaten unprotected biodiversity hotspots in the Southeast.

Figure 22.2. (**a**) The Southeast has lost more forested area to development and other land uses (cropland, grass/shrub, and water) than any other National Climate Assessment region since 1985. (**b**) Many of the region's most biodiverse landscapes remain unprotected, threatening unique species of birds, fish, and amphibians. Future sprawl may threaten these landscapes, known as Areas of Unprotected Biodiversity Importance (AUBIs). Figure credits: (a) Groundwork USA, Oak Ridge National Laboratory, NOAA NCEI, and CISESS NC; (b) adapted with permission from Hamilton et al. 2022.[43]

Unconstrained exurban and suburban sprawl will further expose human development to weather- and climate-related risks such as wildfire,[44] hurricanes,[45] floods,[13,46] intensifying thunderstorms,[47] and tornadoes.[48] Growth along the region's coastlines[49] has increased the population exposed to coastal-specific climate threats.[13,50,51,52,53] Although the Southeast has historically experienced more billion-dollar disaster events than the rest of the country[54] and has weathered multiple hurricanes since 2018 (Figure 22.3), there is considerable regional variation among residents' perceptions of whether climate change will personally harm them.[55,56]

Billion-Dollar Disasters and Hurricanes in the Southeast



The Southeast frequently experiences costly weather-related disasters, which are worsened by climate change.

Figure 22.3. (**a**) The map shows NOAA billion-dollar disasters by state during 1980–2022 in the Southeast. The map adds up billion-dollar events for each state affected (i.e., it does not mean that each state shown suffered at least $1 billion in losses for each event). (**b**) The map shows Southeast hurricane landfalls during 2018–2022. Since 1980, the Southeast has had a higher frequency of billion-dollar disasters than other National Climate Assessment regions. Disasters attributed to hurricanes have been particularly damaging. Hurricane impacts can spread far inland and even outside the region, including major flooding, which is not captured in the Saffir–Simpson Scale depicting hurricane landfall intensity (b). Because map (b) is limited to 2018–2022, it excludes prior billion-dollar hurricanes that hit the Southeast, including Hugo (1989), Andrew (1992), Fran (1996), Floyd (1999), Charley (2004), Rita (2005), Katrina (2005), Matthew (2016), and Irma (2017). Figure credit: Mississippi State University.

Some of the Southeast's growth follows patterns of urban renewal, with affluent and young people returning to urban areas and displacing under-resourced communities to suburban and rural areas.[57] As a result of this displacement and long-standing underinvestment, under-resourced communities face more environmental hazards and increasing risks (Figure 22.4b)[3,13] but have less access to climate-ready infrastructure such as housing (Figure 22.4a), dwellings with strong building codes[58] that minimize disruption during storms,[59,60] public transit,[61] community resource centers for heat and cold relief,[62] and up-to-date stormwater management systems.[63] These communities often also lack a well-resourced local and/or state governmental workforce[64] to analyze, plan for, and mitigate risks (KM 20.1).[16,17,18,65,66]

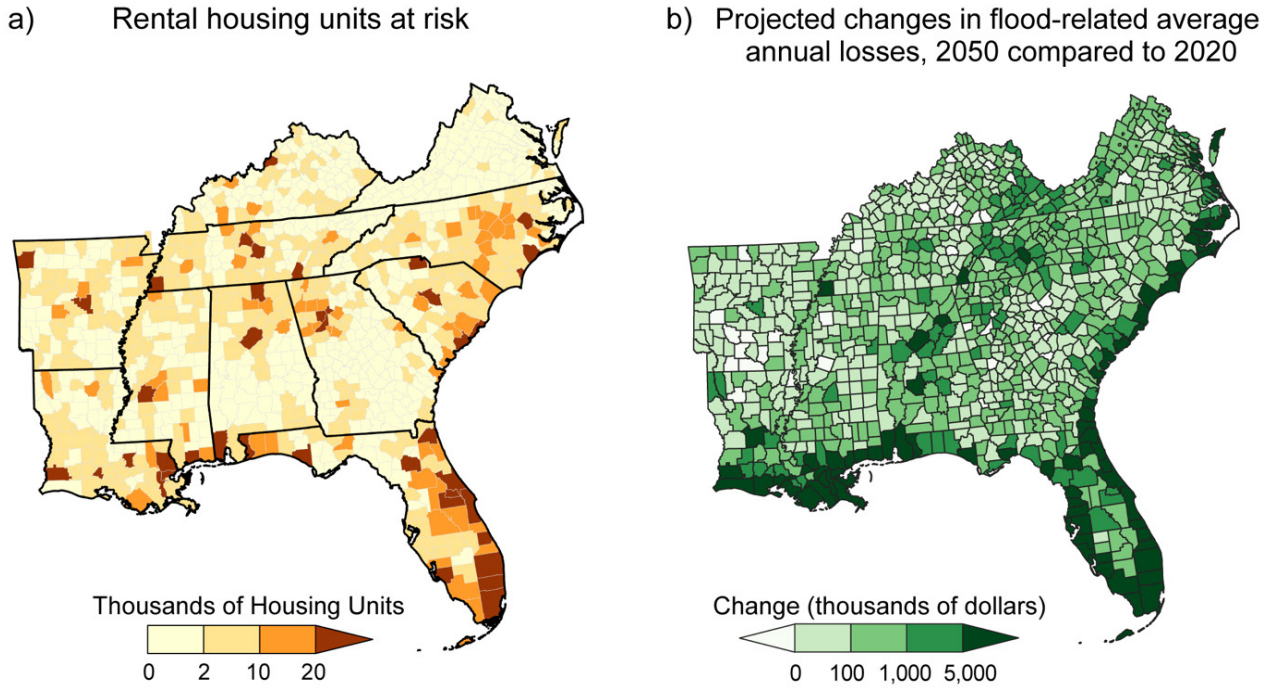
Inland and Coastal Flooding Threatens the Present and Future

Southeast flood risk is inequitably distributed due to both climate and non-climate stressors. Physical stressors such as increases in rainfall, temperatures, and sea level, in addition to land cover change, exacerbate flood risks (KM 4.2),[13,50,67,68] while social and economic policies, including institutional investments and disinvestments, differentially shape risk, vulnerability, and exposure to flooding.[69,70,71] Compounding

preexisting social and economic disparities are changes in precipitation patterns. For instance, shifting autumn precipitation patterns have been attributed to human-caused climate change,[72] and some Southeast counties with higher social vulnerability are experiencing more frequent flooding.[73]

Mandatory flood risk disclosure requirements largely depend on state-by-state policies,[74] and virtually all requirements apply only to home sales. Millions of rental housing units in the region are within counties that have high Expected Annual Loss ratings from FEMA,[75] and confidence is growing that areas currently populated by communities of color, who also are more often renters, will face disproportionately high future flood risks (Figure 22.4).[3,13] Furthermore, other forms of housing that are vulnerable to climate risks include mobile homes and manufactured housing, which are concentrated in the Southeast.[40,76,77] These populations tend to face more barriers to accessing flood insurance and federal flood disaster assistance and more often experience adverse outcomes during disaster recovery, due in part to the lack of disaster relief programs for renters and the rising cost of flood insurance.[78,79,80] Additionally, the potential overvaluation of coastal residential housing stock makes it even more challenging to move people out of harm's way due to the upper limits placed on the amount of compensation these programs can offer and peoples' reluctance to sell these properties and lose rental revenue. For example, in Miami-Dade County, Florida, the total overvaluation of properties is $3.9 billion, and in nearby Duval County, where Jacksonville is the county seat (Figure 22.5), overvaluation exceeds $420 million.[81] Across the Southeast, the average total overvaluation of properties is estimated to be around $110 million per county. Florida has the highest statewide total average overvaluation at $749 million, while Mississippi has an undervaluation of $20 million.[81]

Current and Projected Risks to Homes



Vulnerable homes in the Southeast will face increasing climate threats in the future.

Figure 22.4. (**a**) Thousands of rental housing units across the Southeast are located in counties with at least a "relatively moderate" Expected Annual Loss score in FEMA's National Risk Index. (**b**) Projected future increases to flood-related average annual losses by 2050 compared to 2020 under an intermediate scenario (RCP4.5) disproportionately affect under-resourced populations and communities of color and are amplified by population growth, exposing more people to increased flood risk. (a) Adapted with permission from Harvard Joint Center for Housing Studies, America's Rental Housing, © 2022 by the President and Fellows of Harvard College, www.jchs.harvard.edu. All rights reserved;[75] (b) adapted from Wing et al. 2022[13] [CC BY 4.0].

Flooding impacts infrastructure and, in turn, public health. Injury, illness, and death can result from exposure to mold from floodwater damage,[82,83] onsite wastewater treatment system failures,[84] and carbon monoxide poisoning from misuse of generators for emergency power.[85,86,87] In addition, healthcare facilities may be damaged by flooding or unable to handle an influx of demand.[88,89] Damage to roads and bridges might prevent access to these facilities, disrupt the supply of medications and equipment,[90] and hinder a community's lifeline to emergency services and evacuation routes.[91]

Tropical storms and hurricanes have been responsible for some of the Southeast's biggest and most damaging flooding events since 2018 (Figure 22.3). The likelihood of hurricanes slowing down or stalling near the coast has increased, exacerbating the rainfall-related flooding threat from these systems.[92] However, the impact of climate change on slowing down or stalling tropical storms remains uncertain,[92] although some simulations indicate a potential slowdown of Atlantic storms due to climate change,[93,94] including near the Southeast US coast.[95,96] In addition, rapidly intensifying hurricanes have presented challenges for implementing evacuations,[97] and the frequency with which Atlantic hurricanes rapidly intensify may be increasing in response to long-term human-caused climate change.[98] Also, there is evidence of increased intensification rates near the US Atlantic coast, which may continue into the future.[99] There have been significant improvements in understanding how nontropical systems,[100] atmospheric rivers,[101,102,103,104,105] past and future El Niño–Southern Oscillation patterns,[106,107] flash flooding,[73,108] and urban environments[109,110,111,112,113] add to the Southeast's risk of extreme precipitation and flooding.

With additional global warming, more North Atlantic hurricanes are expected to strengthen to at least Category 4 intensity and to undergo rapid intensification, sea level rise is expected to worsen storm surge inundation, and tropical cyclone–related rainfall is expected to increase.[93,114,115,116,117] The likelihood of storms making landfall could increase, which may offset the potential decrease in the total number of storms and overall exacerbate impacts.[118] However, some uncertainty remains regarding the expected degree of change in hurricane activity impacting the Southeast. Additionally, estimates suggest that some seasonal, annual average, and extreme precipitation amounts across the Southeast will increase, driven mainly by more extreme events (e.g., precipitation of 3 inches or more in 24 hours) at higher levels of warming.[20,67,119]

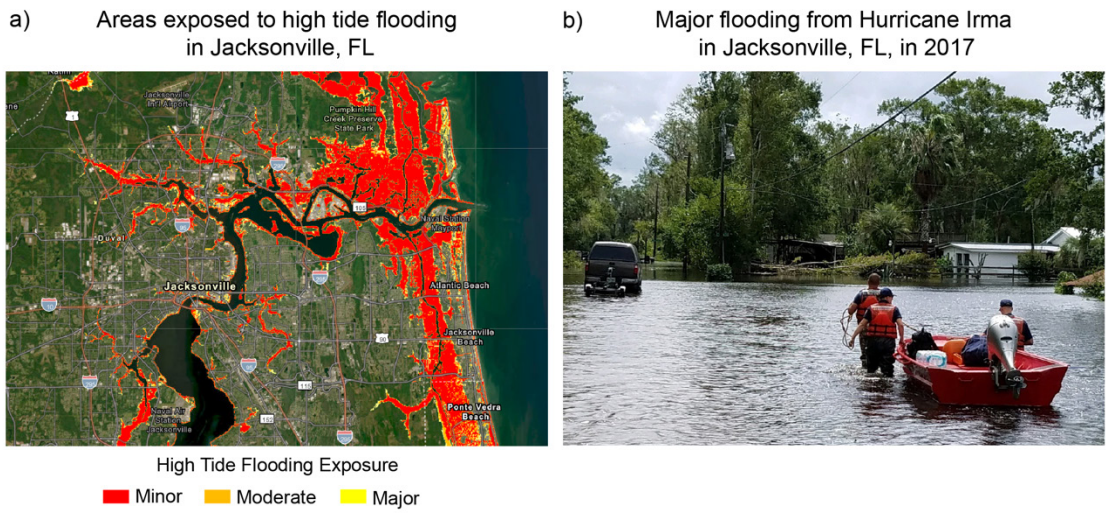
Some Southeast communities plan for these extreme events with an outdated understanding of climate-related risks.[68,120,121] Sewer infrastructure is built to accommodate a particular amount of rainfall over a specified time, and current estimates of precipitation intensity, frequency, and duration generally do not consider future projections of these metrics, posing a significant challenge to civil engineers.[122,123] Estimating future precipitation characteristics and their impact on sewer infrastructure in the Southeast is primarily conducted on a state-by-state basis and relies on different scientific approaches,[121,124] further complicating the development of design standards for climate-ready infrastructure (Figure 22.5; KM 12.2).[120]

Extreme rainfall that occurs at the same time that ocean water inundates populated areas (e.g., because of high tides or storm surges) creates compound flooding events, which can result in decreased property values[125] and roadway obstructions that can hinder first responders (KM 9.2).[66,126] Compound flooding events already affect low-lying areas in the coastal plain,[93,127] and the Intermediate-Low and Intermediate sea level rise scenarios for the Southeast project a higher frequency of compound flooding by midcentury in regions along the Atlantic coast.[128]

Tide gauges throughout the Southeast indicate that relative sea level rose by 6 inches during the 1970–2020 time period, with some variation across the region.[51] The average range of sea level rise by 2050 relative to 2000 in the Southeast (Low to High scenarios)[51] is 16–23 inches (0.40–0.58 m). This increases to a range of 2.2–7.3 feet in 2100 relative to 2000 under the same scenarios.[51] These regional estimates are higher than the projected global average rise due to regional variations in land motion, excessive groundwater pumping,[129] and the effects of sea level changes caused by changes in ocean currents.[51] For example, overall

sea level rise projections by 2050 are 22–32 inches for Grand Isle, Louisiana, 10–19 inches for Jacksonville, Florida, and 15–22 inches for Outer Banks, North Carolina. High tide flooding events in the Southeast may increase by a factor of 5–10 by 2050 due to sea level rise (Figure 22.5).[51] However, many communities will experience comparable increases in these events before 2050 due to changes in tides that exacerbate sea level rise.[52] Saltwater intrusion from rising sea levels has already degraded the health of coastal forests and estuaries while reducing their ability to store carbon,[130,131] and increased soil salinity has reduced yields in the remaining range and farmland.[132] While there is uncertainty in how global ice sheets will respond to additional global warming and thus ultimately determine longer-term sea level rise, the Southeast could experience 3.1–13.2 feet of sea level rise by 2150.[51]

Sea Level Rise and Flooding in the Southeast



Major flood events in Jacksonville, Florida, could become about 5 times more likely by 2050 under an Intermediate-High sea level rise scenario.

