THE FLORIDA WILDLIFE CORRIDOR AND CLIMATE CHANGE

Managing Florida’s Natural and Human Landscapes for Prosperity and Resilience

PRESENTED BY :

Archbold Biological Station
Florida Atlantic University
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The Florida Wildlife Corridor and Climate Change:
Managing Florida’s Natural and Human Landscapes for Prosperity and Resilience

A report by a team of academic and professional experts, led by Florida Atlantic University’s
Center for Environmental Studies, submitted to the Archbold Biological Station

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Executive Summary

The Florida Wildlife Corridor (FLWC) is a world-class illustration of a formal attempt to legislate and incentivize land conservation. The motivation for this effort is to preserve as much biodiversity as possible in Florida in the face of a population boom, which, absent the FLWC, would likely result in a massive transfer of lands from natural or working status to urban or suburban uses. Hopefully the FLWC will permit the continued economic growth of the state while also preserving biodiversity and the state's ability to support rural economies. To date, questions remain regarding how the FLWC interacts with the state's climate resilience across the already conserved 10 million acres and the nearly 8 million acres envisioned for conservation in the future. Such a major shift in land uses is sure to affect (unintentionally) the state's climate resilience by modifying water and energy balances throughout approximately 25-50% of the state's lands. Independent efforts to enhance the state's climate resilience should, again unintentionally, have effects on the FLWC through providing additional incentives to conserve land. More specifically, in the coming decades Florida should expect to experience not only a continued major population boom but also more heat and more rain. Linked with these changes are expected increases in, among others, fire and flood risks. Nascent efforts to adopt methods from the field of urban planning, private climate finance, and climate smart agriculture programs provide avenues for potentially productive and simultaneous advances in both the FLWC and the state's climate resilience.

I. Understanding the Florida Wildlife Corridor (FLWC) in a Changing Climate

I.A. Problem Statement

Landscape connectivity is essential for maintaining biodiversity (Fischer et al. 2007; Haddad et al. 2015). Yet rapid urban growth tends to fragment landscape connectivity, especially when most new growth occurs in sprawling patterns with little or no coordination across counties or cities. This process is rapidly unfolding in Florida, which is now the country's most rapidly growing and third-most populous state, home to a booming population of approximately 1000 new residents per day (Biernacka-Lievestro and Fall 2023). As a result, Florida risks losing a variety of key plant and animal species and associated key ecosystem services that benefit both people and other species.

The Florida Wildlife Corridor (FLWC), signed into state law in 2021, is designed to preserve the state's landscape connectivity without compromising the quality of life for our growing human population. To date almost 10 million of the nearly 18 million acres originally identified for conservation in the FLWC have been permanently conserved, driven by several initiatives, including Preservation 2000 (P-2000) and its successor program Florida Forever, the Conservation and Recreational Lands Program (CARL), and the Rural and Family Lands Protection Program (RFLPP)These initiatives laid the foundation for modern movements regarding the FLWC. As such, Florida's future ability to maintain biodiversity and ecosystem services in the face of a population boom has been substantially improved, with an additional major benefit within our reach if much of the remaining approximately 8 million acres are also conserved.

Yet Florida's population boom, and the attempt to mitigate its biodiversity effects, are not unfolding in a vacuum. While Florida is protecting its biodiversity in the face of a population boom, our state, as with the rest of the world, is also experiencing climate change. Climate change projections for Florida include rising temperatures, higher flood and drought risks due to changing precipitation patterns, more coastal erosion linked with sea-level rise, and new storm patterns. Some of these developments are already part of our recent lived experiences. Moreover, in recent years, various efforts to reduce the effects of climate change for Florida's people and ecosystems have launched at international, national, state, and local levels. Businesses, governments, non-profits, and university researchers are increasingly active in examining and acting to improve the state's climate resilience.

Thus, Florida's familiar baseline environmental conditions are being modified simultaneously, not only by the FLWC and population growth, but also by climate change and climate change-inspired resilience efforts. Yet potential FLWC-climate resilience interactions have not been comprehensively examined as a twinned concept to date. Examples of twinned exposures of a rapidly growing human population and a changing climate are illustrated in five vignettes in section II.B. Topics of these vignettes include pluvial and fluvial flooding, wetland loss impacts, heightened tidal flooding, and storm surge. This is an important gap to fill because given the overlapping foci of these efforts, it is likely that some of the growth and climate management efforts may be unnecessarily duplicative, counter-productive, or mutually reinforcing. For Florida's conservation and climate efforts to be maximally efficient and productive, the efforts should be managed holistically to leverage their potential positive interactions and to minimize their potential negative interactions.

I.B. Purpose Statement

The purpose of this report is to provide the conceptual and analytical foundation for the holistic management of population growth and climate change in Florida. To this end, we characterize relationships between the FLWC and the state's climate resilience. This work builds on a recent study of how the FLWC may affect the state's water resources (Graham et al. 2022). Our goal is to enable a broad array of stakeholders to assess our state's twinned population-climate challenges through the two lenses of land use and ecosystem services. For the purposes of this report, Florida has four primary land uses (natural, intensive agriculture, working, developed) and four primary ecosystem services types (provisioning, supporting, regulating, cultural). Working lands in our categorization include ranchlands used for cattle grazing and commercial timberland. Both land uses vary in intensity but are generally less intensively managed than cropland, which exemplifies our intensive agriculture category. We outline likely effects in general terms because there is little underlying science precisely relevant to the many specific locations, projects, or impacts across the entirety of this vast study region. Therefore, this report should not be used as a prescription for how to manage individual parcels. Instead, this report sketches what is known versus what is not known in a way to suggest productive future directions for policy, engineering, and research studies.

Florida is nationally and internationally at the forefront of climate exposure due to its annual hurricane risks, extensively (and increasingly) populated low-lying coastline experiencing sea-level rise, and fire-prone ecosystems. Less well-known is that the state is at the vanguard of conservation for land and habitat connectivity thanks to decades of work by universities, agencies, landowners, and nonprofits toward the creation of the FLWC. State-funded land acquisition and easement programs are among the best in the country (when funded) and the FLWC is the most ambitious statewide land conservation vision in the U.S., if not the world. This report, therefore, stands to serve as a key example for other regions, states, and countries to assess the synergies and/or tensions between large-scale land conservation and efforts to enhance the resilience of people and nature to climate change.

I.C. Conceptual Framework

The foundational concepts for climate change reports such as this one draw from an interdisciplinary set of literatures, including geography, engineering, climatology, ecology, and economics. The central pillar is Gilbert White's (1941) PhD dissertation on the curious and troubling trend of U.S. flood deaths and damages increasing during a time of growing technological knowledge on and awareness of how to reduce flood risks and impacts. Later work attempted to decompose how climate enters the day-to-day evolution of human-environment interactions embodied by the path-breaking international work of Kates et al. (1985). This work played an important role in the launch of the Intergovernmental Panel on Climate Change (IPCC) in 1988, the global scientific body charged with regularly summarizing the state-of-the-art of climate change research worldwide. Refinements of these ideas by O'Brien and Leichenko (2000), Turner et al. (2003), and Dawson et al. (2011) constitute the bedrock concepts for this report on interactions between the FLWC and climate resilience. Specifically, there are four principal concepts for understanding interactions between climate change and the FLWC:

Exposure describes the intersection of the specific climate stresses, including their approximate geographic and temporal boundaries, with the coupled human-environment systems experiencing the stresses. These systems are readily identifiable assemblages of people and things people value, plus the dominant environmental features of the place (Kates 1985; Turner et al. 2003; Polsky and Eakin 2011). For this report, there are two broad categories of stresses to which our state is exposed: changes in temperature and precipitation. We assess how these changes may matter using the lens of land use. Four land use types are identified as characteristic of the FLWC: Developed (Urban/Suburban), Conservation Lands (Natural), Intensive Agriculture (e.g., Row Crops), and Working Lands (Seminatural; Ranching and Timber).

Sensitivity describes the effects of exposures to the stresses. For example, Florida is a leading producer of sweet corn crops, and exposing a sweet corn farm to the stress of increasing heat and dryness will likely result in diminished yields due to lower photosynthetic capacity. The diminished yield is the sensitivity.

Adaptive capacity describes potential and observed responses to the effects of exposures to the stresses (Dawson et al. 2011). To continue the example above, the sweet corn farmer can shift planting dates to next season to avoid exposing the crop to the stress, thereby reducing the diminished yield. Similarly, the farmer could switch from one sweet corn varietal to another, selecting for seeds to plant with a lower sensitivity to increasing heat and dryness.

Double exposure is the simple concept that however important a given climate change may be at a given place and time, the climate exposures, sensitivities, and adaptive capacities do not unfold in a vacuum (O'Brien and Leichenko 2000). Instead, there are typically other large-scale stressors operating in parallel that modulate how the climate exposures feed through the system. Failing to account for the simultaneous non-climate storylines means the resulting climate-only assessment may be inaccurate (Schröter, Polsky and Patt 2005; Polsky et al. 2007). In the case of Florida, the obvious additional stressor to consider alongside climate change is population growth. Indeed, the FLWC, perhaps the largest example of a legislated land conservation program in U.S. history, is a manifestation of Florida's adaptive capacity vis-à-vis that stressor. More to the point, motivation for the FLWC does not include climate questions. Adopting a more realistic twinned climate-population exposure gives rise to more realistic characterizations of our actual twinned sensitivities and twinned adaptive capacities.

We aim to paint a holistic picture of the key potential human and environmental effects of and responses to unfolding climate and population changes in Florida, and how the FLWC (if it were fully enacted) may modify those outcomes. Typically, such assessments require years of data collection and analysis. For this report we have limited time and personnel, so our goal is to sketch generally what is known versus not known in this far-reaching field for the vast study area (nearly 18 million acres) of the FLWC. Hopefully in the long-term this sketch will prove a useful roadmap for future policymakers and researchers to implement in more detail if given the opportunity. In the short-term we hope the report illuminates some important ways for Florida to manage its population growth and climate change not in artificial isolation but instead in realistic combination.

I.D. History of the FLWC

The FLWC (Figure 1) provides a leading example of ambitious landscape conservation planning on a regional scale. The Corridor aims to maintain or restore habitat connectivity, focusing on large carnivores and herbivores as focal species.

There were several key theories that led to action regarding the FLWC in the 1980s. The "corridor" concept was influenced by island biogeography theory, emphasizing the importance of habitat connectivity and the suggestion that the theory could be usefully applied to the design of nature reserves and regions that were fragmented by anthropogenic land uses (Diamond, 1975; Wilson and Willis, 1975). Later studies supported the idea of connectivity of habitat corridors that facilitate movement of species and contribute to both species persistence and richness (Beier and Noss 1998; Bennett 1998, 2003; Damschen et al. 2006; Gilbert-Norton et al. 2010; Hilty et al. 2020). Progress in the metapopulation theory (Levins, 1969; Hanski, 1998, 1999) bolstered arguments regarding corridor connectivity, supporting the idea that a well-connected network of reserves or habitat patches may support viable populations of wide-ranging, area-sensitive species and may minimize the potential for extinction of a species that experienced changes on a local scale (Hanski 1999).

The development of landscape ecology (Forman and Godron 1981, 1986; Forman 1995) also influenced the FLWC significantly. The concept of "landscape linkages" to tie together large conservation areas was applied to Florida regions. An example of a linkage was the use of the Pinhook Swamp to connect Osceola National Forest and the Okefenokee National Wildlife Refuge in the northern peninsular Florida region and adjacent land in the state of Georgia. Such linkages were recognized and advocated for by Professor Larry Harris of the University of Florida during the 1980s and are part of the FLWC today.

Reed Noss (1987, 1991, 1992; Noss and Cooperrider 1994) developed the first statewide Florida Wildlife Corridor (called a "wilderness recovery network") in 1983. The FLWC was first introduced to the public in a Wildlife Corridors conference during the spring of 1986.