Figure 22.5. Sea level rise under an Intermediate-High scenario[51] would drastically increase the likelihood of flood conditions by 2050. For Jacksonville, Florida (**a**), this would mean that "minor" flood conditions (red colors) will be about 30 times more likely, "moderate" (orange colors) will be about 20 times more likely, and "major" (yellow colors) will be about 5 times more likely. This would translate to more than 250 minor floods, 10–50 moderate floods, and about 1 major flood per decade in 2050. (**b**) Major flooding impacts would resemble those experienced during Hurricane Irma in 2017, when Jacksonville experienced record-high flooding conditions. (a) Adapted from NOAA/NOS/CO-OPS 2023.[133] Data layers provided by © Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community. (b) Photo credit: Department of Homeland Security.

Indigenous Communities: Loss and Leadership in a Rapidly Changing Region

Indigenous communities have long faced displacement from and loss of cultural and desirable lands from settlers and government (Figure 16.1). Settler colonialism and climate change are forcing the displacement of Indigenous communities once again, causing stress and grief (KM 16.1). Indigenous communities experience substandard housing and infrastructure, as well as limited insurance coverage, which increases their vulnerability to climate stressors (KM 16.2).[134] In addition, land dispossession in the Southeast has impeded Indigenous Peoples from enduring climate hazards and deprived them of the benefits of the natural environments they once stewarded.[135,136,137,138]

Climate change and a shift from Indigenous-managed cultural landscapes to settler-managed landscapes threaten cultural knowledge and practices.[136] This shift can be seen in the loss of plants and animals of cultural significance to Southeast Indigenous communities (Figure 22.2; Box 22.3). This loss has contributed

to decreased physical and mental well-being as Tribal citizens have had to shift away from subsistence lifestyles that connect them to their cultural landscapes and contribute to cultural continuance.[22,139] Climate change also alters the ranges of native plants while enhancing the growth of invasive species that may out-compete them.[140] The loss of native species adversely affects Indigenous populations who rely on these resources for subsistence or cultural value,[141] such as coastal communities with economies driven by forests or fisheries.[142] However, Tribal Nations are finding ways to lead in responding to climate change (KM 16.3) while exercising their rights to cultural continuance and sovereignty through numerous actions and projects, including revitalizing rivercane ecosystems (Box 22.3).

Southeastern archaeological sites reveal a rich history of how Tribal Nations have met challenges similar to those they are experiencing now by using their Indigenous Knowledges.[143] However, many of these sites are exposed to the threat of rising sea level because they are located in coastal lowlands.[144] A sea level rise of approximately 3 feet (about 1 m) could result in the loss of more than 13,000 historic and prehistoric archaeological sites (with significantly more lost under more severe scenarios) while directly harming contemporary Indigenous communities across the Southeast.[144] Sea level rise also threatens coastal marshes in the Southeast more than anywhere else in the US.[145] The potential loss of these marshes, teeming with biodiversity and critical ecosystem services, could adversely affect the communities that depend on them. The ability of marshes to move (or "migrate") landward in response to sea level rise will depend on the availability of onshore land that in many cases is already developed. Planning for the migration of marshes will require a further understanding of their dynamics, as well as social trade-offs to accommodate their migration into new areas.[145]

Moving Out of Harm's Way, Protecting Existing Communities, and Planning Ahead for Growth and Potential Resettlement

The Southeast is responding to climate threats; however, these actions are spread unevenly across the region (Figure 31.1). Many communities are adopting adaptation plans, including anticipating population growth due to climate-driven relocation.[146,147,148] Tribal governments achieve greater success in developing comprehensive climate adaptation plans when joining strong cross-Tribal networks that share knowledge of effective strategies.[149] However, Southeastern adaptation plans (especially for drought and heat) are less comprehensive than those in other regions.[150,151,152,153]

Adaptation actions include avoidance, planned relocation, protection, accommodation, or some combination of these. Avoidance involves limiting development in hazardous areas. Retreat from the coast or riverine floodplains involves removing infrastructure, housing, and public facilities from hazardous areas over time while limiting future development. Protection strategies use physical infrastructure like seawalls, levees, and beach nourishment, although these may not provide long-term protection if designed for past climate conditions.[154] Accommodation involves elevating structures or using building materials that can withstand being submerged by floodwaters or are less prone to damage when exposed to fire (Figures 22.6, 22.7).

Funding needed to implement adaptation projects remains elusive for many communities, especially those with limited resources and high levels of preexisting social vulnerability.[80,155] One strategy for advancing climate adaptation is applying for FEMA Hazard Mitigation Assistance (HMA) grants.[156,157,158] However, state hazard mitigation officers who manage these grant programs have described differing levels of capacity to help local governments develop and implement HMA grants.[16] While FEMA updated its hazard mitigation planning guidance in 2022 to require that local governments and states address equity and future conditions as part of their new strategic plans,[156] the impacts of these changes have yet to be effectively assessed relative to the quality of the plans. Despite these challenges, a growing number of localities are factoring intensifying climate-related stressors into adaptation plans[35,159,160,161] and helping guide new policy (Box 22.2).

Current Tools Could Ensure Equitable Adaptation

There are several types of climate adaptation tools available to communities in the Southeast, including buyouts, information clearinghouses, land use policies, and city design and planning (Figures 22.6, 22.7).

Buyouts—acquiring hazard-prone housing that is demolished and converted to open space—are widely recognized as one of the most cost-effective strategies for reducing future losses,[162,163] including those associated with adapting to a changing climate.[164] However, while buyouts do require that the land be converted to open space after purchase, applying other proactive land-use planning techniques that guide development to safer locations or limit future growth in hazard-prone areas remains an uncommon practice.[165,166] As a result, there remains considerable uncertainty around whether communities are actually reducing risk when accounting for the losses avoided with buyouts relative to increased hazard exposure associated with new development in hazard-prone areas.[167,168,169] For example, some buyouts resulted in people relocating to an area of similar risk as their original dwelling,[170,171] and relocation in a broader context has meant moving from one risk zone to another.[172] Buyouts can also reduce a community's tax base, which can be particularly devastating in smaller jurisdictions with limited revenue to support governmental services.[173] Questions of equity in buyouts include whether buyouts are preferred by residents, whether choosing to participate in buyouts is in their best interest, and whether frontline communities are involved in deciding how and where buyouts occur (KM 20.5; Figure 20.3).[174,175,176,177,178,179] Additional buyout challenges include the long-term management of resulting open spaces, tracking buyout land in a given area, and strategies to achieve co-benefits such as creating climate-resilient recreation amenities like parks, greenways, water retention areas, and ballfields.[180,181,182] Buyout migration and relocation from one place may also exacerbate local housing pressure in another. For example, in Miami, wealthier individuals are moving from higher-flood-risk coastal areas to safer higher-elevation areas, increasing inland property values and displacing residents,[183,184,185] although the exact pressures driving gentrification and displacement within any community are complex.[186,187] There is evidence that points to the migration of some Black residents out of floodplains in the Southeast, including the case of Edgecombe County, North Carolina, where the Town of Princeville, discussed in Box 22.1, is located.[53]

A growing number of climate adaptation resource clearinghouses are available (KM 31.4), and they include Southeast case studies.[188,189] In addition, Southeast-focused organizations like the Southeast Climate Adaptation Science Center, USDA Southeast Climate Hub, and the Southeast and Caribbean Disaster Resilience Partnership provide resources needed to advance adaptation strategies, including resources for rural and/or under-resourced communities.[18,64] Some climate change planning documents even now center on additional considerations such as equity in their frameworks.[190] However, inequitable access to resources and constraints on workforce capacity to effectively use these tools can also lead to unequal progress toward implementing strategies across communities.

Climate-resilient community design principles are being employed by urban planners, landscape architects, and architects, as well as by an increasing number of municipalities (Figures 22.6, 22.7, 12.8).

Climate-Resilient Neighborhood Design

Climate-resilient community design can ensure the long-term vitality of cities.

Figure 22.6. Climate-resilient urban design may incorporate nature-based, infrastructural, and community-based solutions to alleviate the harm from climate stressors such as extreme heat and flooding. Participatory processes can foster shared ownership of climate resilience strategies and promote the distribution of resources to where they're needed most. Equitable reduction of climate risks and ensuring the reliability of critical services can create social benefits. Figure credit: Groundwork USA and North Carolina State University.

Box 22.1. Reducing Flood Risk in Princeville, North Carolina

Land-use decisions dating back to the post–Civil War Reconstruction era placed Black communities in lower-lying, historically flood-prone areas across the Southeast. One example is the community of Princeville, North Carolina, located along the Tar River.[191] Princeville is the oldest incorporated independent Black community in the United States, originally settled by formerly enslaved people.[192] The town, located entirely in a floodplain, has flooded numerous times. In 1967 the US Army Corps of Engineers constructed a levee that protected Princeville until Hurricane Floyd struck in 1999 and caused widespread flood damage to the town.[192] Research suggests that repeated exposure to varied water levels over time has reduced the levee's protective capacity.[193] Although state officials offered to use buyouts to move the town to higher ground following Hurricane Floyd, residents refused due to their deep attachment to the place.[194] In 2016, Hurricane Matthew flooded Princeville again. Residents then accepted the state's offer to fund several risk-reduction measures, including buyouts, converting acquired land to open space, elevating homes, and building replacement housing in compliance with local flood standards. The state also purchased a 52-acre parcel of land adjacent to the town's borders but located outside of the 100-year floodplain where critical facilities, businesses, and new housing are to be built.[173] Princeville provides a powerful example of how existing post-disaster funding programs and policies can guide risk reduction and adaptation in the face of a changing climate. The long-term impact of these programs on the community's overall social and physical cohesion, as well as their resilience to future storms, remains an open question.

Box 22.2. Reshaping FEMA Policy to Aid Disaster Recovery in the Gullah Geechee Cultural Heritage Corridor

The Gullah Geechee Cultural Heritage Corridor is a National Heritage Area established by Congress to recognize the unique culture of the Gullah Geechee people who have traditionally resided in the coastal areas and the sea islands of North Carolina, South Carolina, Georgia, and Florida —from Pender County, North Carolina, to St. Johns County, Florida.

Communities often consist of coastal families who represent five or more generations of Gullah Geechee heritage and whose quality of life is inextricably connected to the environment and the ecosystem services it provides. Gullah Geechee residents and other coastal citizens who reside on heirs' property, or property passed down through family members by inheritance, are highly vulnerable to negative impacts associated with extreme weather events and changing climate and ocean conditions. One such impact was former federal disaster aid policies that did not recognize the uniqueness of heirs' property, where possession is authentic but documentation can be complicated. The Gullah Geechee Cultural Heritage Corridor worked with FEMA to identify policy barriers and revisions for Gullah Geechee citizens seeking disaster and recovery aid. The Corridor used its communication network to educate communities about the newly created disaster aid revisions made to support owners of heirs' property before the 2022 hurricane season. When powerful storms struck communities in South Carolina, the Corridor team reached out to families and directed FEMA representatives to areas that were hardest hit. Through its community-driven ad hoc subcommittee on natural resources and climate change, the Corridor has also used a similar grass-roots approach to understand how climate change may be experienced differently in the coastal communities of the Corridor and has worked to identify nature-based solutions that may benefit some communities.

Climate Resilience in the Southeast

Southeast communities are adapting to climate threats in a number of ways.

Figure 22.7. (**top left**) A 60,000-acre-foot stormwater reservoir in Palm Beach County, Florida, temporarily stores peak stormwater flows. (**top right**) Transit advocates in Richmond, Virginia, document the cooling efficiency of shade structures at public bus stops. (**bottom right**) Construction workers prepare to raise a home's foundation along Virginia's Eastern Shore. (**bottom left**) Rain gardens like this one can be highly place- and community-driven projects to absorb excess stormwater and improve green space, while nonprofits like Groundwork RVA build

skills for a green economy. Photo credits: (top left) South Florida Water Management District [CC BY-ND 2.0]; (top right) © Jeremy Hoffman, Science Museum of Virginia; (bottom left) © Robert Jones; (bottom right) Aileen Devlin, Virginia Sea Grant [CC BY-ND 2.0].

Key Message 22.2

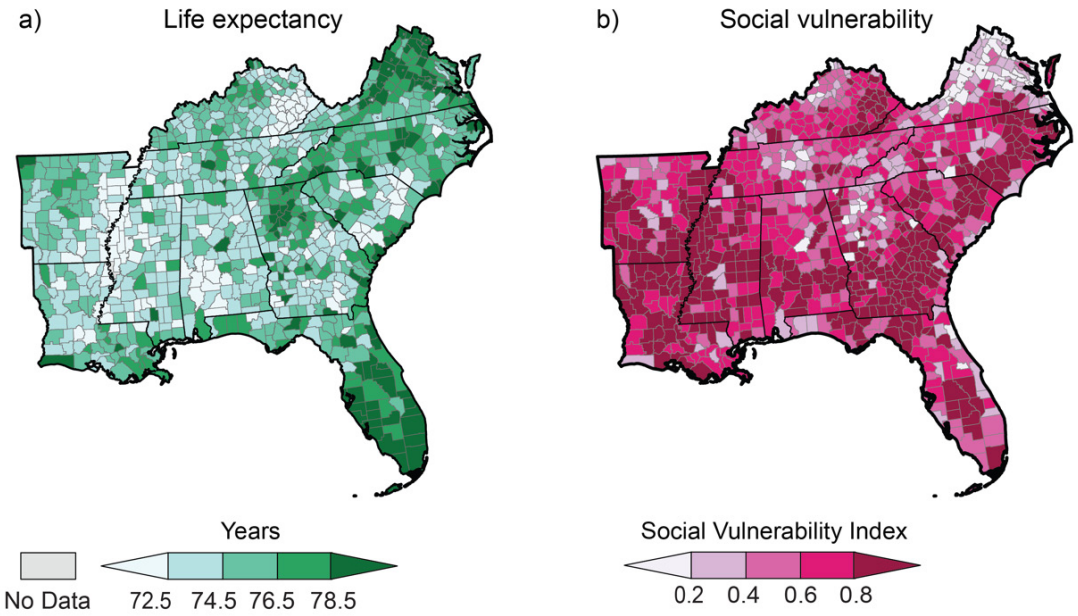
Climate Change Worsens Human Health and Widens Health Inequities

Human health and climate stressors are intimately linked in the Southeast (*very high confidence*). Community characteristics such as racial and ethnic population, chronic disease prevalence, age, and socioeconomic status can influence how climate change exacerbates, ameliorates, or introduces new health issues (*very high confidence*). Climate change is already impacting health in the region (*very likely*, *very high confidence*). There are effective strategies to address the health impacts of climate change in the Southeast that have multiple benefits across social and environmental contexts (*high confidence*).

Underlying Health Issues and History in the Southeast

Public health status is an important indicator of vulnerability to climate stressors,[190,195] and Southeasterners are consistently ranked among the unhealthiest in the Nation, with shorter life expectancies than the US average (Figure 22.8).[196] Health disparities in the Southeast are related to various social determinants of health, such as lack of access to healthcare, low socioeconomic status, and poor health behaviors (e.g., smoking and drug and alcohol abuse).[197] Sedentary lifestyles are reinforced by the quality of the surrounding built environment: the Southeast is home to 8 of the 10 least-walkable cities,[198] 15 of the 20 most dangerous cities for pedestrians,[199] and 4 of the top 10 deadliest states for cyclists in the United States.[200]

Present-Day Health Inequities



Present-day health inequities in the Southeast exacerbate climate-related risks.

Figure 22.8. (**left**) Southeastern states rank among the lowest in the Nation for life expectancy, although there is considerable variation within the region and within individual states. These patterns in life expectancy are reflected in estimates of social vulnerability (**right**)—a measure of how societal stressors like poverty, crowded housing, older populations, and lack of access to transportation may diminish a community's ability to avoid human distress and financial damages in a disaster like those made worse by climate change. Figure credits: (left) Groundwork USA, NOAA NCEI, and CISESS NC; life expectancy data from University of Wisconsin Population Health Institute, County Health Rankings & Roadmaps 2022, www.countyhealthrankings.org; (right) Science Museum of Virginia, NOAA NCEI, and CISESS NC.

The Southeast has more Black residents than any other NCA region,[40] and health-related challenges faced by communities with majority Black populations differ from those with majority White, Hispanic, or Asian populations.[201] Communities with majority Black populations tend to have even lower life expectancies and less access to resources that promote health, such as grocery stores, safe places to exercise, and quality healthcare than whiter and wealthier populations.[202] These communities also have fewer opportunities for economic prosperity (Figure 22.12), fewer employment opportunities, limited access to quality education, and higher unemployment rates, all of which shape health outcomes.[11] Black communities in the Southeast, therefore, shoulder a disproportionate level of health risk associated with climate change.[3,12]

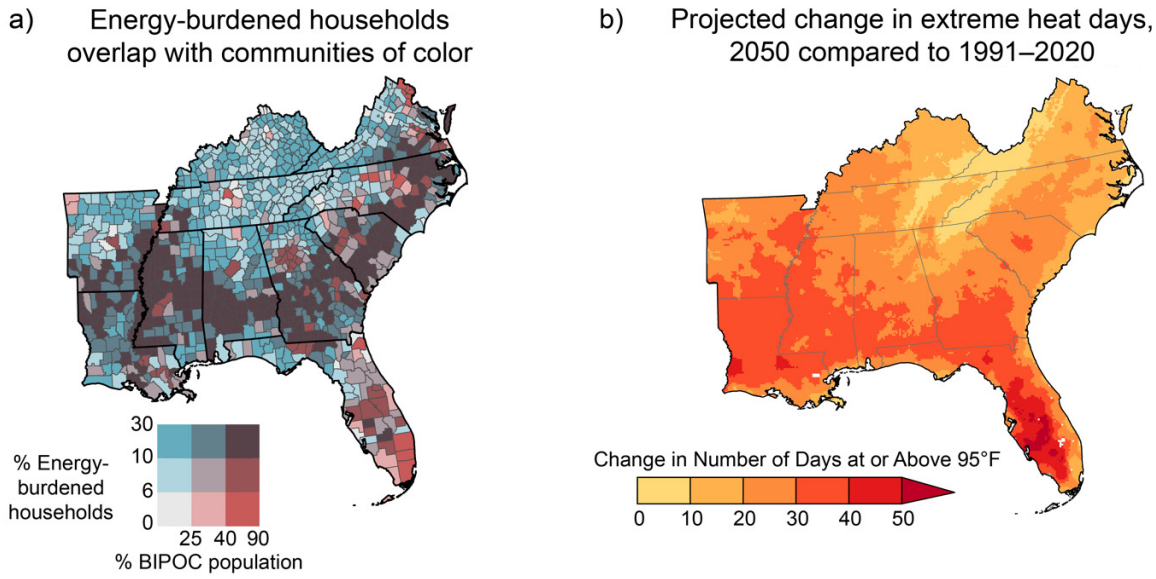
Keeping Cool as Temperatures Rise

Extreme heat affects everyone, but particularly at risk are pregnant people;[203,204,205] people with heart and lung conditions;[206,207] older adults and young children;[208,209] people with mental health conditions;[210,211] outdoor workers in construction, agriculture, and the service industry;[212,213] athletes;[214,215,216] and populations who lack adequate shelter or are incarcerated.[217,218]

Southeasterners rely on air-conditioning to cool living spaces, and air-conditioning demand is expected to grow across the Southeast as the climate warms.[219] However, air-conditioning prevalence varies along racial and economic lines.[220] Furthermore, the Southeast has high rates of households that experience energy insecurity.[221] While the Southeast has the lowest energy rates in the US, households there pay the country's highest energy bills.[222] High energy bills disproportionately impact rural and under-resourced residents, elderly residents on fixed incomes, and communities of color (Figure 22.9).[222] Historical *de facto* as well as

de jure segregation policies such as redlining—the New Deal–era practice of classifying communities with significant Black, Asian, and immigrant populations as hazardous for financial investment—neighborhood housing covenants, and urban renewal have had lingering effects on frontline communities in the Southeast, resulting in their low proportion of homes that are energy efficient and affordable.[222] There is evidence that the number of blackout events (power outages) affecting more than 1,000 residents for more than one hour due to increasing energy demands and extreme weather events is increasing.[223,224,225] The Southeast has experienced many such blackout events annually and during the warm season (May–September) since 2011 (Figure 22.10).[226]

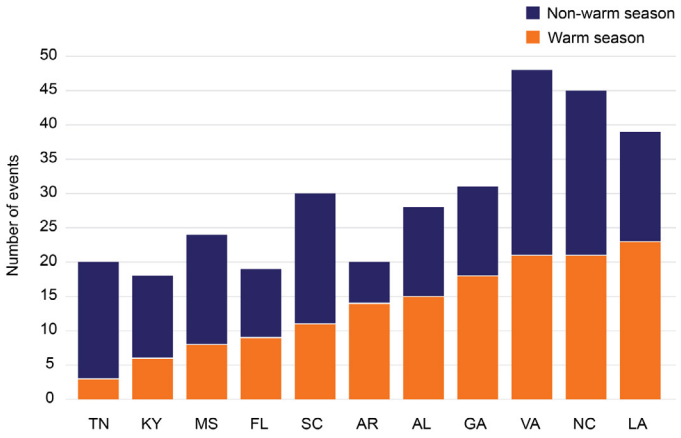
Inequitable Heat Burden and Future Heat Exposure



Projected increases in heat extremes disproportionately affect communities of color and other energy-burdened groups.

Figure 22.9. Present-day inequities will be amplified by the increased threat of extreme heat in the future. Panel (**a**) shows overlap between the percentage of the population that is BIPOC (Black, Indigenous, and People of Color) and the percentage of low- and moderate-income households with a high energy burden, or households that spend a disproportionately high amount of money on energy costs relative to their income. The dark purple areas show high overlaps between BIPOC households and high energy burden. Panel (**b**) shows the projected increase in the number of extreme heat days (maximum temperature at or above 95°F) in 2050 relative to 1991–2020 under a high scenario (SSP3-7.0). Figure credits: (a) adapted from Bryan 2020;[227] (b) NOAA NCEI and CISESS NC.

Blackouts Affecting More than 1,000 Residents for More Than 1 Hour (2011–2021)



Warm-season blackouts add to heat-related risks for residents in Southeast.

Figure 22.10. For several Southeast states, major blackout events occur most often during the warm season (May–September). Major blackouts during the warm season generally occur during heatwaves, placing people at higher risk of heat exposure and heat-related illness because they do not have access to air-conditioning. The figure shows reported major blackout events—defined as electrical grid failures affecting more than 1,000 residents for more than 1 hour—in Southeast states during 2011–2021. Data are presented as warm season (orange, May through September) and non-warm season (blue, October through April). Figure credit: Georgia Institute of Technology, Groundwork USA, CDC, NOAA NCEI, and CISESS NC.

Public cooling centers are temporary health interventions for those without adequate air-conditioned shelter on exceptionally hot days (KM 15.3). However, in some areas of the Southeast, these centers are not located within walking distance of the populations most in need.[228] Furthermore, the Southeast has the lowest public transportation access for households without a private vehicle.[229]

Heatwaves in the Southeast are happening more frequently and are occurring during a longer heat season, with some cities also showing increasing trends in their duration and intensity (Ch. 2).[3,230,231] The number of extreme warm days (above 95°F) is expected to continue increasing with every increment of global warming (Figure 22.9b; Ch. 2). Wet-bulb globe temperature (WBGT)—which measures the combined effects of temperature, humidity, wind, and sunlight on thermal comfort and which may be a better metric for the Southeast than more traditional measures of extreme heat[232,233]—has already increased due to anthropogenic climate change in parts of the region[234,235] and is expected to increase across the region throughout this century.[230,235] Additional heat stress within cities can be attributed to the urban heat island effect (Figure A4.4), whereby cities experience warmer temperatures than outlying rural areas and some neighborhoods within a city are hotter than others.[236,237] Heat island intensities across the Southeast are systematically higher in formerly redlined communities[5] and in counties with higher proportions of Black, Hispanic, and Asian residents, people with education no higher than a high school diploma, people with lower median incomes, and single-parent households.[238] However, there is a lack of consistent and appropriate thresholds used to evaluate heat risk. For example, most work-related heat illnesses across five Southeast states occurred below the heat index range designated as dangerous by the National Weather Service.[239]