Previous regional planning efforts aided later action regarding the FLWC. First, beginning in the 1970s, there was the creation of statewide system of Water Management Districts, in addition to several land acquisition programs such as the Environmentally Endangered Lands, Save Our Rivers, Save Our Coasts, and the Conservation and Recreation Lands (CARL) program (Henderson 2022), and growth management legislation (since disabled). Still, the corridor concept faced challenges and opposition in the 1980s but gained momentum in the late 1980s and early 1990s with increased conservation initiatives in Florida.

The passage of the Preservation 2000 (P-2000) Act in 1990 increased availability of significant funds ($3 billion in one decade) for conservation land efforts fostered growth. In 1991, the Nature Conservancy, Florida Audobon, and the Florida Department of Natural Resources brought together a group of experts resulting in the development of a statewide map of conservation priorities to inform P-2000 decisions. There were revisions made to the initial map over the following years by the Florida Natural Areas Inventory (Henderson 2022). Cox et al. (1994) assembled data to identify Strategic Habitat Conservation Areas and Regional Biodiversity Hot Spots across Florida, yielding maps that included varying amounts of connectivity between the identified priority areas.

In 1991, the Conservation Fund and 1000 Friends of Florida initiated the Florida Greenways Program, leading to the convention of a gubernatorial committee that produced a report in 1994, later adopted as the Greenways Legislation of 1995 (Hoctor, Carr, and Zwick 2000). The program was administered by the Florida Department of Environmental Protection. Later, in 1995, the ecological component of the Greenways system was created, leading to the Florida Ecological Greenways Network (FEGN) (Hoctor, Carr, and Zwick 2000; Hoctor, Carr, and Teisinger 2005; Hoctor et al. 2008). The FEGN represents a substantial refinement of the original FLWC (Noss 1987, 1991, 1992). The implementation of the FEGN includes identification of Critical Linkages based on ecological value and threats from development (Hoctor, Carr and Zwick 2000).

In 2005, the Florida Century Commission was created to envision Florida 50 years in the future with a focus on sustainability. The commission called for identifying lands and waters in the state critical to the conservation of natural resources. This yielded the Critical Lands and Waters Identification project (CLIP), developed by the University of Florida Center for Conservation Planning in cooperation with the Florida Fish & Wildlife Conservation Commission. CLIP serves as a database of statewide priorities for conservation across natural resources, including landscape function, surface water, biodiversity, groundwater and marine resources (Florida Natural Areas Inventory 2024).

This also led to the Cooperative Conservation Blueprint, which was a multi-partner strategic conservation process that was part of Florida's Statewide Action Plan that brought together multiple conservation organizations with businesses, landowners, and governmental bodies in an effort to build agreement on voluntary and non-regulatory conservation incentives and connection priorities where the existing and new incentive ideas could be applied (Florida Fish and Wildlife Conservation Commission, 2022).

The modern Florida Wildlife Corridor initiative was founded on Earth Day in 2010, by Carlton Ward Jr. and Tom Hoctor, alongside Richard Hilsenbeck of the Nature Conservancy and a group of stakeholders across conservation organizations, academic, and the state agencies of Florida.

The modern FLWC emphasizes the significance of large-scale movements of wildlife, including Florida panthers and black bears. In 2012 and 2015, there were two documented expeditions covering extensive areas of Florida, which garnered positive publicity. The culmination of four decades of research and advocacy led to the passage of the Florida Wildlife Corridor Act in 2021, signifying a bipartisan effort to protect approximately 18 million acres, with 10 million already in conservation areas, thanks to the above-mentioned programs like CARL, P2000, Florida Forever, and others. The Governor signed the law on July 1, 2021, after votes of 115-0 in favor in the House and 40-0 in favor in the Senate. The scientific foundation of the FLWC is based on the Florida Ecological Greenways Network (FEGN) (specifically, the top three priority layers; https://conservation.dcp.ufl.edu/fegn), and is revised every two to three years. The FLWC's ongoing evolution reflects its commitment to adapt to new information and partnerships with organizations including the University of Florida Center for Landscape Conservation Planning, Florida Natural Areas Inventory, Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, and the Florida Department of Agriculture and Consumer Services. For more about the history and status of the Florida Wildlife Corridor, see Noss and Hoctor (in preparation).

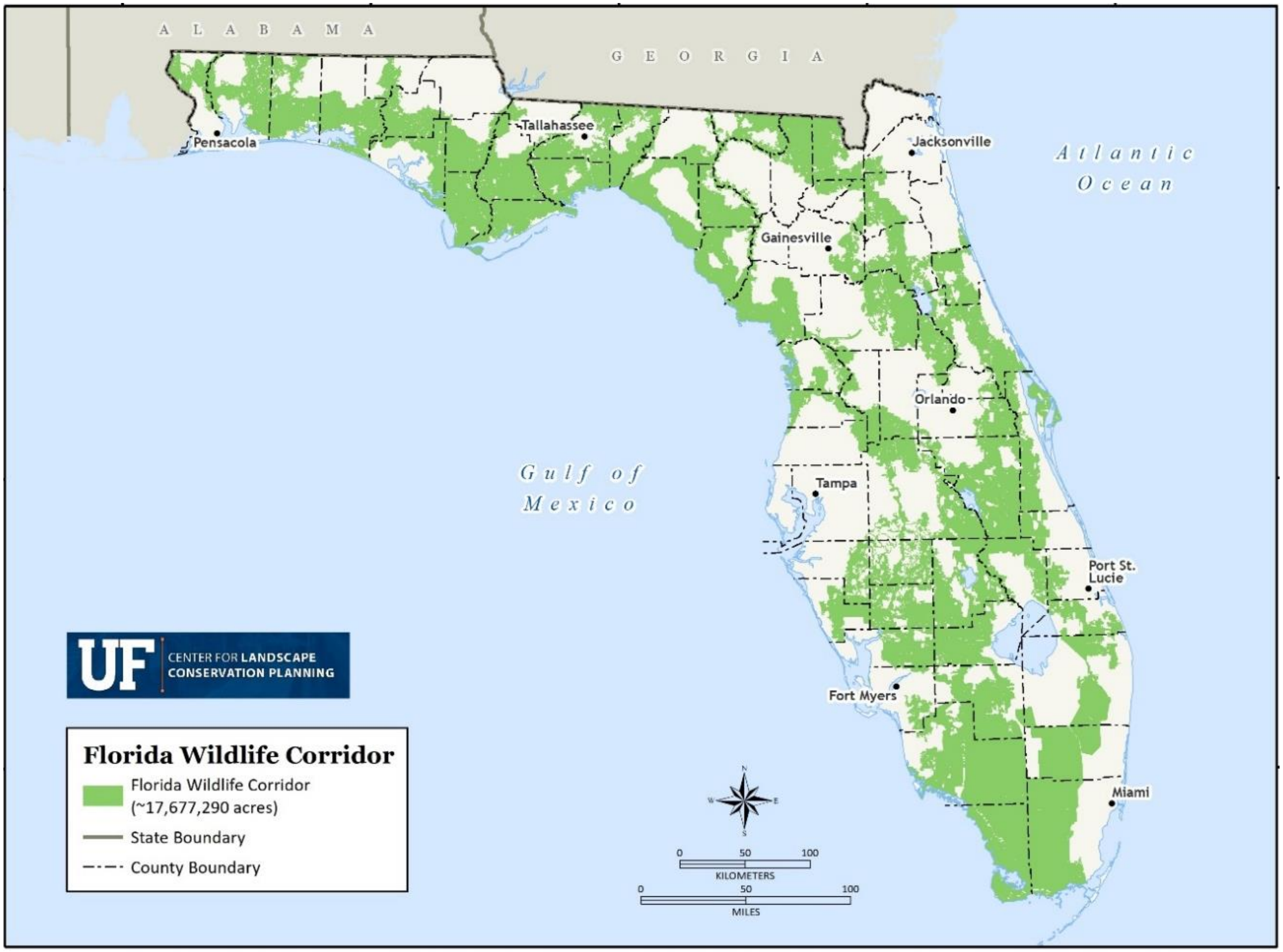


Figure 1. The Florida Wildlife Corridor. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2023b.)

I.E. Current Climates of the FLWC

The state of Florida – and by extension the FLWC because it spans virtually the entire state – has one of the most unusual climates in the United States. The region's climate is shaped by its low southern latitude, its peninsular shape with massive water bodies on either side, low elevation, and a landscape with plentiful rivers, surface water, wetlands, agricultural lands, and highly urbanized regions (Winsberg 2003). The state of Florida is predominantly classified as subtropical, except for South Florida, which has a sub-humid to humid tropical climate (Figure 2). A humid subtropical climate is characterized by hot, humid summers and winters that are cool to mild and by a wet-dry annual rainfall regime. Tropical climates are characterized by warm year-round temperatures, with abundant annual precipitation (greater than 59 inches annually), and a small annual temperature range (NOAA 2023a). Portions of the southernmost region of the peninsula are designated as tropical savanna with weather patterns resembling the Caribbean Islands, with monsoon seasonality – having high amounts of rainfall during the summer months and significant decreases in precipitation during the winter season (Emrich et. al 2013).

Some local altitudinal differences can account for temperature variation, particularly during winter months where grove owners have historically recorded that citrus trees planted in land depressions are more susceptible to seasonal freezes (Winsberg 2003). The maximum elevation occurs along the Florida-Alabama border at Britton Hill at 345 feet (105 m), and in the Peninsula 312 feet (95 m) on Sugarloaf Mountain in Lake County, though much of the rest of the state exhibits subtle topography close to sea level (Emrich et. al 2013). The Bermuda High, a high-pressure system that is semi-permanent off the Atlantic Coast, also plays an important role in Florida's climate. Often, the Bermuda High draws moisture to its north or west, which contributes to the warm and moist summers with afternoon and evening thunderstorms (Runkle et al. 2022).