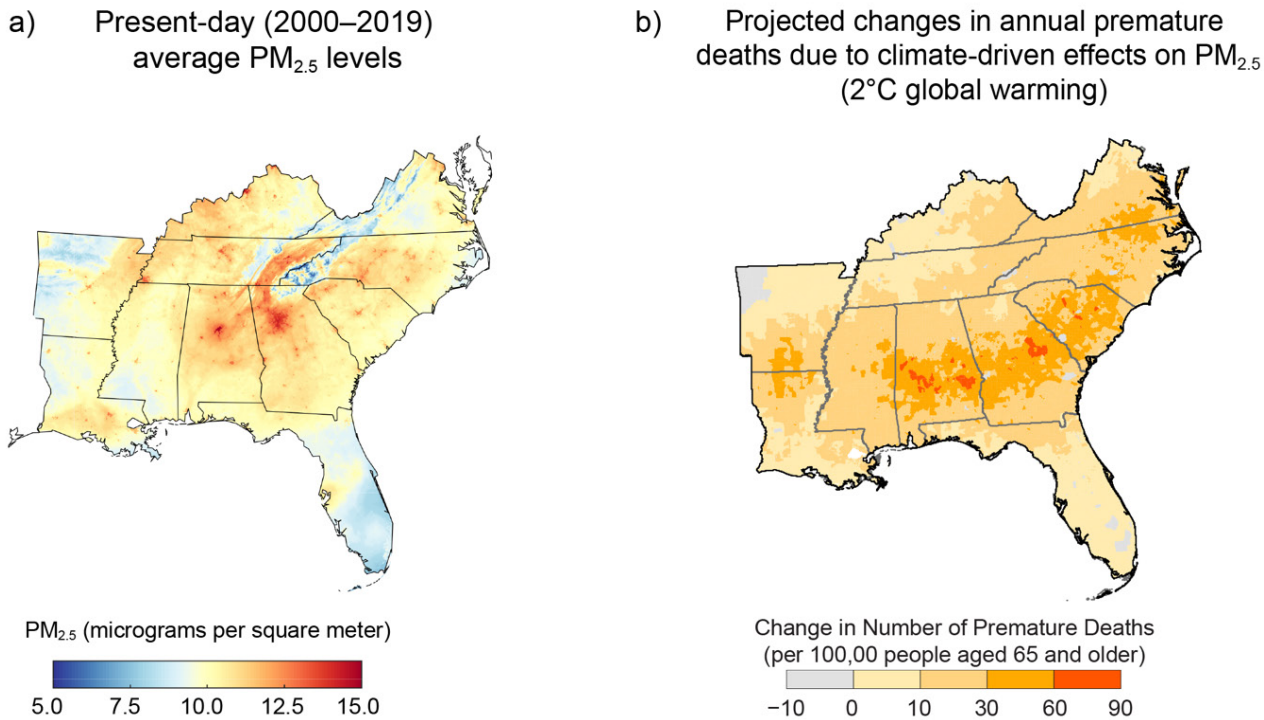
Climate change is increasing the risk of multiple dangerous weather events occurring simultaneously or in close proximity, resulting in worsened health effects (Ch. 15). An example of this is when a heatwave occurred after Hurricane Laura devastated the coast of Louisiana in 2020, resulting in at least eight deaths due to heat and an increased risk of heat-related illness, particularly for those who lost electricity and outdoor workers assisting with the recovery.[240]

In response to heat threats, Miami has institutionalized the first city heat officer to coordinate heat preparedness and response efforts to reduce impacts to the most vulnerable.

Blowing in the Wind

In the Southeast, climate change threatens Clean Air Act improvements by creating favorable conditions for increases in smog[241,242,243] and wildland fire emissions.[244,245,246] The Southeast already has significant amounts of particulate matter ($PM_{2.5}$; Figure 22.11a) as a result of anthropogenic pollutants[247] and extensive vegetation,[248] and the associated health effects are experienced disproportionately by communities of color and populations with lower socioeconomic status (Ch. 14).[249,250] Future premature deaths due to $PM_{2.5}$ in the region could be avoided through significant emissions reductions, even when considering future warming (Figure 22.11b; KM 14.3).[3,251,252] This is particularly relevant to the Southeast, which is projected to have the highest number of premature deaths due to climate-induced increases in $PM_{2.5}$ and ozone exposure.[3,251,252]

Current $PM_{2.5}$ Levels and Projected Change in Deaths Due to $PM_{2.5}$ at 2°C of Global Warming



Rising levels of air pollution from a warming climate pose profound threats to human health.

Figure 22.11. (**a**) Present-day (2000–2019) patterns of particulate matter ($PM_{2.5}$) pollution in the air are associated with excess mortality. (**b**) Potential future patterns (projected changes at 2°C of global warming relative to the 1986–2005 average) of premature deaths in people aged 65 and older due to $PM_{2.5}$ show that even when accounting for reduced particulate emissions in the future due to developments such as vehicle electrification, the Southeast is particularly sensitive to increases in $PM_{2.5}$ from increased temperature alone. (a) Adapted from van Donkelaar et al. 2019.[247] (This is an unofficial adaptation of an article that appeared in an ACS publication. ACS has not endorsed the content of this adaptation or the context of its use.) (b) Adapted from EPA 2021.[3]

In addition, airborne pollen can pose significant health risks to populations living in the southeastern United States.[253] Since 1992 in Atlanta, tree pollen concentrations have increased by approximately 4% in the spring and 10% in the fall, and weed pollen has increased by approximately 5% in the spring.[254] Some species of trees and weeds are exhibiting an earlier and longer pollen season, correlating with warmer spring temperatures.[254] Pollen increases pose significant health risks, including aggravating respiratory conditions such as

asthma, which has been linked to a loss of school and work days (KM 14.4). These health risks are expected to worsen as pollen seasons shift earlier and lengthen due to climate change (KM 14.4; Figure 8.2).

Fire Danger

Wildfire risk disproportionately disrupts the lives of socioeconomically disadvantaged communities in the Southeast.[2] As more people inhabit forested areas, there is an attendant increase in wildfire risks to human health and property.[255] More hot days may also exacerbate soil moisture deficits, leading to heightened wildfire risk in the region.[244,256] Rural, mountainous portions of the Southeast are more exposed to and less equipped for mitigating wildfire.[257]

Forest managers conduct controlled, low-intensity fires, known as prescribed burns, to reduce the amount of deadwood and vegetation, thereby managing wildfire risk.[258] While the impacts of wildfires on air quality are widely recognized (KM 14.2), less is known about the impacts of prescribed burns versus wildfires on air quality.[246,259] Prescribed burns reduce the risk of wildfire damage to the environment, homes, and infrastructure, although areas with intensive prescribed burning tend to be near communities with higher social vulnerability scores, which subsequently experience more negative health outcomes from the smoke.[260,261] As conditions favorable for wildfire and unfavorable for prevention become a greater risk for southeastern communities due to a warming and drying climate,[256,262] communities may need to invest in more robust equipment and infrastructure. In 2016, wildfires in western North Carolina and eastern Tennessee highlighted the connection between exceptional drought and fire in the Appalachians.[263] Power outages and damage to PVC pipelines that supplied water to sprinkler systems led to a lack of water to combat fires, resulting in more significant damages.[264,265] That year, nearly 50% of US wildfires occurred in the Southeast, yet these fires contributed to only 29% of the total area burned that year, indicating that southeastern wildfires are smaller.[244,246,258]

Rolling Red Tides

Harmful algal blooms (HABs), also known as red tides or brown tides, occur in fresh, brackish, and salt water.[266] HABs result from the overgrowth of algae due to runoff water containing excess nutrients from agriculture and lawn maintenance, rising water temperatures, and other land-use development.[267] Since 2011, large masses of sargassum, which can fall under a HAB classification, have been increasing from Florida across the Caribbean, causing harm to coastal social–ecological systems. This problem could be intensified by rising temperatures from climate change.[268,269] HABs have significant negative impacts on human and animal health, as well as broad-reaching environmental and economic effects.[270,271,272,273]

Humans may experience various health issues from HAB exposure, such as diarrhea and headache.[273] HAB events also threaten national and local economies, as tourist areas become less desirable to visit.[271] Fisheries and aquaculture industries suffer from the loss of marine life and decreased species diversity as ecosystems are disrupted and hypoxic conditions occur,[274,275,276] and consumers are potentially exposed to seafood poisoning.[277,278] On Florida's Gulf Coast, prolonged algal events have caused a devaluation of coastal properties.[270,272]

More Than Just a Bug Bite

Temperature and precipitation changes are anticipated to shift the geographic distribution and season of certain disease-carrying mosquitoes and ticks in the Southeast (KMs 15.1, 8.2). For ticks that carry diseases such as Lyme and Rocky Mountain spotted fever, models project varying shifts in ecosystem suitability in the Southeast depending on the species, land-use changes, and host abundance.[279,280,281,282,283] Of particular concern are mosquito-borne diseases such as chikungunya, dengue, malaria, West Nile virus, and Zika virus. All have been documented in the Southeast and pose potential risks to human health.[284] Black and under-re-

sourced neighborhoods in Chatham County, Georgia, were identified as hotspots for West Nile virus, as well as being home to communities with limited understanding of personal risk and protective measures against mosquitoes.[285,286]

The Mind–Climate Connection

The Southeast is home to 5 out of the 10 highest-ranked states for the prevalence of mental illness[287] and 8 out of the 10 lowest-ranked states for access to mental healthcare services.[288]

Climate change significantly affects mental health as a result of 1) acute disaster events such as hurricanes, floods, and wildfires (KM 15.1); 2) long-term changes such as drought[289] and heat stress;[210] and 3) existential threats of long-lasting climate change impacts that make people feel less secure in their physical environment.[290] Those who are either directly impacted by or concerned about the threat of climate change to themselves or others may experience "eco-anxiety" or "climate anxiety."[291,292]

While extreme weather events commonly occur in the Southeast, climate change has increased their frequency and magnitude (Ch. 2), causing residents to face repeated trauma and displacement at an unprecedented level, which can lead to stress and the onset of new psychiatric disorders or the worsening of preexisting mental health conditions,[293] especially among children and under-resourced and BIPOC residents.[290,294,295] The Florida Department of Health in Monroe County conducted an evaluation of its emergency shelter effectiveness in serving people with particular access and functional needs and found significant room for improvement, leading to updates to strategic planning processes and procedures related to the operation and communication of specialty emergency shelters to ensure more equitable access to shelter services.

Key Message 22.3

Climate Change Disproportionately Damages Southeastern Jobs, Households, and Economic Security

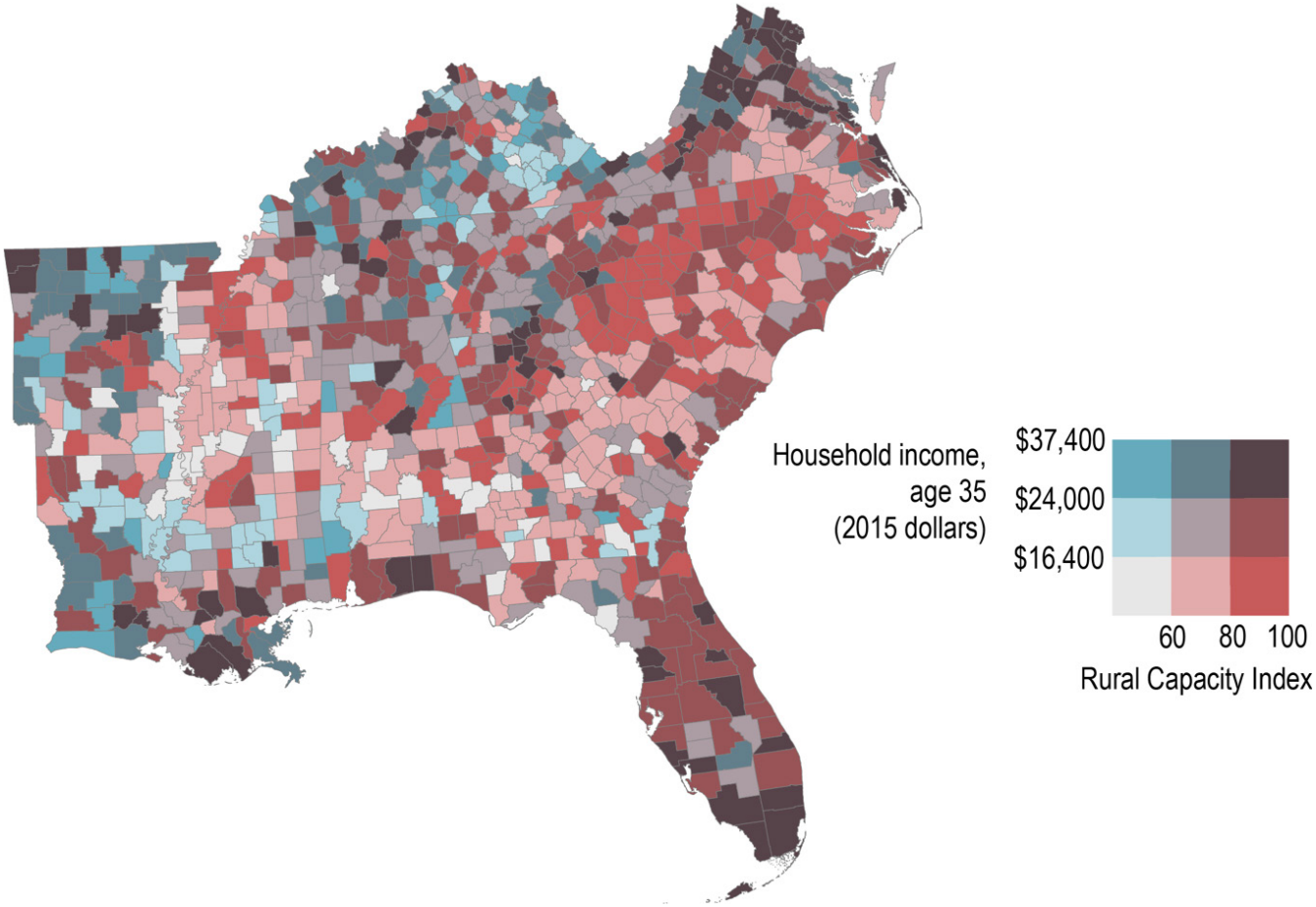
Over the last few decades, economic growth in the Southeast has been concentrated in and around urban centers (*high confidence*) that depend on climate-sensitive infrastructure and regional connections to thrive (*medium confidence*). Simultaneously, rural and place-based economies that rely on the region's ecosystems are particularly at risk from current and future climate changes (*very likely*, *high confidence*). Global warming is expected to worsen climate-related impacts on economic systems, labor, and regional supply chains in the Southeast, with disproportionate effects on frontline communities (*very likely*, *high confidence*). A coordinated approach that recognizes present-day inequities and the interdependencies between rural and urban communities will be necessary to secure the region's economic vitality (*very likely*, *high confidence*).

Economic Risks in the Southeast: "Less Money, More Problems"

Across the Southeast, disaster losses have increased over the last several decades, primarily due to rapid growth in hazardous areas that are driven, in part, by national, state, and local policies that incentivize development in such areas.[166,296,297] Rising disaster costs negatively impact local and regional economies, some of which are already affected by limited upward economic mobility for their population, as well as by limited administrative, institutional, and social capacity (Figure 22.12). Moreover, these multisectoral impacts

are expected to worsen substantially due to climate change,[298] especially in the Southeast region (Figures 22.13, 22.14, 19.1; KM 19.1).

Household Income and Rural Capacity for Action

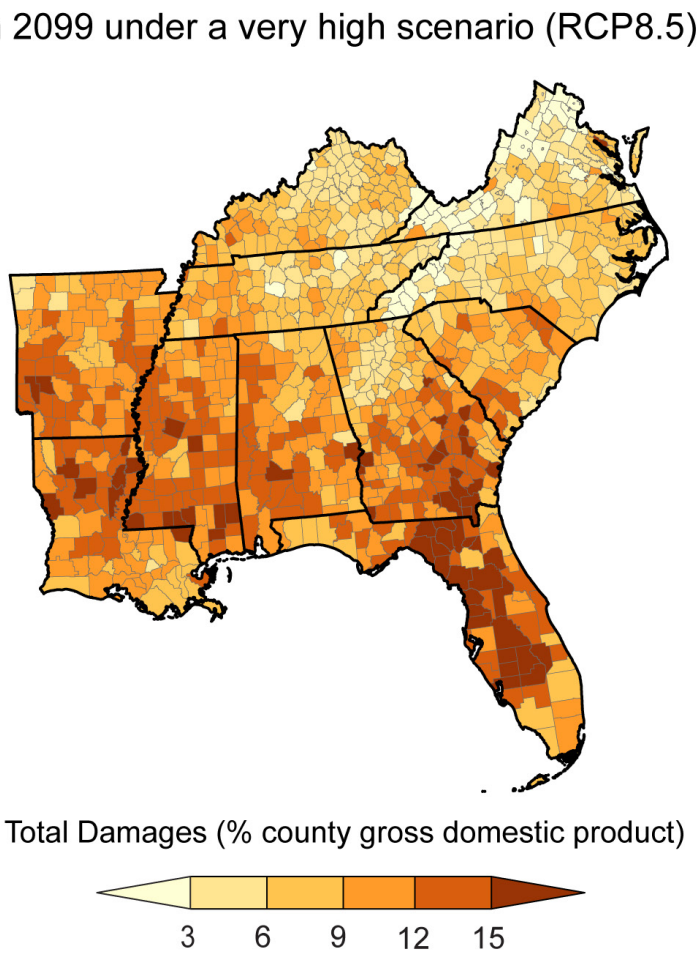


Counties where low-income households overlap with limited community capacity (shown in light gray) highlight rural climate risk challenges.

Figure 22.12. In the Southeast, children born to parents who make the lowest incomes also tend to earn low incomes as adults (blue hues), especially within frontline communities. These pockets of limited generational upward mobility may also overlap with lower scores on the Rural Capacity Index (red hues), as measured by under-resourced governance structures and limited public participation in civic processes like voting.[64] This lack of resources may leave these communities more at risk from damage due to climate change. Figure credit: EPA, Groundwork USA, NOAA NCEI, and CISESS NC.

Losses attributed to climate change are expected to increase as rapid development continues to occur in hazardous areas, particularly along coasts (Figure 22.4b),[299] while rural residents face increasing levels of isolation and economic decline (Figure 22.12).[62]

Projected Annual Economic Damages from Unmitigated Climate Change



The Southeast region faces substantial economic risks from climate change impacts.

Figure 22.13. Direct annual climate damages, as measured by the percent of county GDP, are projected to be especially large in the Southeast. The map shows damages under a very high scenario (RCP8.5) at the end of the century. Adapted from Hsiang et al. 2017.[300]

Regional Impacts of Extreme Weather Events

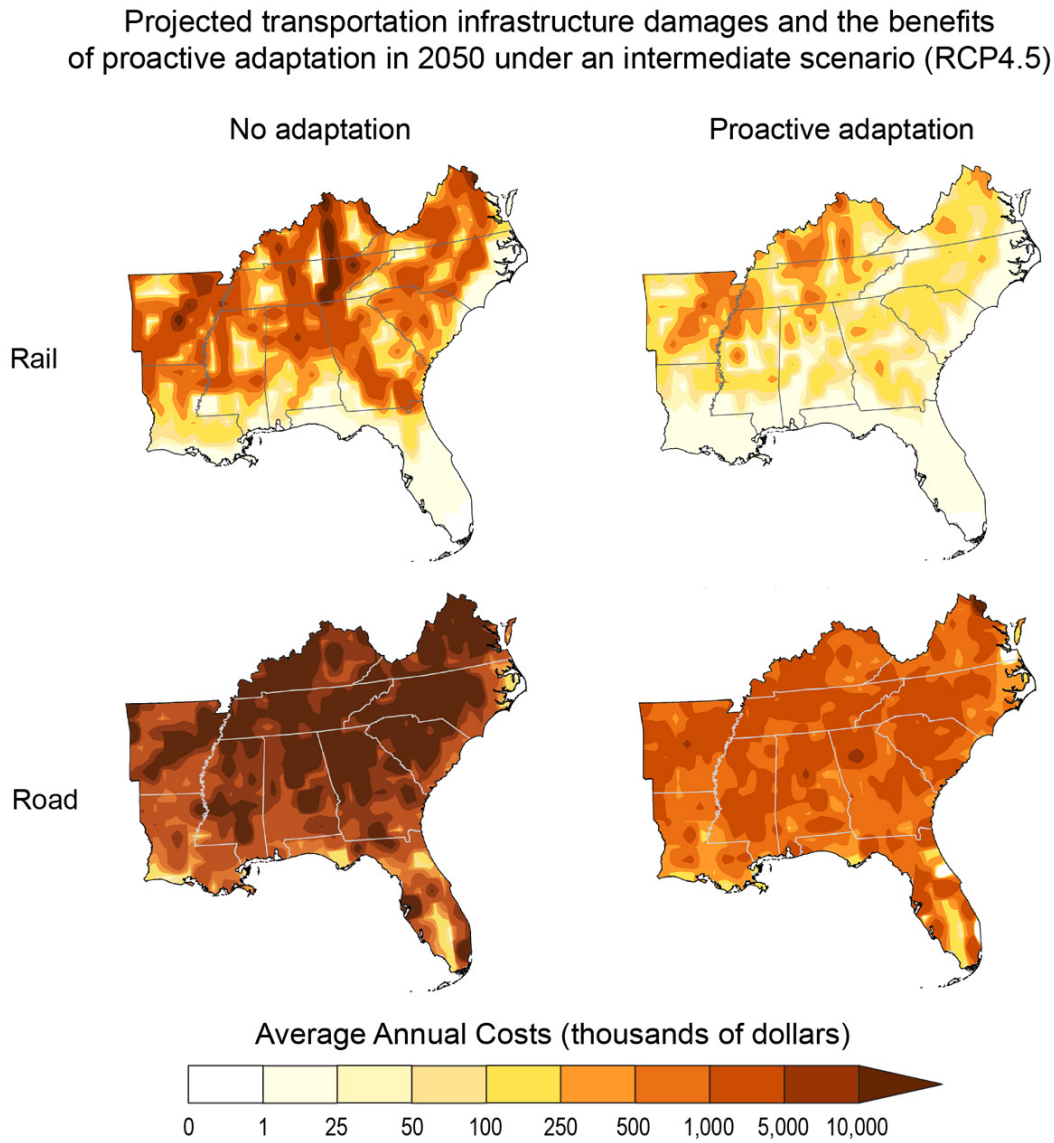
The Southeast is impacted by a wide variety of extreme weather events.

Figure 22.14. The impacts of weather and climate extremes can be seen in photos from the Southeast (**clockwise from top left**): A flooded neighborhood in Kissimmee, Florida, is shown after Hurricane Ian (2022), which heavily impacted local livelihoods. Drought conditions in Alabama (2016) directly impacted farmers' incomes and potentially increased prices for customers. Regional drought-induced low-flow conditions on the Mississippi River caused barges and towboats to become stranded for several days (2022). Flood damage in northeast Arkansas impacted transportation infrastructure and crops and may have impacted supply chains (2017). Image credits: (top left) Robert Kaufmann/FEMA, DHS; (top right) Bruce Dupree, Alabama Extension [CC0 1.0]; (bottom left) Sonny Perdue, USDA; (bottom right) adapted from NASA Earth Observatory.

Place-based economies that are located in hazardous areas and are reliant on unique ecological systems (e.g., aquaculture, farming, and recreation/tourism) face numerous challenges, including the uncertainties associated with the stability of freshwater and saltwater ecosystem services that support business and cultural attachment to place.[301] For example, some fishing communities are facing threats to fishing infrastructure due to sea level rise and more intense coastal storms, as well as threats to fisheries stock habitats that are vulnerable to the effects of a changing climate, such as increasing bottom-water temperatures.[142,302,303] Meanwhile, inland towns and cities with ecotourism attractions also face significant economic losses due to increased flash flooding,[73,108] including lower-income rural areas in Appalachia, as exemplified by the 2022 floods in eastern Kentucky. Rapidly growing urban centers in the Southeast are increasingly vulnerable to drought and the challenges tied to the provision of water for residents and businesses.[304,305,306,307] The Southeast is more drought-prone than other parts of the eastern US due to higher rates of evapotranspiration.[308,309] Evapotranspiration is expected to increase due to future climate warming (Ch. 2). Alabama cities' drought plans were evaluated as less comprehensive and lacking pre-drought preparation compared to those of California cities.[152] In rural, agriculturally dependent economies, increased heat, drought, and water-laden tropical storms currently threaten the productivity of crops and livestock (KM 22.4),[310,311] as well as the health and livelihoods of workers, who tend to be Latino migrants.[312] Future global warming will increase this threat, potentially further reducing labor productivity and costing billions

of dollars, particularly in the already hot and humid Southeast (KM 2.2).[212,313] The Southeast's economy relies on the region's ports, rivers, rail, air, and road networks, which are at risk from sea level rise, flooding, extreme heat, drought, and other climate-related hazards.[61,314] However, proactive adaptation can offset potential future climate-related damages substantially (Figures 22.13, 22.15, 22.17). Unplanned disruptions to these systems can potentially affect consumer pricing of goods, services, and livelihoods throughout the region and elsewhere (Figure 22.16).[315,316]

Proactive Adaptation Offsets Future Transportation Infrastructure Costs



Proactive adaptation to climate change could save millions of dollars in future transportation infrastructure costs.

Figure 22.15. Future climate change impacts (under RCP4.5) may cost US transportation infrastructure billions in damages by 2050, with especially high costs in the Southeast. The **left panels** show the additional annual average system costs (as compared to 1986–2005 in 2018 dollars) to rail infrastructure (**top**) and road networks (**bottom**) in 2050, assuming no adaptation. Proactive adaptation—anticipating climate risks and investing up front in strengthening these systems before damage occurs—could reduce significantly, but not eliminate, these costs (**right panels**). Proactive adaptation strategies include temperature sensors for railroad tracks and working to reduce disruption times for roads undergoing repairs. Adapted from Neumann et al. 2021[317] [CC BY 4.0].

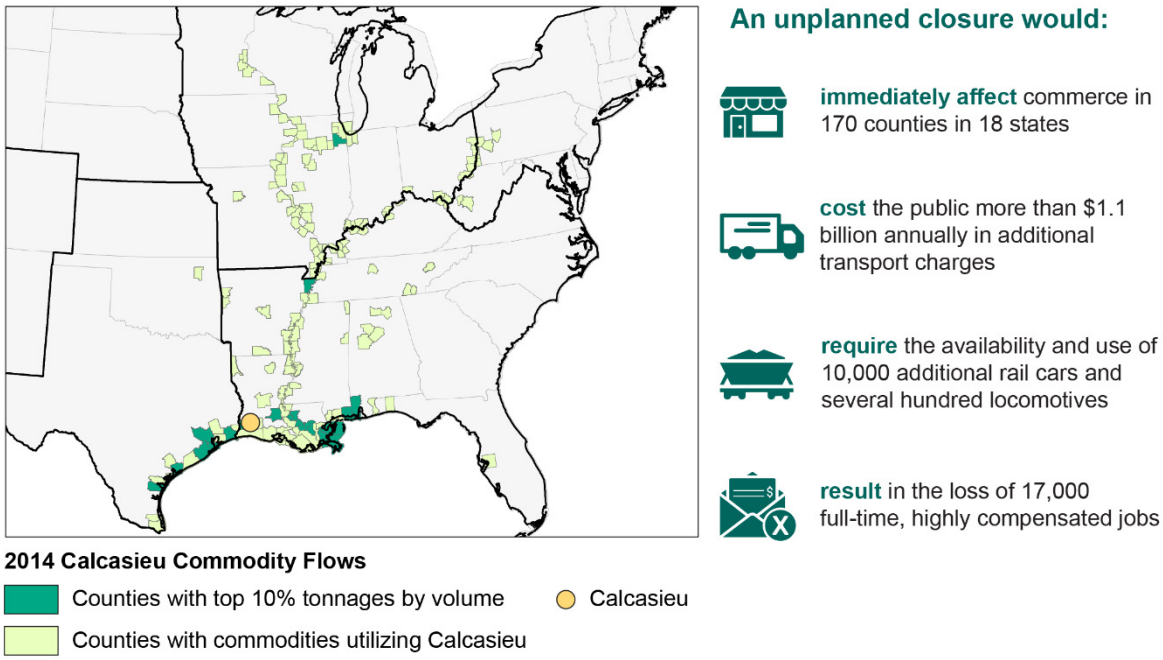
Supply Chain Impacts Affect Places Outside the Southeast