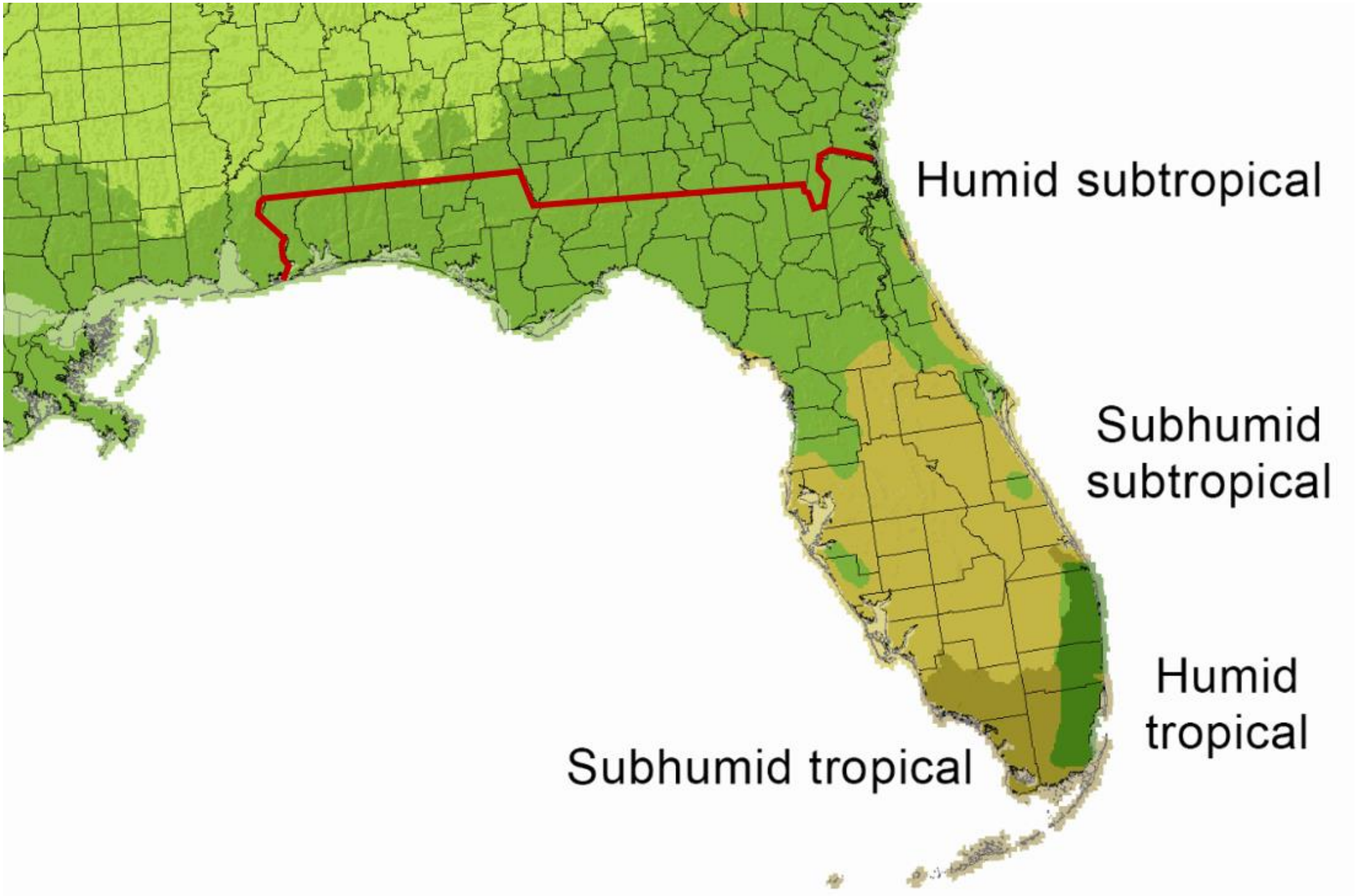


Figure 2. Köppen's Classification Zones of Florida. (Kartesz 2015.)

I.E.1. Temperature - Summer Season

Florida's summer season is hot and humid across all portions of the state, with daytime highs averaging in the low 90's (degrees Fahrenheit) and nighttime lows in the lower to mid 70's. But there are regional and local differences. Areas within approximately 5 miles of the coast experience temperatures moderated by the onset of the sea breeze on most afternoons, while inland areas continue to heat.

Typically, average maximum temperatures begin to rise in the month of April, in the interior regions of the peninsula and later spread towards the coasts (Winsberg 2003). The average maximum temperature experienced during this period can rise above 88 °F on the west coast during the month of May and later along the east coast in June, supported by easterly trade winds and sea breezes that can reach approximately 25 miles into the interior of the peninsula (Winsberg 2003). Figure 3 shows the average temperatures that occur across the entire state during July, where variability is consistent with the major climate divisions that occur across a state with a generally homogenous climate (Powell 2023).

North Florida and the Panhandle are more prone to extreme hot days, i.e., temperature approaching or over 100 degrees (the hottest daytime averages are shown on Figure 4) and heat waves when the flow is predominantly northwest and brings hot, dry continental air. South Florida afternoons are usually more moderate and dominated by easterly trade winds off the Atlantic. A heat wave is a sequence of days and nights with both the maximum and minimum temperatures above a region-specific high percentile threshold value between the 90th and 99th percentiles of the entire daily temperature distribution (Keellings and Waylen 2014). Heat waves are also typically defined temporally by their number of consecutive days above the threshold temperature (Tan et al. 2007 as cited in Keellings and Waylen 2014). Across the U.S., heat waves are occurring with increasing frequency, from an average of two heat waves annually during the 1960s to approximately six per year beginning in the 2010s (NOAA 2022 as cited in EPA 2022). Similar trends have been observed in Florida (Zierden 2023). High maximum and minimum temperature events, as well as heat wave duration, have increased in frequency across Florida (approximately 80% of the state), with the greatest increases occurring across South Florida (Zierden 2023). Additionally, heat wave magnitudes are increasing, especially in South Florida where the scale has increased greater than 0.4 °C (Keellings and Waylen 2014). Figure 5 shows the monthly mean maximum temperature for the month of July (1991-2020).

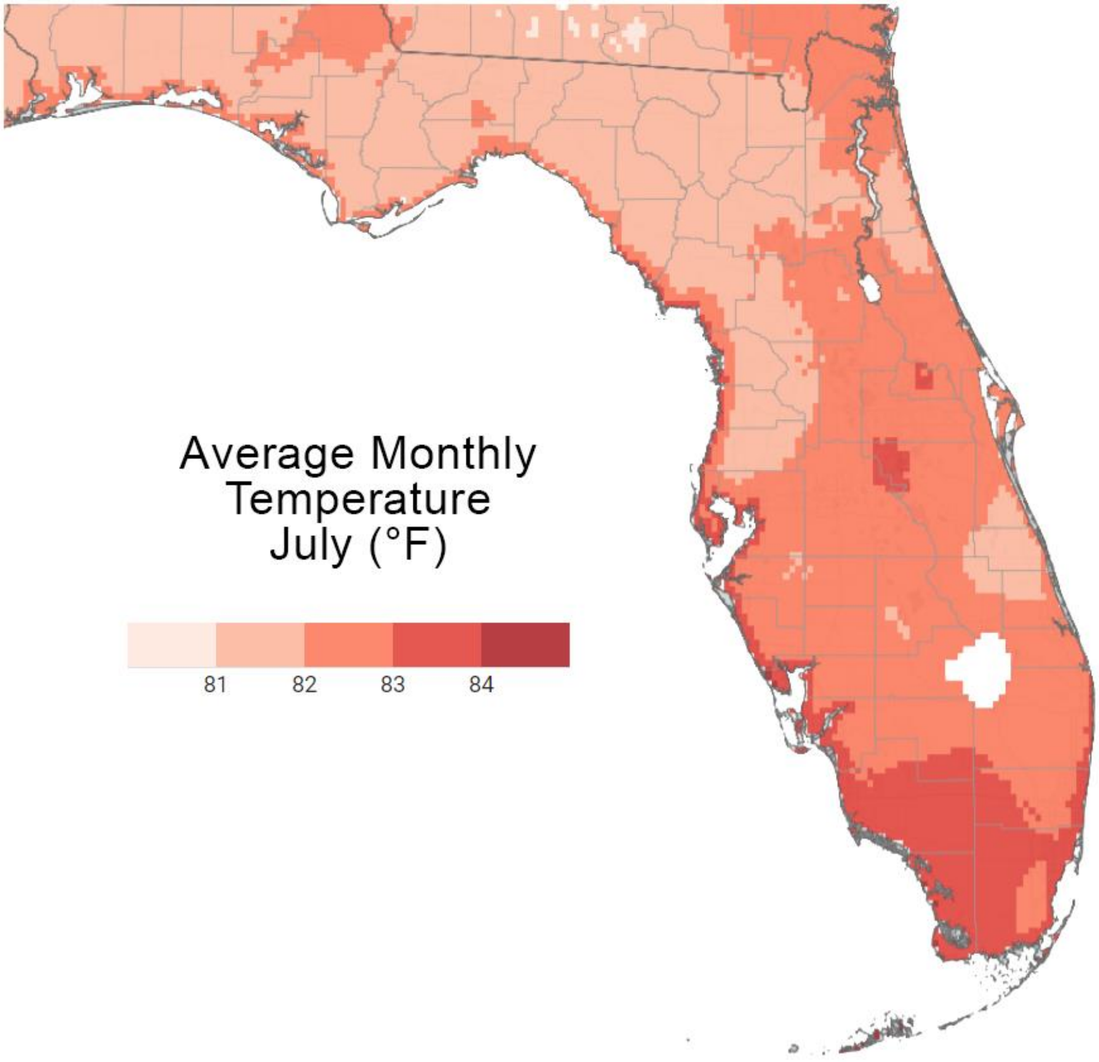
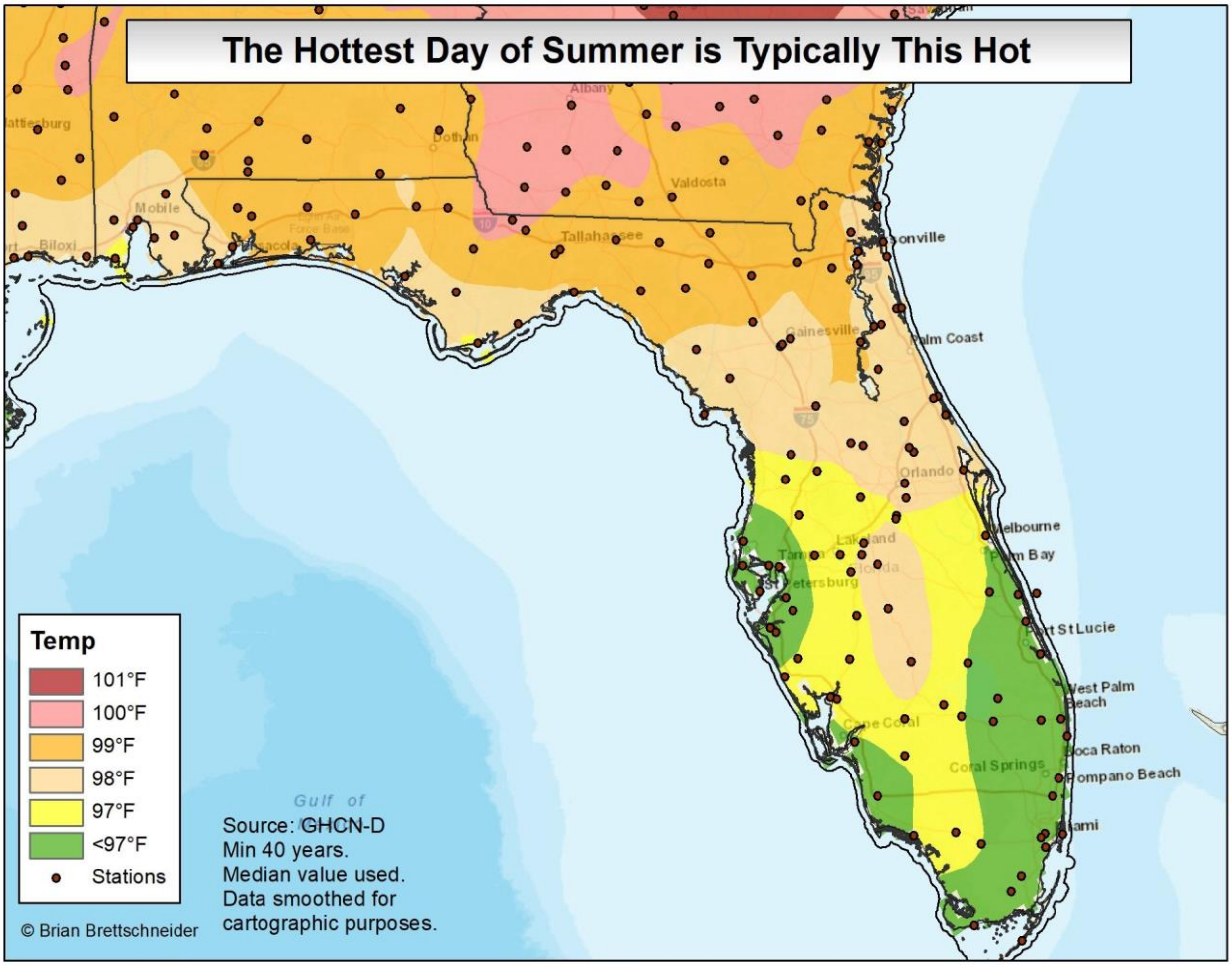


Figure 3. Florida Average July Temperatures, 1991-2020. (Data from National Centers for Environmental Information (NCEI) Normals (1991-2020) using Gridded Mapper Tool at https://ncei-normals-mapper.rcc-acis.org; Center for Environmental Studies (CES) 2024i.)



Source: GHCN-D
Min 40 years.
Median value used.
Data smoothed for
cartographic purposes.

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Figure 4. Average Hottest Day of the Summer. (Reprinted from Brettschnieder 2018.)

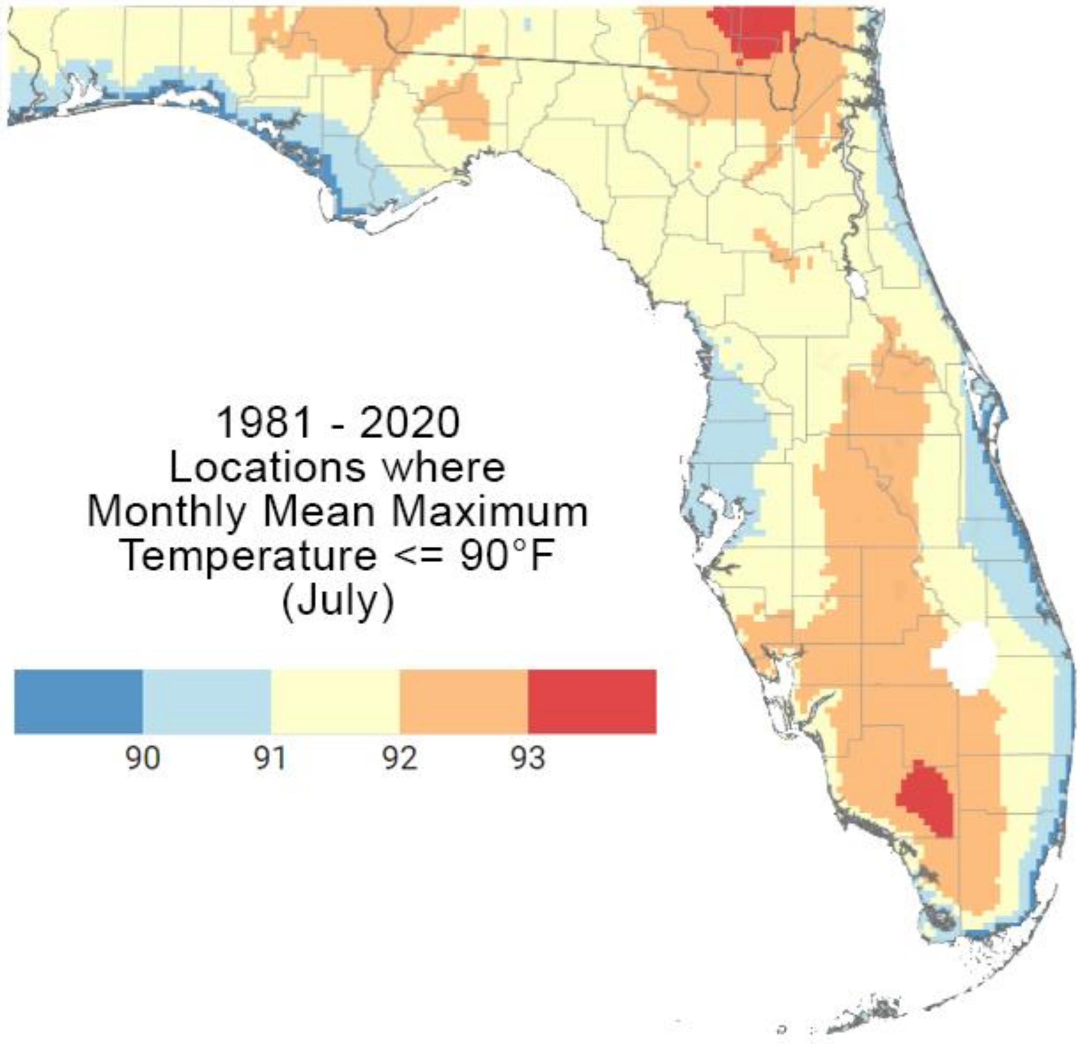


Figure 5. Florida Locations Where Monthly Mean Maximum Temperature (July) >=90 °F. (Data from NCEI Normals (1991-2020) using Gridded Mapper Tool at https://ncei-normals-mapper.rcc-acis.org; CES 2023b.)

I.E.2. Temperature - Winter Season

Winter temperatures are a different story, with substantial differences between North Florida and the Panhandle, Central Florida, and South Florida (Figure 6). Average temperatures in December through February are in the low 50-degree range for North Florida and the Panhandle, transitioning to the high 60’s in South Florida. During the cold season, extratropical cyclones are responsible for significant variability in weather patterns, where cold waves can have major impacts to the landscape (Runkle et al. 2022).

Strong cold fronts frequently bring freezing temperatures to the northern regions where the number of freezing nights averages 15-20 per year. That drops to an average of less than 5 per year in central Florida and less than once per year for much of South Florida. Freezes in winter months are one of the major causes of agricultural damage. During the early 19th century, agricultural producers of citrus, sugarcane and winter vegetables were forced to shift towards South Florida due to a series of strong freezes. Additionally, the number of freezing nights that occur annually varies by region (Figure 7), where the Panhandle and Northern Florida experience more freezing nights on average than the rest of the Peninsular region of the state. Freezing temperatures pose a substantial risk for Florida’s agriculture including citrus, winter vegetables, and the tropical aquatic fish industry. Additionally, a decline in the frequency and severity of freezing temperatures also leads to an increase in the populations of disease-carrying insects such as mosquitos, agricultural pests and diseases, and the northward spread of invasive species.

Particularly under El Niño conditions, Florida tends to have more precipitation during winter months and winter mean temperatures are lower (Hansen et al. 1999 as cited in Goto-Maeda, Shin, and O’Brien 2008). Extremely cold events, however, have predominantly occurred in ENSO neutral years, which are neither associated with El Niño or La Niña (Goto-Maeda, Shin, and O’Brien 2008). While there have been no long-term trends established in the number of freezing nights, the higher numbers have generally decreased since the late 1970’s (Runkle et al. 2022).

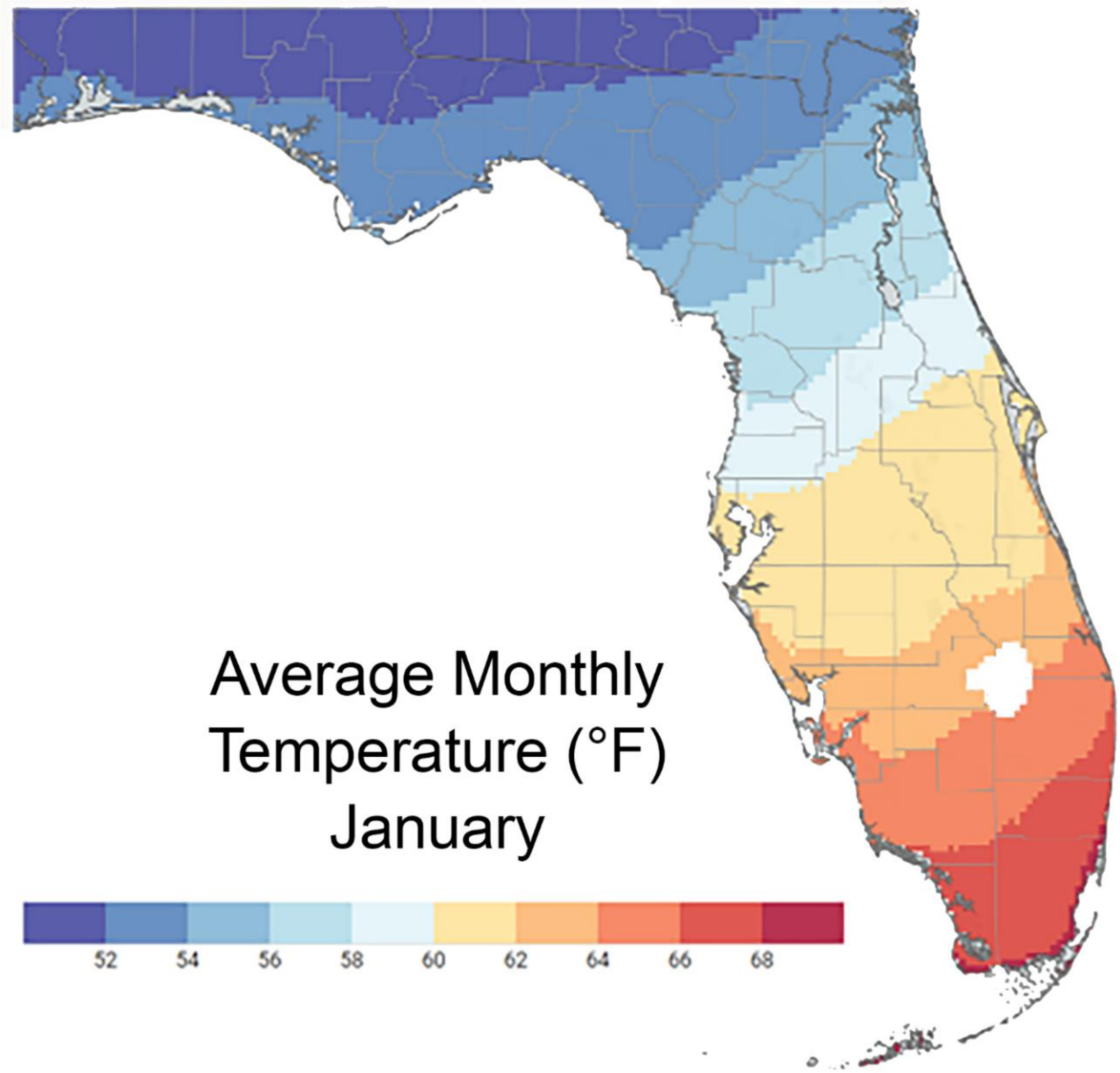


Figure 6. Florida Average January Temperatures, 1991-2020. (Data from NCEI Normals (1991-2020) using Gridded Mapper Tool at https://ncei-normals-mapper.rcc-acis.org; CES 2023a.)