There is an urgent need to address climate change risks to global supply chains (Focus on Risks to Supply Chains; KM 19.1).[318] In the Southeast, climate change–induced transportation infrastructure risks affect all modes (e.g., air, water, highway, rail, and even pipelines; Figures 22.15, 22.16; Ch. 13). Transportation agencies across the region appear to be planning for infrastructure improvements on different schedules and often lack the capacity to include climate data in the planning process (Ch. 13).[319] Coordinated and proactive adaptation strategies could offset significant future damage to these systems (Figures 22.15, 22.17).[317,320,321]

Many Southeast roadways and rail lines are located along waterways and frequently cross bodies of water, making them vulnerable to potential floods and heat-related impacts. High future costs are expected if no adaptive investments are made today (Figures 22.15, 22.17).[317] Inland navigation and the Mississippi River are critical to supply chains in the Southeast and much of the central portion of the United States, as evidenced by the 2021 closure of the Interstate 40 bridge over the Mississippi River at Memphis, Tennessee.[322] Unscheduled lock outages resulting from floods, droughts, earthquakes, or hurricanes can cause cascading impacts. For example, an unplanned outage of the Calcasieu Lock in southern Louisiana would affect economies in 170 counties and 18 states (Figure 22.16).[315,323] In the Southeast, manufacturing facilities for industries such as automotive (including electric vehicles and charging stations),[324] solar panels, agriculture,[325] and construction often rely on parts or materials originating from other locations, including some from international sources. The Mississippi River serves as a gateway to the Nation for imports of such materials and exports of goods such as agricultural products. In recent years, low-flow conditions due to regional droughts on Southeast waterways such as the Mississippi have halted or delayed the movement of barges carrying bulk goods, with regional and national implications (Figures 22.14, 22.16).[326,327]

Disruptions can impact not only the delivery of finished goods and products to customers but also production and the livelihoods of individuals working in jobs dependent on materials from other locations that may not arrive in time, leading to revenue loss and even potential job loss if disruptions become regular and significant enough. The impacts of climate change on supply chains include not only disruption to systems and additional costs associated with the transportation of goods but also potential health impacts to workers in industries that require working outdoors, such as agriculture,[325] fisheries, construction, and last-mile delivery,[328,329] who may be exposed to extreme heat or cold. Workers in these jobs may require additional heating or cooling or adjustments in shift times to avoid exposure to adverse weather conditions (KM 22.2; Ch. 19).[330]

Expected Impacts of an Unplanned Calcasieu Navigation Lock Closure

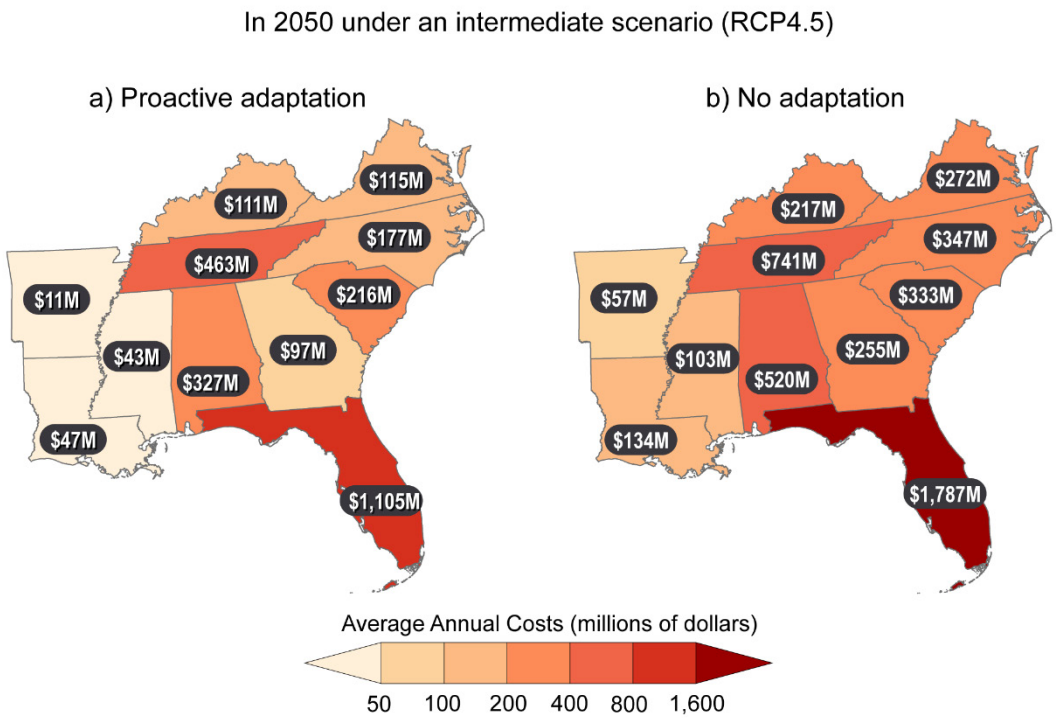


An unplanned closure of the Calcasieu Navigation Lock would have impacts that extend well beyond the Southeast.

Figure 22.16. The commodity flow impacts associated with an unplanned shutdown of Calcasieu Lock extend well outside the Southeast, affecting 170 counties across 18 states. Weather and climate extremes such as regional drought and low-flow conditions on the Mississippi River can result in unplanned shutdowns of the Calcasieu Lock. Adapted with permission from Burton et al. 2017.[315]

Furthermore, the Southeast is a hub of activity for oil refineries that provide fuel to the eastern half of the United States.[331] Climate change is expected to negatively impact not only refineries that are located along the Gulf Coast but also the distribution networks of the petroleum products that many rely on for emergency services, backup power generation, air travel, and more.[60,332,333]

Projected Annual Energy Infrastructure Costs



Proactively investing in strengthening our electrical infrastructure offsets significant future costs due to climate change damage.

Figure 22.17. The Southeast faces some of the highest economic risks related to energy infrastructure damage without proactive adaptation measures in place—such as energy utilities and policymakers' anticipating climate risks to electrical grid infrastructure and investing upfront in strengthening these systems in advance of any damages. As shown in the maps, in 2050 under an intermediate scenario (RCP4.5), proactive adaptation (**a**) could save as much as twice the total costs (in 2017 dollars) of no adaptation (**b**). These costs could be passed onto consumers. Adapted from Fant et al. 2020[320] [CC BY 4.0].

Securing Economic Vitality

Protecting businesses and urban and rural infrastructure investments may require adopting a combination of adaptation measures (KM 22.1). However, to avoid unintended disparities in service provision, these infrastructure investments should consider the needs of frontline communities in their design criteria.[334] For instance, Charleston, South Carolina, has explored questions surrounding the appropriate selection of adaptation measures, including protection techniques such as a seawall versus a greater reliance on nature-based solutions.

Justly transitioning to a low-carbon economy provides opportunities for businesses[335] as well as labor,[336] assuming that marginalized populations and women are included in this workforce to avoid the inequities of our current energy labor markets.[337] Business and governmental agencies could commit to workforce programs for employees in the oil, gas, and coal-producing industries,[336,338] as workforce training in green technology must address challenges associated with transitioning away from economies that are closely tied to a community's way of life.[339,340] Additionally, ecosystem restoration and nature-based green infrastructure solutions (e.g., urban forestry, stormwater retention gardens, green roofs) may also provide meaningful job opportunities (Ch. 19).[341] Key to adapting to climate change and leveraging new opportunities is the need for training and workforce development, which will require investment and prioritization (Ch. 19).

Key Message 22.4

Agriculture Faces Growing Threats, but Innovations Offer Help

Changes in temperature, drought, extreme rainfall, and sea levels are already threatening the Southeast's agriculture and other food-related systems (*likely*, *very high confidence*). Moreover, these climate-related hazards are expected to worsen with every increment of global warming, disproportionately harm farmers and small-scale operations, and increase the competition between urban and rural communities for valuable resources such as water and land (*high confidence*, *very likely*). However, innovative agricultural techniques such as precision farming show promise for adapting to future climate changes in the region (*likely*, *high confidence*).

Agriculture is critical to the economy of the Southeast through its production of food and fiber and employment. In the United States as a whole, agriculture, food, and related industries contributed $1.26 trillion (in 2022 dollars; a 5.2% share) to the gross domestic product in 2019.[342] In the Southeast, nearly 500,000 farms produced market sales of more than $83.8 billion (in 2022 dollars),[343] and the region's agricultural products are consumed locally and exported throughout the United States and the world.[344] Food systems distribute agricultural products throughout the region, although food deserts are present in urban and rural areas.[345] Disparities in food distribution are especially pronounced in areas with concentrations of Black, Indigenous, and under-resourced communities.[345]

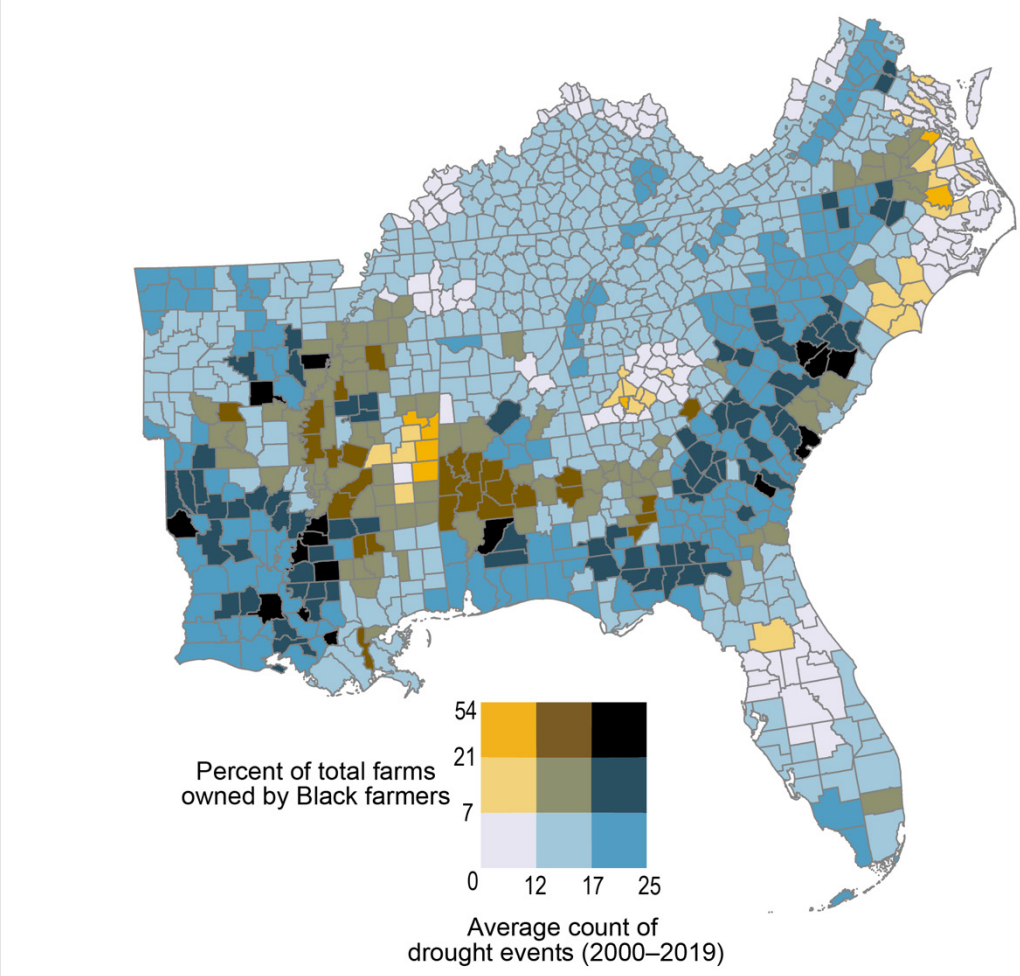
Climate Stressors on Agriculture and Food Systems

Climate change stresses agriculture and food systems (Ch. 11). Threats from a changing climate include both direct threats through impacts of climate extremes on crops, forests, ecosystems, and livestock and indirect threats through impediments to transportation, the health of outdoor workers and animals, degradation and loss of natural ecosystems, reduced productivity and loss of traditional crops, increased threats from invasive species and weeds, and loss of livelihood for vulnerable communities such as rural BIPOC farmers. For example, increased average and extreme high temperatures[346] have led to increased heat stress on livestock[325,347] and outdoor workers. Warmer winter temperatures have reduced the number of chill hours (the total number of hours a plant experiences temperatures below 45°F over the winter months), which are essential for fruit production,[348] and have caused unusually early blooming of crops such as peaches and blueberries, which makes them vulnerable to damaging frost events. In spite of warmer winters, however, the change in the average date of the last spring frost is not consistent across the region.[349]

Higher temperatures, particularly overnight temperatures, have reduced crop yields,[350] and these impacts are projected to worsen with additional global warming (Figure 22.19; Ch. 11). They have also led to an increase in the occurrence of drought in the region (Figure 22.18).[351,352,353] The Southeast is the only region in the eastern half of the United States that is prone to extreme drought,[308] and flash droughts occur with higher frequency there than in any other region.[354] Longer-term droughts in the Southeast appear to be increasing in severity but do not appear to be occurring more frequently.[355] Changes in climate conditions have also contributed to increased pressure by invasive species that have resulted in crop yield losses and damaged productive natural ecosystems.[356,357] Increases in the frequency of heavy rain events[358] and lengthening of dry spells between rain events at some locations in the region[359,360,361] make water resources unpredictable. Hurricanes and tropical storm winds, as well as increasing accumulated rainfall in coastal areas, pose unique threats to agriculture.[92,362] For example, following Hurricane Florence, swine feces markers were detected in surface waters in North Carolina, suggesting that management practices should be examined in areas at risk of increased extreme precipitation.[363] Rising sea levels have increased saltwater intrusion in coastal aquifers, reducing the extent of available forests and farmland[130,131] and threatening

seafood harvesting in estuaries by altering the salinity and turbidity in freshwater streams and marine nurseries.[364] Extreme weather and coastal stressors have also disrupted food distribution by closing ports and highways,[365,366,367] reduced the catch of fish, and diminished crop production.[140]

Droughts and Black Farmers in the Southeast



The Southeast's Black farmers face disproportionate weather and climate risks.