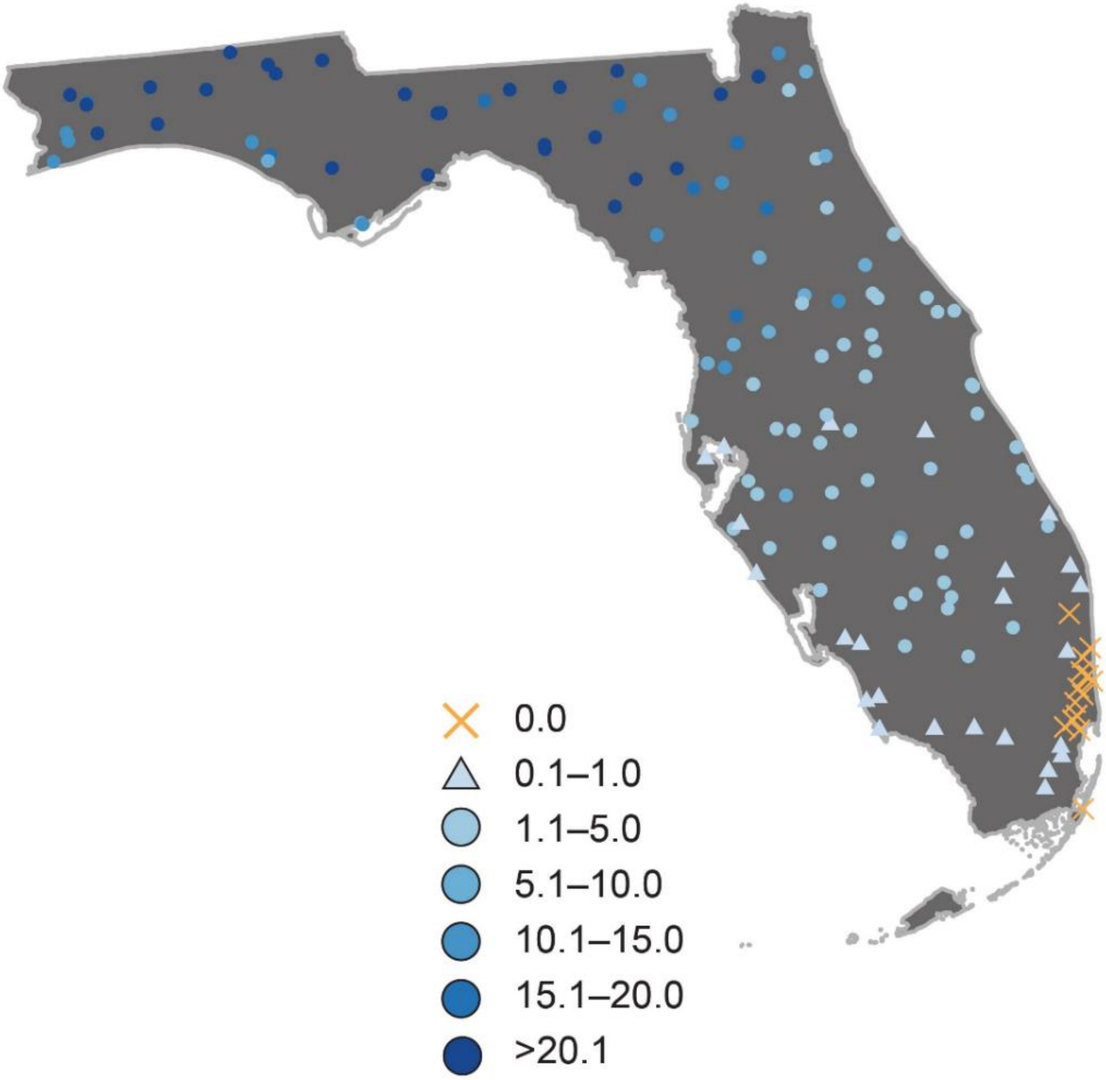


Figure 7. Average Number of Freezing Nights (<=32 °F). (Runkle et al. 2022.)

I.E.3. Precipitation

Florida is the second wettest state in the nation after Louisiana (Winsberg 2003). On average, approximately 54 inches of rainfall occurs across the state annually, with higher localized averages in the Southeast Peninsular region due to convection and the Northwest Panhandle due to a combination of passing fronts and convection across two rainy seasons (Winsberg 2003). Florida's precipitation is subject to regular and in some cases predictable natural variability, both on an annual and on a decadal basis (Zierden 2023). The wettest year on record was 1947 with 72.9 inches of rainfall, and the driest was 2000 with 40.3 inches of precipitation (Runkle et al. 2022). The driest long-term period was 2006-2010 where only 47.9 inches of rainfall fell annually on average.

Peninsular Florida has a well-defined summer rainy season (May 15–October 15) that is characterized by frequent afternoon thundershowers, often initiated by convergence from the inland progression of the sea breeze from the west and east coast. Historical averages for February and June illustrate this seasonality (Figure 8). Rainfall from tropical systems, whether a named storm or a weaker depression or wave, is another contributor to summer rainfall totals with estimates of 30-40% of rainy season rainfall. Rainfall generally averages 6-8 inches or more per month during the rainy season, but only 3 inches or less during the dry season. The Panhandle also experiences a second wet season during winter months, caused by frontal passages and low-pressure systems that impact the region (Collins et al. 2017), which is why the Panhandle is one of the wettest parts of the state. Southeastern Florida is also considered one of the wettest regions, while the Florida Keys and the offshore bar of Cape Canaveral are the driest. On days where there is a measurable amount of precipitation across the state, approximately 30 to 35% of events have accumulations of at least a half inch (Winsberg 2003). Recent data shows that eastern Florida has experienced a slight decline in annual rainfall, while western Florida has experienced a slight increase (Marvel et al. 2023: Fig 2.4).

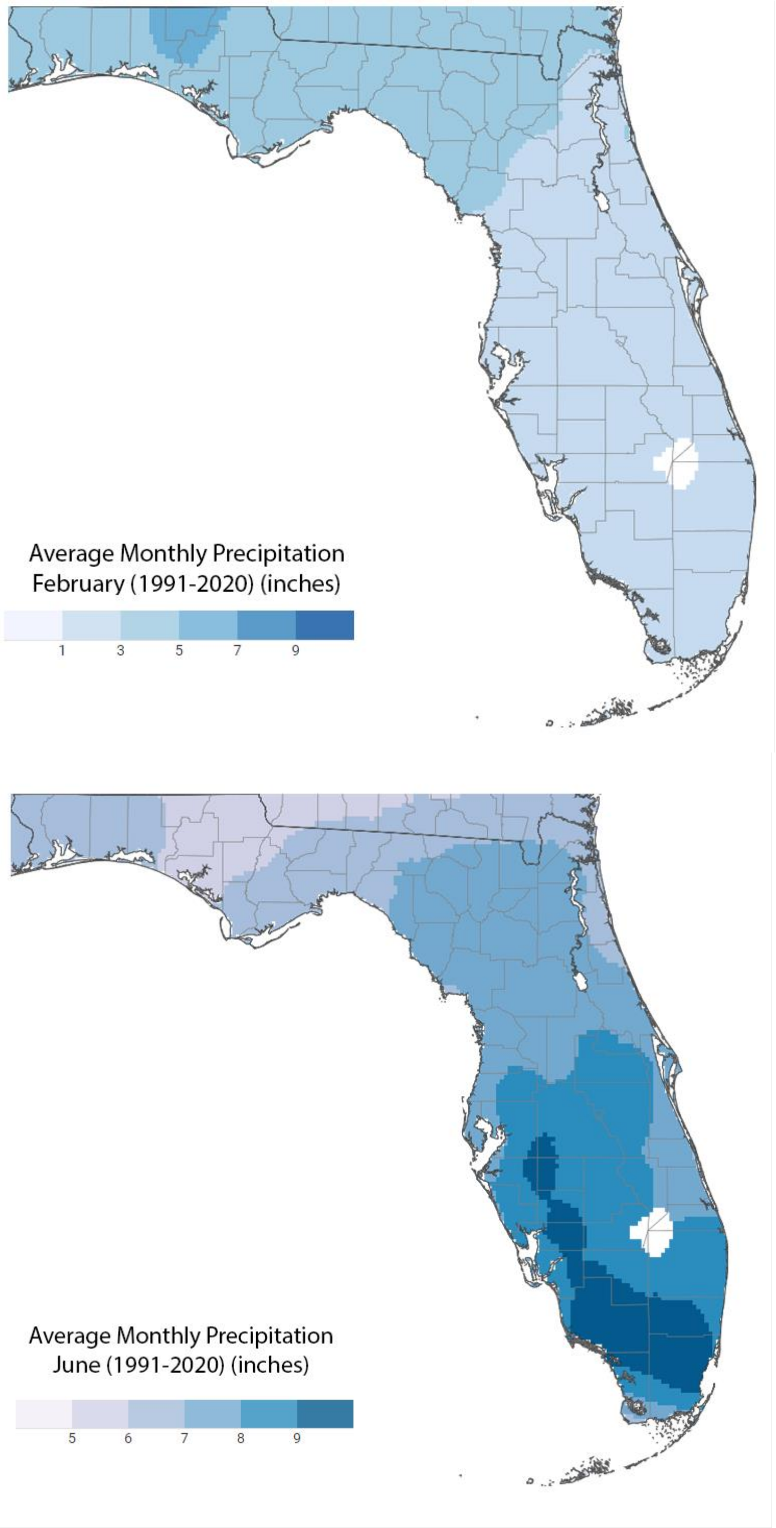


Figure 8. Average February (top) and June (bottom) Rainfall in Inches Based on 1991-2020 Normals. (Data from NCEI & National Oceanographic Atmospheric Administration (NOAA); CES 2024a and 2024b.)

I.E.4. Climate Variability and Trends

Additionally, Florida’s climate is subject to natural variability due to the influences of the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the Atlantic Multi-decadal Oscillation (AMO), and other factors such as the North Atlantic Oscillation (NAO)/Arctic Oscillation (AO) and solar cycles (Kirtman et al. 2017).

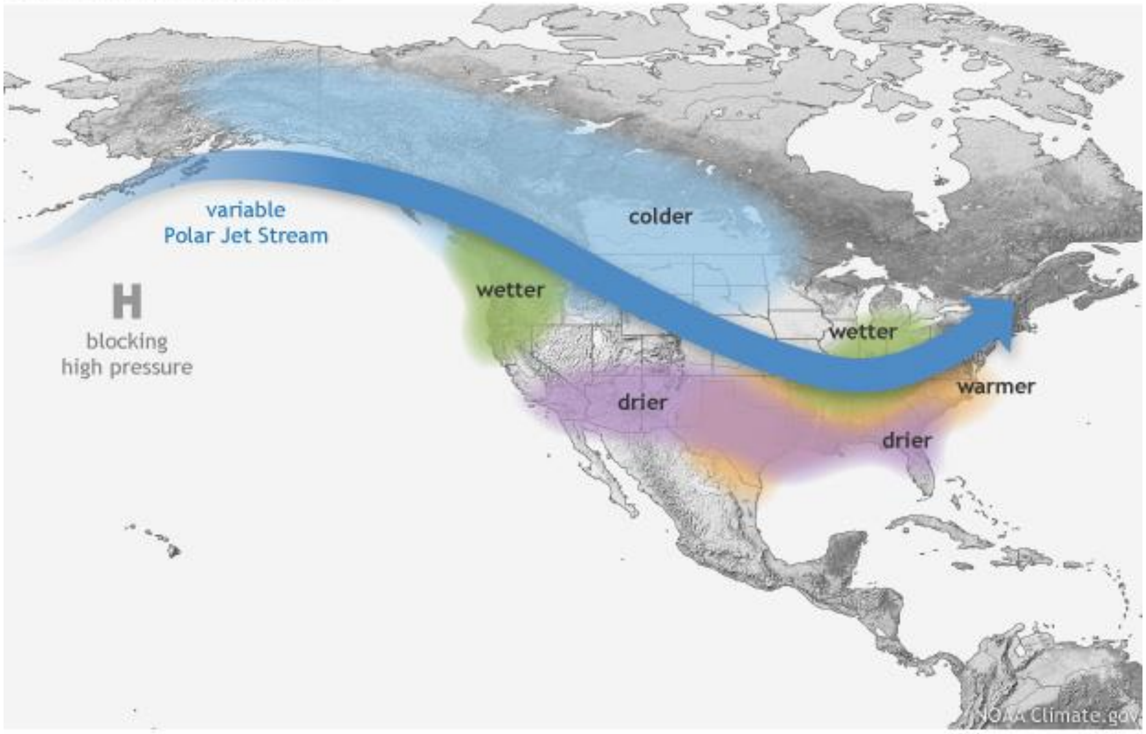
The most identifiable driver of these interannual changes is the El Niño/La Niña cycle in the Pacific Ocean. Very briefly, the El Niño/La Niña cycle describes year-to-year (or longer) changes in the ocean and sea surface temperatures of the equatorial Pacific Ocean, from the coast of South America extending to the international date line. Because of ocean dynamics and changes in the persistent trade winds, this area can become unusually warm every 2-7 years (El Niño) or unusually cold (La Niña). The presence or absence of this source of heat and humidity from the ocean’s surface works its way into the upper atmosphere, ultimately impacting the normal strength and position of the jet streams over North America and the climate of the colder months (November through March). The schematic below (Figure 9) shows the typical response of the jet streams and ensuing temperature and precipitation patterns during El Niño and La Niña episodes.