Figure 22.18. In the Southeast, areas with a higher number of drought events from 2000 through 2019 often overlapped with counties that are home to relatively higher proportions of Black producers, as identified in the 2017 USDA Census of Agriculture. The Southeast has the highest proportion of Black producers when compared to any other National Climate Assessment region, highlighting how disparities in climate risks require innovation and equitable adaptation, especially for those producers who have smaller operations and fewer resources to adopt new technologies. Figure credit: Groundwork USA, University of Georgia, NOAA NCEI, and CISESS NC.

Disproportionate Impacts on Under-Resourced Communities

Climate stressors such as drought have a disproportionate impact on small-scale, Black, Indigenous, and economically disadvantaged farmers, who are more concentrated in the Southeast compared to other NCA regions (Figure 22.18).[368,369,370] These groups are under-resourced, making adaptation to climate change more difficult.[371] Knowledge gaps in best practices for small-farm management complicate information-sharing among communities across the region. Access to broadband in rural areas may limit producers' ability to monitor their fields and make appropriate management decisions.[372,373] Small-farm owners also have limited financial resources, which means they have less ability to invest in necessary farm equipment, insurance,

and other risk-reduction methods such as irrigation that could mitigate climate stress and reduce farmland value losses.[374,375] Small-scale farmers and those with limited resources may find targeted USDA programs as well as innovative techniques such as organic farming and agroforestry to be well-suited to use on their smaller farms in the future.[376,377]

Competition for Resources

Southeastern agriculture and food systems are further stressed by land, water, and resource competition between urban and rural areas.[378] Competition is highlighted by decades of lawsuits in the Southeast involving the appropriate distribution of water resources among municipal water users in large cities, agricultural producers using irrigation to protect against drought, and coastal fisheries that rely on balanced salinity levels to maintain the health of estuarine systems.[379] Sprawl is expanding into farmland, reducing the land available for food production and increasing the area affected by urban heat islands.[380] Similarly, native forests have been developed or replaced by commercial forests, which may lack biodiversity and ecosystem resilience.[381]

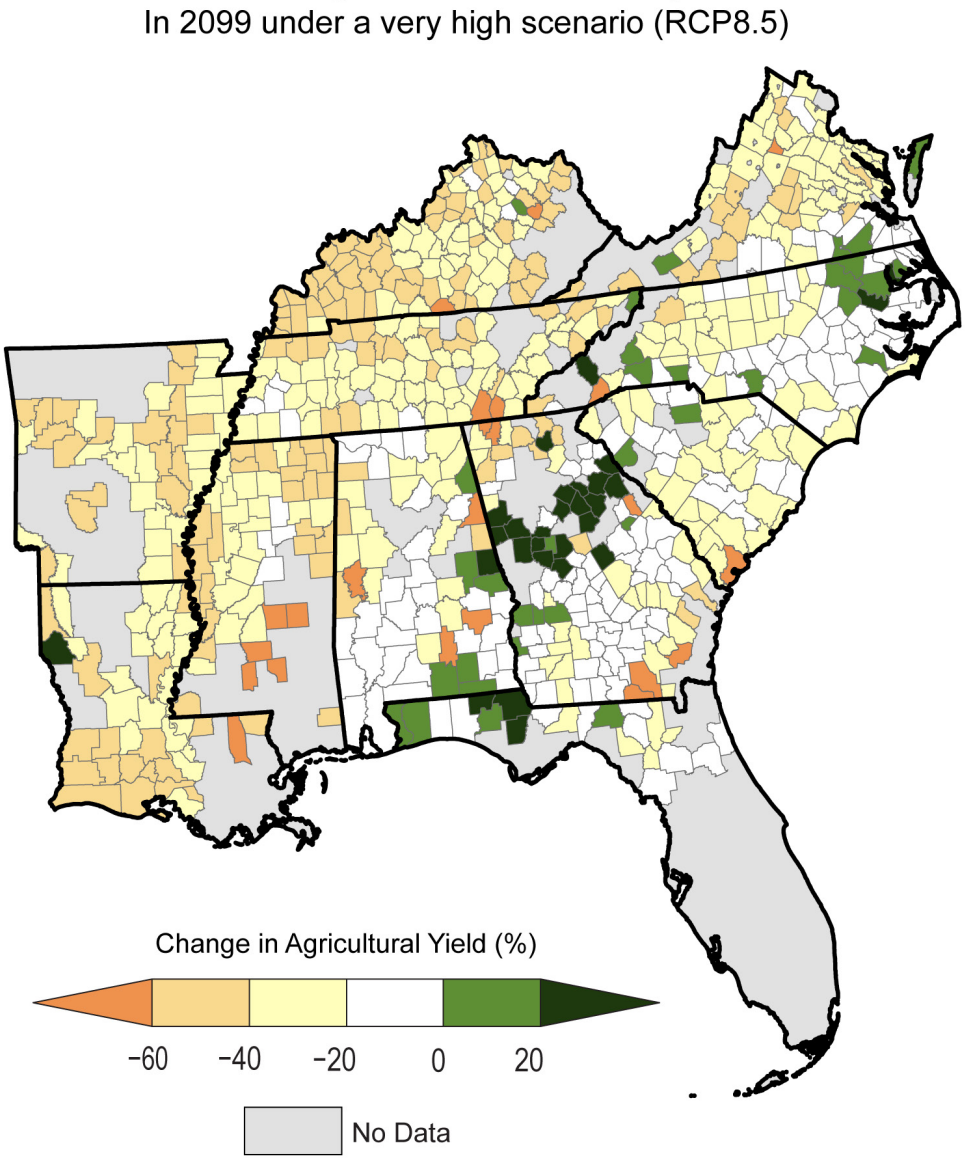
Regional Dependencies

Climate stressors in other regions can have cascading effects on the Southeast and in turn the entire United States. For example, sea level rise is expected to hinder the operation of ports where food, other agricultural products, and other needed supplies are imported and exported (KM 22.3). Additionally, low and high flows from droughts and floods may hamper the movement of food and agricultural products within and through the region, especially in highly urban and rural areas.[382,383] Climate extremes can also reduce crop yields elsewhere and thus the availability of food products for the Southeast, potentially increasing stress on under-resourced populations through cost hikes and decreasing access to nutritious food.[384,385]

How Agriculture and Food Systems Are Adapting in the Southeast

Agricultural producers are using various techniques to respond to increased climate stress, which is expected to result in decreased crop yields in many parts of the Southeast (Figure 22.19).[300] Precision agriculture can minimize water use through the timely and appropriate irrigation of crops based on growth stage and soil moisture.[386] The use of cover crops to preserve soil moisture and nutrients reduces the impacts of soil erosion and the leaching of nitrate into waterways and coastal estuaries, as well as the need for expensive inputs of fertilizer and irrigation water (Ch. 11).[387,388,389] Other innovative agricultural techniques such as organic farming, advanced grazing management, silvopasture, agroforestry, and other agroecological systems (Box 22.3) also show promise for adapting to future climate changes in the region through a reduction in emissions of greenhouse gases and increased carbon sequestration in the soil and vegetation.[376] New crops such as olives and satsuma citrus have been introduced to some areas to take advantage of the shifting plant hardiness zones and favorable market value of the crops.[390,391,392,393] Genetically modified organisms and new cultivars of perennial crops can contribute to reduced emissions of greenhouse gases through reductions in fieldwork and may reduce the need for inputs such as pesticides, as well as provide additional resilience to expected increases in temperature and drought that may threaten long-term yields.[394,395,396] A longer growing season also allows some producers to grow two crops in a year instead of one, reducing the likelihood of a weather catastrophe destroying a year's harvest in a single event.[397]

Projected Changes in Agricultural Yields Under Unmitigated Climate Change



Agricultural yields are expected to decrease under very high warming.

Figure 22.19. Agricultural yields (area-weighted average for corn, wheat, soybeans, and cotton) in the Southeast are expected to decrease due to the warmer climate in the future by 2099 under a very high scenario (RCP8.5). Some areas, however, may see yield increases due to less severe climate changes in these places, as well as limited impacts due to sea level rise and tropical storm damage. Decreases in crop yield are expected to negatively impact regional and national food supplies while threatening agricultural lifestyles and traditions. Adapted from Hsiang et al. 2017.[300]

Box 22.3. Indigenous Stewardship of Southeast Ecosystems: Rivercane

Rivercane (*Arundinaria gigantea*) is a Tribal cultural keystone species[398] and one of only three North American native bamboos. Once abundant and now critically endangered at just 2% of its original range, the species is still found throughout the Southeast.[399] Tribal Nations including the Cherokee, Chickasaw, Chitimacha, Choctaw, Houma, Koasati, and Seminole[400] value rivercane in cultural lifeways. It is used for food, textiles, basketry, medicine, weapons and hunting, and musical instruments. Many Tribal elders have a relationship with rivercane as a non-human relative.[401] Before settler colonialism, rivercane formed canebrakes, thickets of grasses that extended for miles, forming a feature from the South's deepest history.

Native peoples actively managed or tended canebrakes through consistent thinning to provide habitat and the required culms (stems) for cultural uses.[401] Canebrakes competed with European agriculture: cattle readily ate cane, particularly young shoots; pigs rooted for rhizomes,[402] killing the plant; and crops were planted where cane once thrived. Urbanization, removal of fire from the landscape as a management practice, overgrazing by cattle, and lack of public knowledge of rivercane's indigenousness have led to the plant's diminishment. The significantly reduced range of the rivercane is now further threatened by invasive species that are thriving under climate change.[403] Where it still exists, rivercane provides prime habitat for more than 50 animal species,[400] and at least six species require rivercane to complete their life cycles.[404]

Rivercane provides ecosystem benefits such as soil and water quality improvements and river and stream bank stabilization.[405] Rivercane produces seeds during rare mass fruiting events, the timing of which is unknown. For this reason, controlled reproduction has been limited and requires more research if the plant is to thrive in the future.[401] Current efforts are underway to restore rivercane, especially large swaths of canebrakes, as part of Tribal efforts to maintain sovereignty and cultural continuance.

> *I feel like we have to educate the public of Cherokee culture, foods, and artisan resources. It is not just rivercane affected by climate change, loss of habitat, and the public's lack of understanding of their cultural significance to our Tribal members, and other Tribes of the Southeast. — Mary W. Thompson, Eastern Band of Cherokee Indians*[406]

Rivercane in North America

Rivercane, a native bamboo, is culturally important to many Tribes in the Southeast.

Figure 22.20. (**left**) Rivercane grows by the French Broad River in Buncombe County, North Carolina. (**right**) Basket weaver Ramses King (Mississippi Band of Choctaw Indians) creates a "double-weave" basket (2014). The significantly reduced range of rivercane, largely due to land cover changes and agriculture, is now further threatened by invasive species that are thriving under climate change. Photo credits: (left) © Adam Griffith, Revitalization of Traditional Cherokee Artisan Resources; (right) Lance Cheung, USDA.

Traceable Accounts

Process Description

Author selection for the Southeast chapter began with assessing the geographic distribution, career level, and academic expertise of the individuals listed in the Federal Register Notice nomination list. The chapter lead author (CL) then also assessed a number of other characteristics including demographics and previous experience with National Climate Assessment (NCA) chapter development. Initial invitations were sent following US Global Change Research Program (USGCRP) guidance. The CL extended multiple rounds of invitations until the final list of authors for the Zero Order Draft (ZOD) was complete in February 2022, achieving a distribution of career stages, expertise, and geographic representation. Additional authors were added after ZOD reviews from USGCRP agencies were assessed. Author team meetings were held virtually and were used primarily to gather consensus on the direction of the chapter content. In preparation for the public engagement workshops that were held in January and February 2022, the author team worked through the format of the engagement and how feedback would be gathered and summarized. The CL also gathered ZOD feedback from regionally focused organizations: the Southeast Sustainability Directors Network (January 18, 2022) and the Southeast and Caribbean Disaster Resilience Partnership (January 26, 2022), as well as a youth-focused event put on by the Youth Environmental Alliance in Higher Education (February 15, 2022).

Subsequent drafts of this report reflected changes and edits agreed upon by a simple majority of authors in response to several dozen comments and suggestions from public, National Academies, and USGCRP Agency reviews. Consensus on chapter-wide changes was usually unanimous, with very few changes needing considerable discussion. The largest changes to the chapter occurred during the drafting of the Fourth Order Draft (4OD), as this was the draft that would need to respond to a large number of public and National Academies comments. Many of the changes would be instituted during the All-Author Meeting in April 2023. Review Editor Tisha Holmes ratified that the changes satisfied all public and NASEM comments before submission of the 4OD for Technical Support Unit editorial review.