Despite being situated on the opposite coast and well away from the Pacific Ocean, Florida is the state that experiences the most impactful and consistent climate variations from the El Niño/La Niña cycle (Winsberg 2003). This oscillation is a well-known predictor of Atlantic hurricane activity with the El Niño phase typically leading to fewer tropical storms and hurricanes that could impact Florida. During the cold weather months, the El Niño phase brings 30-40% more rainfall, frequent storminess, and an increased threat for severe weather to the entire state. La Niña, on the other hand, leads to 30% less winter rainfall and warmer temperatures. El Niño episodes usually only last one year, whereas La Niña can persist for two to three years and set the stage for prolonged and severe drought.

ENSO is the single most important predictor of extreme weather in Florida (Collins et al. 2017). While ENSO causes extreme weather like floods and droughts across most of the world, incidence of torrential rain is often associated with the intermediate La Niña periods in Florida (Winsberg 2003). Precipitation amounts during the Florida dry season have been found to be larger during El Niño years compared to La Niña years as well (Teegavarapu et al. 2013 as cited in Collins et al. 2017).

The AMO is also influential in the weather patterns that occur across the state. AMO warm phases indicate a high likelihood of precipitation events lasting more than 24 hours, particularly associated with tropical cyclone landfalls (Curtis 2008 and Teegavarapu et al. 2013 as cited in Collins et al. 2017) and often shift the precipitation events to earlier in the year (starting in June) rather than the cooler AMO periods which cause later shifts (starting in August). However, the effects are not uniform, as some areas of Central and Southeast Florida, as well as the Panhandle, experience less sensitivity to AMO than other regions of the state (Collins et al. 2017).

WINTER LA NIÑA PATTERN



WINTER EL NIÑO PATTERN

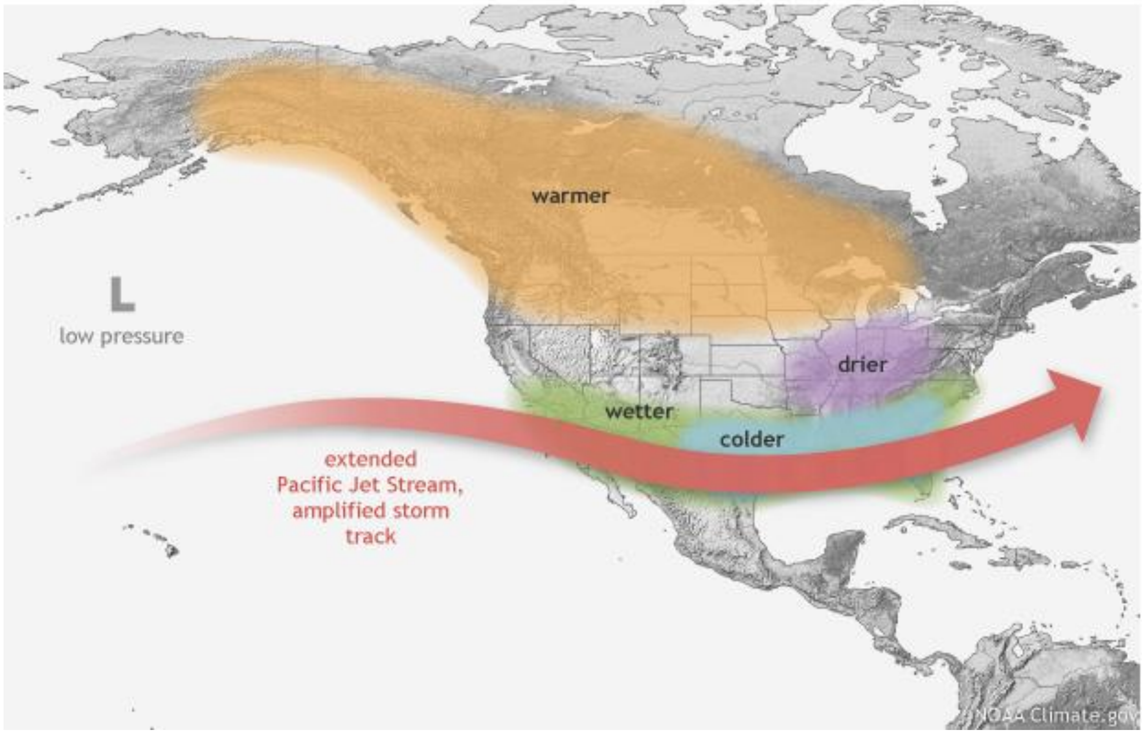


Figure 9. Typical Winter Jet Stream Patterns during El Niño and La Niña Episodes. (Lindsey 2017.)

I.E.5. Hurricanes and Tropical Storms

Since 1953, 83 disasters have been declared in Florida for severe and tropical storms (FEMA 2023). Of those, 59 declarations were designated as a Major Disaster Declaration and 24 were designated as an Emergency Declaration. Severe thunderstorms, lightning, tornadoes, wind, tropical storms, and flooding are among the most common hazards experienced by Florida (Emrich et al. 2013). Figure 10 depicts the number of systems experienced in the Atlantic Basin annually from 1850 - 2015, indicating that Florida is no stranger to storms annually.

Human-induced greenhouse gases are contributing to increases in sea surface temperatures and a strong statistical relationship has been established between sea surface temperatures of the Atlantic and hurricane activity in the same region (Trenberth 2007). During the 1995-2000 period, Atlantic hurricane activity doubled in comparison to the preceding 24 years (Goldenberg et al. 2001). Furthermore, Song et al. (2018) indicated an increasing trend in the global lifetime maximum intensity of hurricanes from 1981-2016. Additionally, there is a strong correlation between the reduction of hurricane landfalls and El Niño, where during an El Niño year, the probability of 2 or more hurricanes making U.S. landfall is only 28% but is 48% during neutral years and 66% during La Niña (Bove et al. 1998).

I.E.5.a. Hurricane Example #1: Hurricane Michael 2018

The destructive power of hurricanes and other tropical storm events for Florida are illustrated by two recent landfalls. Hurricane Michael made landfall near Mexico Beach and Tyndall Air Force Base on October 10, 2018, as a Category 5 hurricane, producing a significant storm surge of an estimated 9 - 14 feet above ground level (AGL) across portions of the Panhandle's coast, which led to inundation and ultimately destruction to many buildings located adjacent to the coast. In addition, Michael produced high amounts of rainfall, with localized rainfall totals exceeding 10-inches and widespread totals of 3 - 6 inches (Figure 11). Sixteen known tornadoes were produced by the storm. Two tornadoes were in Florida, three in Georgia, four in South Carolina, and seven in Virginia. A combination of storm surge, rainfall and high winds resulted in 16 deaths (7 in Florida). In addition, there were 43 indirect deaths in Florida from medical issues compounded by the hurricane, falls during post-storm clean up, and traffic accidents. Jackson County, FL in particular experienced great impacts, with more than 400 destroyed buildings and 600 reported as experiencing major damage (Beven, Berg and Hagen 2019). Figure 12 illustrates some of the damage caused by Hurricane Michael in Mexico Beach, FL.

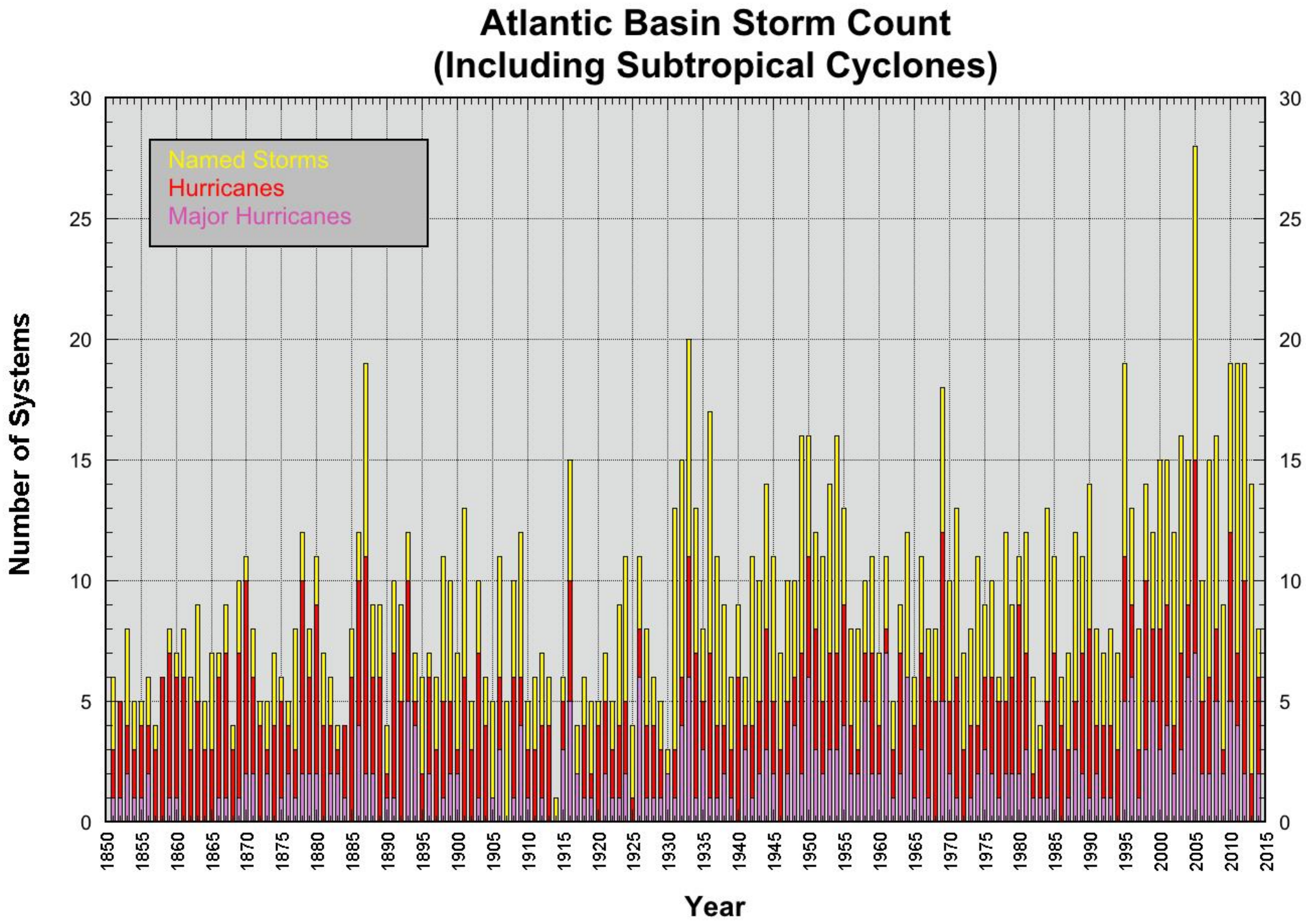


Figure 10. Number of Tropical Storms and Hurricanes in the Atlantic Basin from 1850 to 2015. (National Hurricane Center 2024.)