Key Message 22.1

Regional Growth Increases Climate Risks

Description of Evidence Base

Population growth and land-use change in the Southeast have been widely reported on in a variety of contexts, including in previous NCAs. This evidence has only gotten more detailed since NCA4.[19]

The relationship between global warming and increases in regional sea level trends has recently been substantially improved, allowing for highly detailed descriptions of future relative sea level and thus flood risks.[51] Other advances related to projections of future rainfall intensity, duration, and frequency tied to both nontropical[100] and tropical systems[92] have greatly improved our understanding of future changes in the Southeast, including its potential downstream impacts on frontline communities.[13,53]

A wide body of quantitative research and qualitative practice has shown that the proactive adoption of risk reduction measures can significantly reduce future losses tied to natural hazards, including those exacerbated by a changing climate.[154] Furthermore, there is widespread agreement that natural hazards and climate change is disproportionately impacting socially vulnerable populations.[3] Planning and the distribution of funding have the potential to significantly reduce hazard risk, including that associated with climate change. However, the application of land-use planning techniques varies widely, and access to external grant funding is more often obtained by wealthier communities.[16,17]

Major Uncertainties and Research Gaps

Projections of future population are based on many assumptions. Research on how future land-use change will exacerbate particular climate stressors in southeastern cities and across the region could help inform the best use of interventions and application of growth strategies. There have been limited analyses of adaptation activities in the Southeast, data inputs used, and evaluation of impacts. Downscaling global climate change models to inform geospatially targeted adaptation tools and techniques at the neighborhood and parcel scale is improving. However, the use of this downscaled information requires continued refinement to improve accuracy; in addition, better processes for sharing this information would help local officials, including low-wealth jurisdictions with limited staff and technical expertise. There still exists uncertainty regarding how future intensification of storms will impact design standards, such as determining the appropriate design standard in an era of climate change, who makes these decisions, and who pays for the additional costs. These questions apply to housing, public facilities, and infrastructure. It remains uncertain how well communities are reducing hazard risk when accounting for both individual projects (which have been captured effectively in terms of future losses avoided) and ongoing development, which includes a variety of standards, ordinances, and public investments. There is limited literature estimating sub-daily precipitation metric projections for the Southeast. The degree to which future land use and urbanization will exacerbate or overpower climate change–intensified risks at the local level, especially in frontline communities, is under-explored in the current literature.

Description of Confidence and Likelihood

Population trends from the US Census Bureau are highly reliable through time and space, and as such, we ascribe *very high confidence* to reporting their data as well as future population estimates that virtually without exception agree on continued regional growth, warranting a *very likely* assessment. Risk management and assessment literature is extremely consistent on how sprawl and development relate to natural disaster risk, earning these statements *very high confidence* and *likely* assessments. That governance structures of varying scales are using outdated and/or limited information on climate-related risks is a well-reported feature within the flooding, disaster preparedness, and urban planning literature, so we assign *high confidence* to these statements. There is overwhelming consensus that climate adaptation efforts are concentrated in wealthier, more resourced communities, and therefore we assign assessments of *high confidence* and *likely*. There is overwhelming consensus that under-resourced, older, and marginalized communities are at higher and increasing risk from present and future climate extremes, although the risk in rural areas is less fully assessed quantitatively, thus resulting in our assignment of *high confidence* and *likely*.

Key Message 22.2

Climate Change Worsens Human Health and Widens Health Inequities

Description of Evidence Base

There is strong evidence and consensus that climate change is already affecting the health and well-being of populations in the Southeast.[19] There is also strong evidence and consensus that climate-related environmental health stressors are projected to worsen.[19]

There is evidence that residents in the Southeast have poorer health in general compared to other US regions[196] and have limited access to healthcare resources.[202,288]

It is well established that there are preexisting inequities in health and healthcare access, safe and affordable housing, and access to resources to adapt to climate change, and that these inequities are associated with communities with a high proportion of under-resourced and BIPOC (Black, Indigenous, and People of Color) residents.[3,12,202,220]

The occurrence and projection of more frequent and intense extreme heat events are well documented by temperature models of the Southeast.[3,230,231] The literature assesses the disproportionate health impacts of heat on those most affected, including people who work outdoors,[212,213] student and nonstudent athletes,[214,215,216] and those who do not have adequate housing or cannot afford the energy costs of air-conditioning their homes.[218,220,222]

The literature outlines the causal pathway of how climate change is compromising air quality in the Southeast as a result of increasing favorable conditions for wildfires,[244,245,246,256,262] longer and more intense pollen seasons,[253,254,407] and increased production of smog,[241,242,243] as well as the subsequent health impacts. There is some evidence that warmer temperatures are associated with an increase in harmful algal bloom events,[267] which occur in fresh, brackish, and salt water, commonly occur in coastal areas in Florida, and can have detrimental effects on ecosystems, affecting plant, animal, and human health.[273]

The literature has established that climate change broadens the geographic distribution and season of certain disease-carrying mosquitoes and ticks, particularly in the Southeast, for tick-borne illnesses such as Lyme disease[281,282,283] and mosquito-borne illnesses such as West Nile virus and Zika virus.[284]

Mental health data have established that the Southeast ranks worst among all regions of the US in the prevalence of mental illness and access to mental health care services,[287,288] which is of particular concern as extreme weather events occur more frequently and intensely in the Southeast, causing displacement and stress.[293]

Major Uncertainties and Research Gaps

The degree to which health will be affected by climate change and climate adaptations is uncertain, due to various compounding factors that can influence health effects. There are few studies that quantify the health impacts of climate adaptation interventions in the Southeast, so there is a limited understanding of effective public health strategies for addressing climate change.

Because there is limited data on pollen and vector-borne diseases in the Southeast, it is challenging to fully understand the impacts of climate change on these disease exposures.

There is also limited quantitative data on the mental health impacts of climate change. This information tends to rely on survey data, qualitative data, and anecdotal information.

Description of Confidence and Likelihood

There is a high degree of agreement in the scientific literature that climate change will impact and is already impacting extreme temperature and precipitation events, air quality, water quality, the spread of vector-borne diseases, and the prevalence of algal blooms, all of which have an impact on the health of people in the Southeast, as evidenced by health outcome information including health impact assessments of recent events, health projections of future events, and environmental health trends in the Southeast. Based on this information, the authors assigned *very high confidence* that the changes in temperature and precipitation due to climate change, in conjunction with changes in air quality, water quality, the spread of vector-borne diseases, and the prevalence of algal blooms, will impact, and is *very likely* already impacting, the health and well-being of people in the Southeast.

It is well established that the conditions in which people live and work have an impact on health, which is understood as the social determinants of health. It is also well established by the literature and lived experience that marginalized populations will experience disproportionate health impacts, as that is seen consistently across public health and particularly in environmental health. For this reason, as well as because of the breadth of literature on the disproportionate impacts of climate change on the health of marginalized populations, the authors assigned *very high confidence* that community characteristics such as

racial and ethnic population, chronic disease prevalence, age, and socioeconomic status, can influence how climate change exacerbates, ameliorates, or introduces new health issues, widening the gap in health status.

Based on models of health impacts under varying climate scenarios, it is well-established that lower emission scenarios will result in less severe health outcomes. The literature is less established on the health benefits of climate adaptation efforts, as there is not a breadth of literature or evaluations on this topic, although from the literature that is available it is apparent that climate adaptation actions can improve health. For this reason, the authors assigned *high confidence* that climate mitigation and adaptation efforts can save lives and reduce the public health burden of climate change, particularly around reducing air pollutants and targeting already-marginalized communities, which is where the literature is more established.

Key Message 22.3

Climate Change Disproportionately Damages Southeastern Jobs, Households, and Economic Security

Description of Evidence Base

There is a rapidly growing literature presenting both qualitative and quantitative evidence that livelihoods across the Southeast are already being impacted by climate change in a variety of important ways (Ch. 19),[298] including place-based economies such as construction, tourism, and agriculture and aquaculture (e.g., fisheries are being impacted not only by significant hurricanes but also by geographical shifts among species in ocean waters),[408,409] as well as systems like transportation infrastructure[317] and electrical grid infrastructure[320] that undergird the distribution of goods and services in these places. Extreme weather-related disruptions and adverse working conditions created by climate change can affect both people and infrastructure systems that support local and regional economies by impacting the local community as well as regional and global supply chains.[326,327] References and figures included in Chapter 19 were instrumental to establishing author team consensus around key statements related to economic impacts being relatively larger in the Southeast than in other NCA regions.

Major Uncertainties and Research Gaps

Localized impacts on inland agriculture and tourism are not fully understood to date. The relocation of individuals and households away from climate-affected areas to other locations and their need to establish new livelihoods are not well understood, nor is the effectiveness of federal funding to support the construction of new settlements in less hazardous areas. The degree to which small and midsized businesses are adapting to climate change–related threats remains uncertain. The extent to which climate changes will impact large-scale agriculture is fairly well established, but the fiscal impact on small-scale family farms is not as well understood. There is limited research on the low-flow conditions and projections related to drought and its impacts on the Mississippi River and its tributaries as well as on the potential impacts to economies, despite how disruptive the events are to the regional, national, and global economy.

Description of Confidence and Likelihood

Based on the author team consensus reached through evaluating the evidence base presented in the literature as well as through direct and related experience in recent extreme weather and climate events impacting the Southeast, the authors have assigned *high confidence* to the statements surrounding the concentration of economic growth in urban centers, the climate-related risks to place-based economies that rely on ecosystems and to southeastern economies and labor, and the need for coordinated strategies

to prepare for the shocks and stressors of the future. *Medium confidence* was assigned to the evaluation of the extent to which urban centers depend on the interregional connections to more rural places and other urban centers due to limited peer-reviewed literature in this area. While there are reports and white papers on this subject from nonprofits and research think tanks that largely agree on the potential for disruptions to these systems to have impacts on both rural and urban centers, limited peer-reviewed studies seeking to isolate urban/rural dependencies in the face of climate change support at least *medium confidence*. Projections of future climate impacts in the Southeast are particularly robust in their evaluation of future heat and extreme precipitation risks; we assign *very likely* and *high confidence* to our Key Message statements that seek to link climate impacts to economic outcomes in the Southeast. Chapter 19 (Economics) was especially helpful in establishing our *very likely* and *high confidence* assessments.

Key Message 22.4

Agriculture Faces Growing Threats, but Innovations Offer Help

Description of Evidence Base

Evidence of trends in temperature, precipitation, and growing season are well documented in sources such as the NOAA National Centers for Environmental Information's Climate at a Glance Tool and in the scientific literature.[346,350] This literature base is extensive and covers individual states, the Southeast region, the United States, and the globe. Earlier concerns about temperature trends from satellite observations, which did not match surface-based observations, have largely been resolved by improved calibration of satellite measurements.

Trends in precipitation show changes in both amount and temporal and spatial distribution that are more difficult to separate out due to the nature of precipitation in the Southeast and its ties to sub-grid-scale processes like convection and tropical systems.[358,359,360,361] Evidence of trends in drought are less certain because of the combination of interacting contributions from temperature, precipitation variability, and soil characteristics, but are becoming more apparent in recent modeling efforts that are documented in the scientific literature.[351,352]

The impacts of climate variability and change on agricultural production have been well documented in the scientific literature in agricultural journals in recent years.[350,356] More work is ongoing as better methods for collecting in-field measurements are used to fine-tune the relationships between plant physiology and climate variables.

The assessment of the impacts of climate change on the health of workers and livestock, transportation pathways for agricultural production, and economic losses to both large-production farmers and small BIPOC farming communities has increased greatly in the last four years and is being reported in scientific journal articles in health, infrastructure, economic, and other social science–oriented journals.[325,347]

Many examples of agricultural producers implementing climate adaptation in farming exist, suggesting a willingness to address the impacts of a changing climate across diverse land ownerships.

Major Uncertainties and Research Gaps

There is significant uncertainty regarding the ability of crop species to keep pace with changes in climate (based on temperature and precipitation), although plant breeders have a long history of producing new hybrids that can improve responses to changing climate conditions. The ability of new crops to be productive in an altered climate is also uncertain due to concurrent changes in temperature, precipitation,

humidity, and soil characteristics, which interact with plant growth patterns. This leads to considerable uncertainty in the extent to which changes in crop choice and management can adapt to the future climate.

There is also uncertainty in the knowledge of carbon interactions between soils and crops, but numerous studies are underway to better document these interactions to improve future predictions.[376]

Since agriculture is a global endeavor, changes in market pricing and availability of inputs such as fertilizer, as well as outputs such as crop variety and yield, interact in a way that hinders the prediction of future agricultural outputs, droughts, and the economic effects of agricultural sales.[410] As a result, economic impacts on both large-scale farmers and economically disadvantaged farmers with small-scale operations are difficult to predict with *high confidence*.

Description of Confidence and Likelihood

Based on the high degree of agreement in agricultural and climate science journal articles in the scientific literature and assessments of recent events, there is *very high confidence* that the interactions of warming temperatures, precipitation changes, sea level, and drought with insect pests, invasive plants, and plant pathogens are already threatening the region's agriculture and food-related systems and will *likely* lead to decreased yields of many crops and production of other agricultural goods.[356,357] Evaluations of recent past storm events coupled with the strong agreement in related journal articles resulted in an assignment of *very high confidence* that rising sea levels and impacts from tropical storms will disrupt coastal and port activities.[325,347] Studies by social scientists published in the literature also demonstrate that small-scale BIPOC producers, as well as those who have limited financial resources, will be disproportionately affected by climate-related hazards;[366,367] on that basis, the authors have described this as *very likely* with *high confidence* in the expected impacts. Additionally, based on examples in the scientific literature of adaptations that producers are already making in response to changes in the climate, the authors assigned a level of *high confidence* that producers in the Southeast will be able to adapt to those changes using techniques such as precision agriculture, changes in crop type, and innovative management of fisheries, livestock, and ecosystems, and a likelihood level of *likely* was assigned based on less agreement in the scientific literature about the degree to which they will be able to do so.[386,390,394]

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