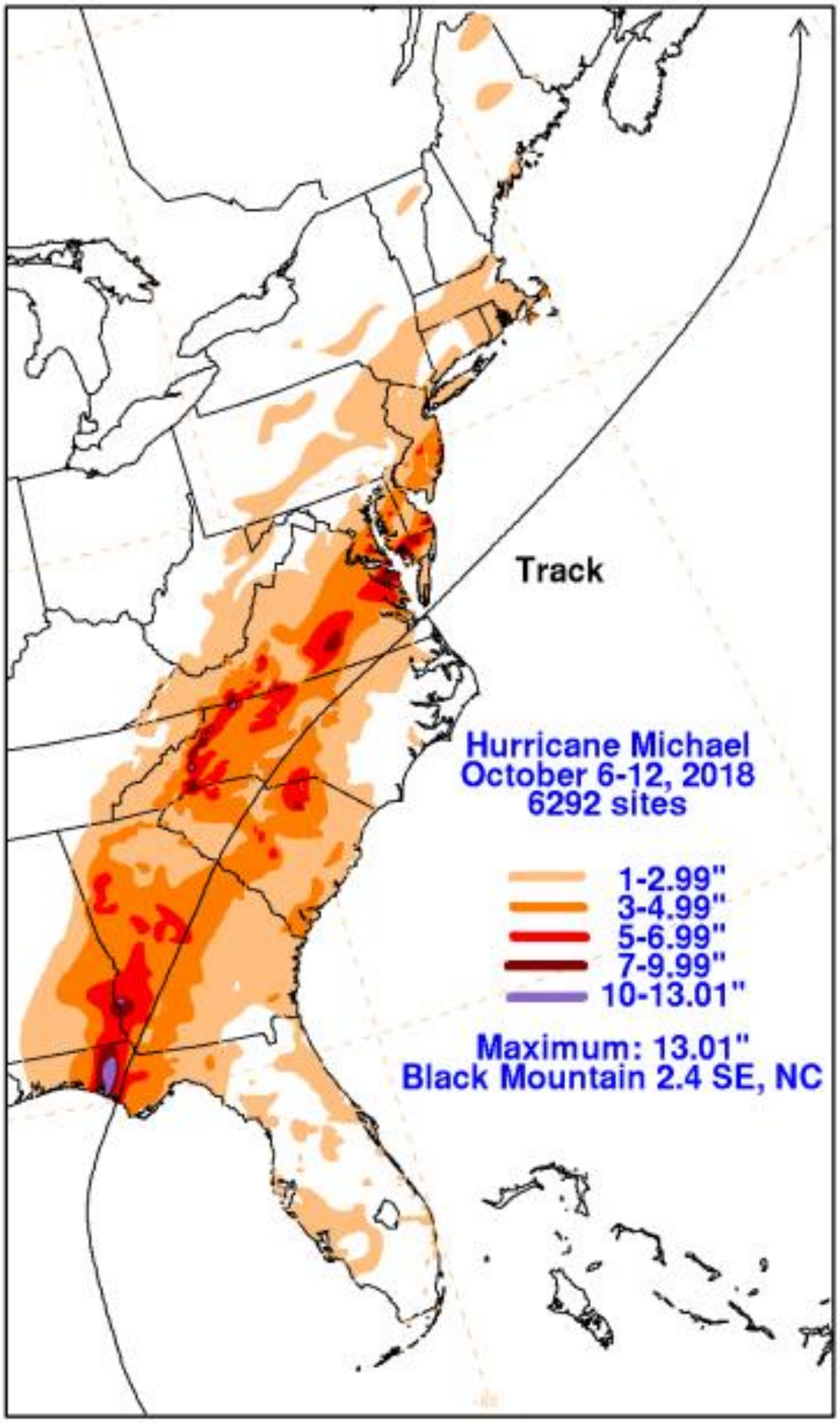


Figure 11. Hurricane Michael Total Rainfall. (Reprinted from Morgan 2019.)

Figure 12. The Ruins of Mexico Beach Following Hurricane Michael’s Landfall. (Reprinted from The New York Times, Milano, 2018.)

I.E.5.b. Hurricane Example #2: Hurricane Ian 2022

Hurricane Ian made landfall near Cayo Costa, Florida as a Category 4 hurricane with sustained winds of 150 miles per hour (Figure 13). A large portion of the coastal barrier islands of Sanibel, Captiva, Pine, and Fort Myers beach were totally washed away by a combination of storm surge and high winds. Ian also crossed the state, causing inland flooding in Central and Eastern portions of the state, due to approximately 10 to 20 inches of rainfall. Some counties exceeded 20 inches of rainfall, including Orange, Brevard, Volusia, and Seminole (Figure 14). After landfall, more than 2.6 million customers were without power, the Sanibel Island causeway was partially washed away, the Pine Island bridge (connecting the island to the mainland) was destroyed, and 152 deaths occurred (NOAA 2022).

I.E.6. Changes in Extreme Temperatures

While the number of cold days has decreased across the United States, the Southeastern region already experienced very few cold days historically. Simultaneously, the number of nights where the temperature exceeds 70 °F is increasing across much of the U.S., including the Southeastern region and the rate of growth of hot summer nights is growing faster than hot summer days (Marvel et al. 2023). The number of very warm nights has risen significantly since 1995, as the 2015-2020 multi-year average is more than twice the 1930-1934 multi-year average (Runkle et al. 2022). This decline in evening cooling is consistent with predictions about climate change. Such a phenomenon can present significant challenges for crop yields and human health.

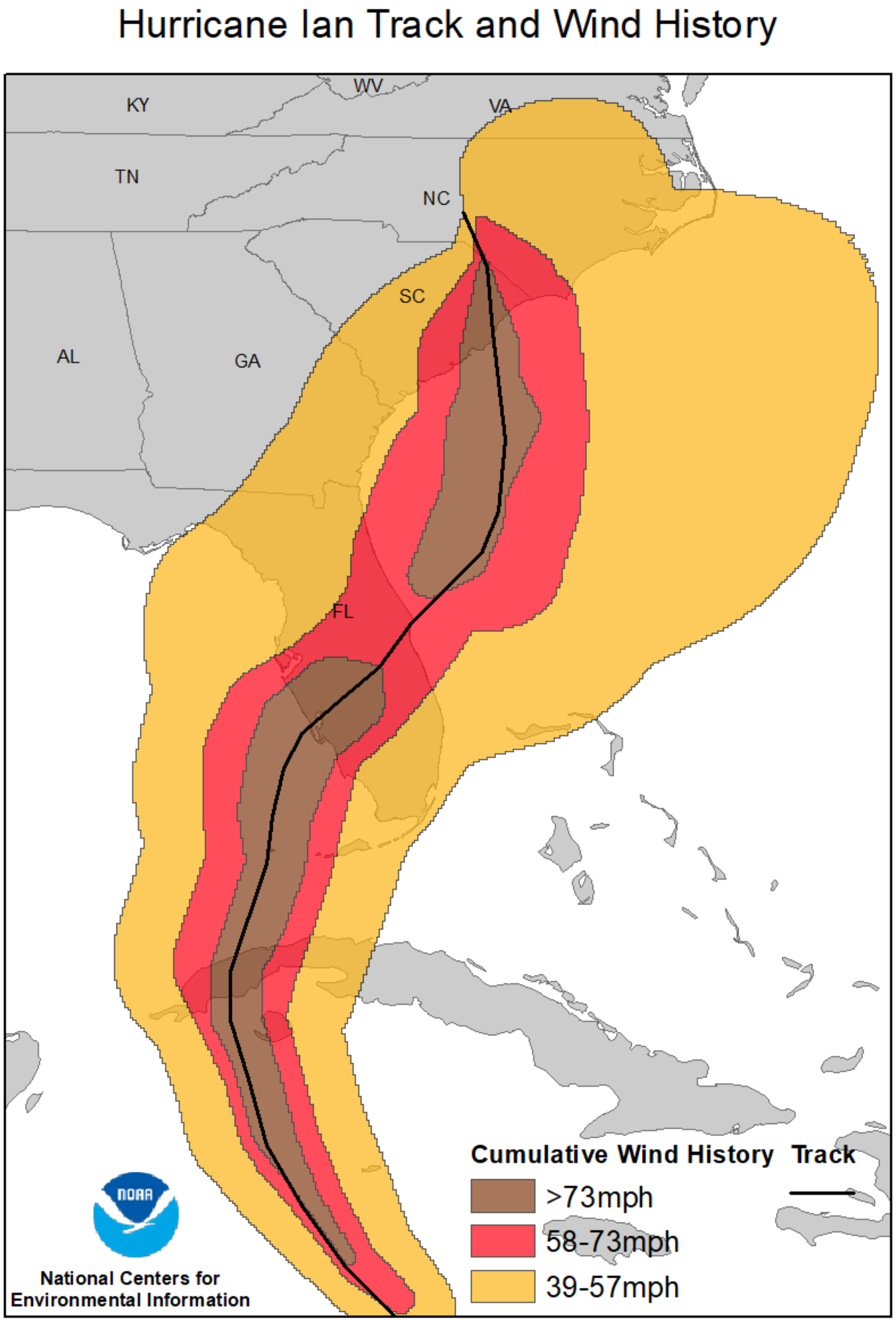


Figure 13. Hurricane Ian Track and Wind History: September 27-30, 2022. (NOAA 2023b.)

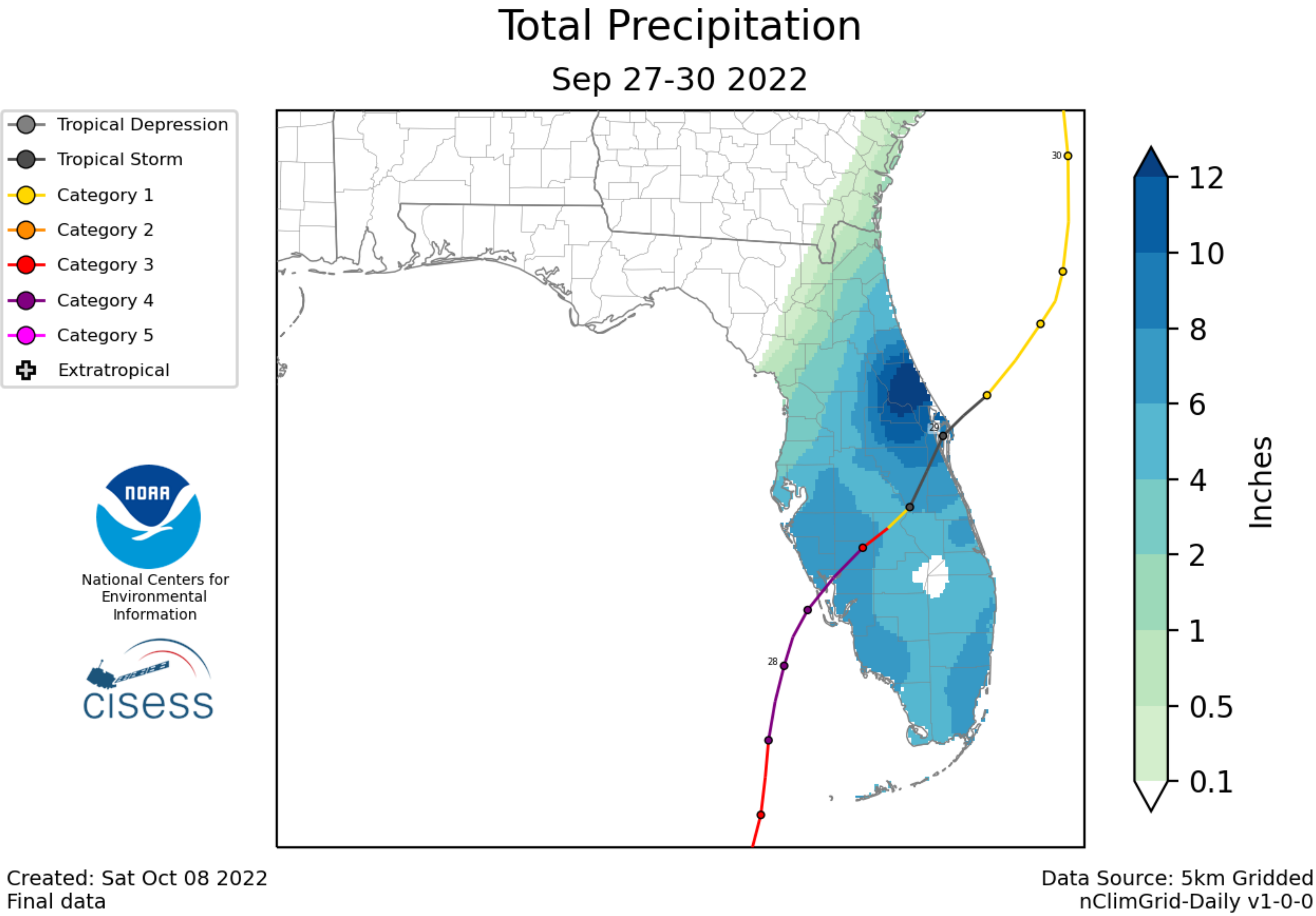


Figure 14. Hurricane Ian Total Precipitation: September 27-30, 2022. (NOAA 2023c.)

I.E.7. Climate Trends - Temperature

Since 1985, the average annual temperature of Florida has increased by approximately 1.6 °F, which is roughly equal to the global increase of average temperature during the same period (Zierden 2023; Figure 15). However, the rate of change has not remained constant during the entire period. Since 1950, Florida has exceeded average global increases of 2.7 °F, with a rise of 3.5 °F (Zierden 2023). Since the year 2000, the rate has continued to climb annually (Zierden 2023).

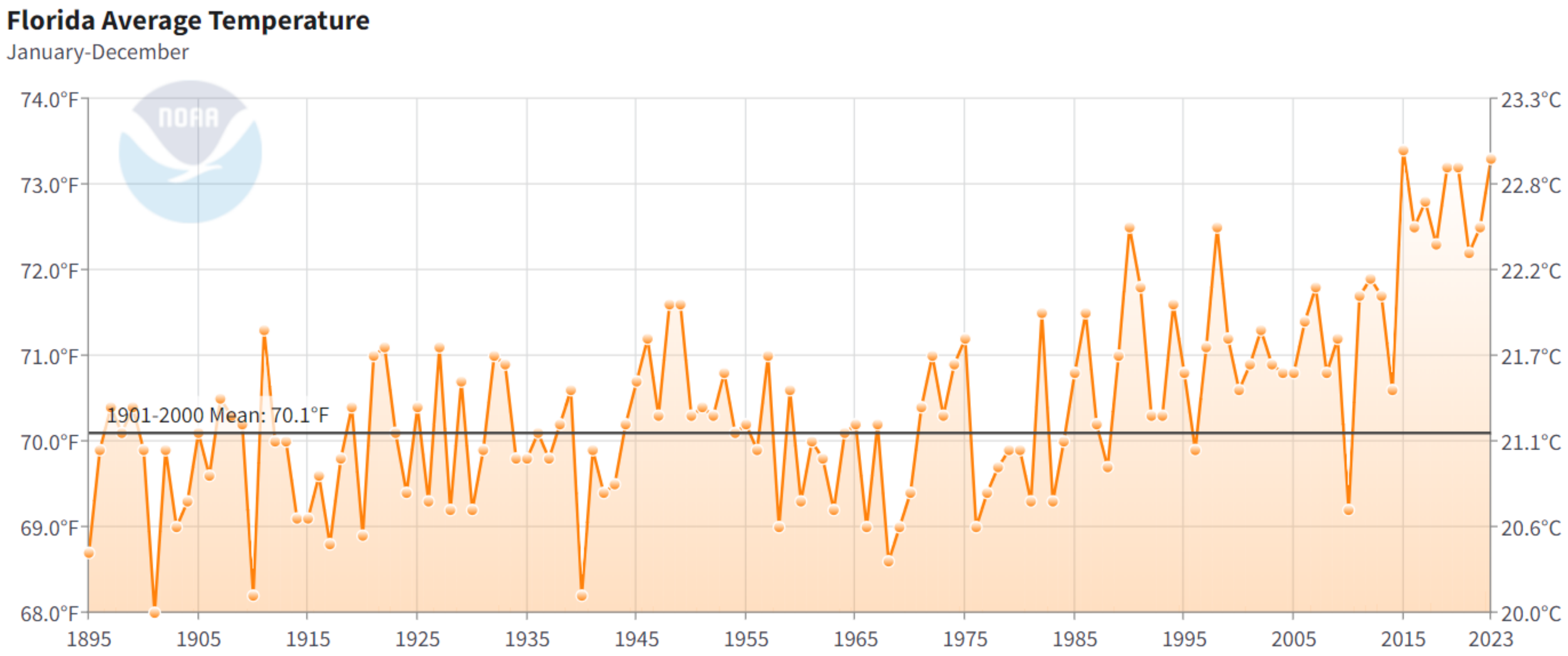


Figure 15. Florida Average Annual Temperatures, 1895-2023. (Created with NOAA - NCEI, Statewide Time Series Data Tool; CES 2024c.)

I.E.8. Precipitation

Despite increased precipitation in much of the Eastern US, compared to the first half of the 20th century, the average annual precipitation across the state has not changed significantly (Figure 16). While average annual precipitation has not varied significantly, there have been shifts in patterns and intensity of precipitation.

Weather and climate extremes reflect temporary shifts that occur in the large-scale patterns of circulation in the climate system (Karl et al. 2008). In general, extreme precipitation events (classified as a minimum of three inches of rainfall in a 24-hour period (Winsberg 2003) are becoming more frequent and intense in connection with climate change (Powell and Keim 2015; Rahman, Senkbeil, and Keellings 2023). While the average annual precipitation across Florida has not changed significantly (Zierden 2023), 1-12 hour and 1-day extreme rainfall events are becoming more frequent (Mahjabin and Abdul-Aziz 2020).

Extreme precipitation events are significantly correlated with the AMO, particularly during warm phases, especially for events that last longer than 24 hours (Curtis 2008 and Teegavarapu et al. 2013 as cited in Collins et al. 2017). Additionally, rain of this magnitude is frequent along Florida's coasts and less frequent in the interior, where rainstorms are concentrated mostly to the warm months in areas outside of North Florida (Winsberg 2003).

Approximately 10% of the total annual precipitation that falls in Florida occurs during torrential rainfall events, and during the La Niña phase of ENSO, torrential rainfall events of 5-inches or more in a day were more common historically (1949 - 1999) (Winsberg 2003).

Florida also experiences the highest number of thunderstorms in the United States annually (Runkle et al. 2022). Often, thunderstorms are associated with convective lifting into an unstable atmosphere, which then cools and condenses into cumulus clouds. Latent heat is released into the atmosphere during condensation, increasing instability in the atmosphere and leading to the development of towering clouds of vertical development, called cumulonimbus clouds. When convective cells contain strong updrafts of air, caused by both frontal wedging and differential heating, severe weather conditions are more likely to develop. Most of the lightning that strikes Florida occurs during the warm season, focused predominantly on the central peninsula, driven by convection (Collins et al. 2017). A relationship between ENSO and lightning activity has been found, where more lightning occurs during warm El Niño episodes across the tropical-extratropical land (Satori et al. 2009 as cited in Collins et al. 2017).

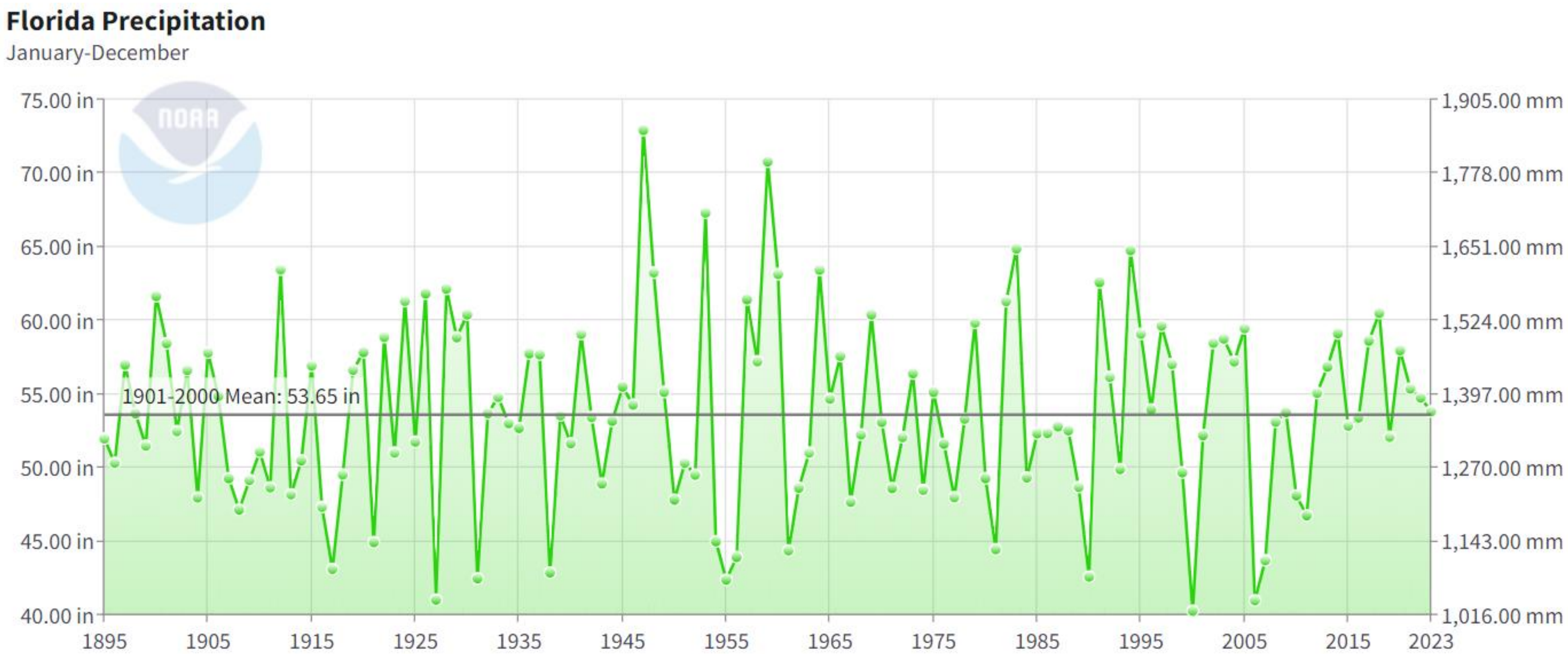


Figure 16. Florida Annual Precipitation Average, January-December 1895-2023. (Created with NOAA - NCEI, Statewide Time Series Data Tool – Florida; CES 2024e.)

I.E.9. Sea-Level Rise

Since 1900, the global average sea level has risen between 7 and 8 inches, and it is expected to continue to rise with a warming climate in the future (Runkle et al. 2022). Florida is vulnerable to sea-level rise, as it has low-lying coastal topography, coupled with 8,400 miles of shoreline (Zierden 2023). The main causes of sea-level rise globally are thermal expansion due to the warming of ocean temperatures and melting of land-based ice resulting in the addition of freshwater into the ocean (Zierden 2023). Sea levels also vary frequently due to vertical land movement, ocean circulation patterns, local gravitational changes, and variations in temperature and salinity of ocean water (Zierden 2023).

The Southeast region of the United States has experienced a 0.12-inch change in sea level annually since the early 1990s. This value is roughly equivalent to global estimates of sea-level rise (Zierden 2023). This has resulted in a change of approximately 8 inches of total height. The southeastern Virginia Key sensor indicates a change of 8 inches since 1950[1], but also a 1-inch increase every 3 years over the past ten years, based on continuous tide gauge data (NOAA 2024; Figure 17). Around Miami, sea-level change has been approximately 6 inches over a 31-year period (1985 - 2016), but is anticipated to reach 6 additional inches of increase within a 15-year time period from that time.

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[1] Earlier data stored in database as station 8723170 and 8723080 (NOAA Tides and Currents 2023).

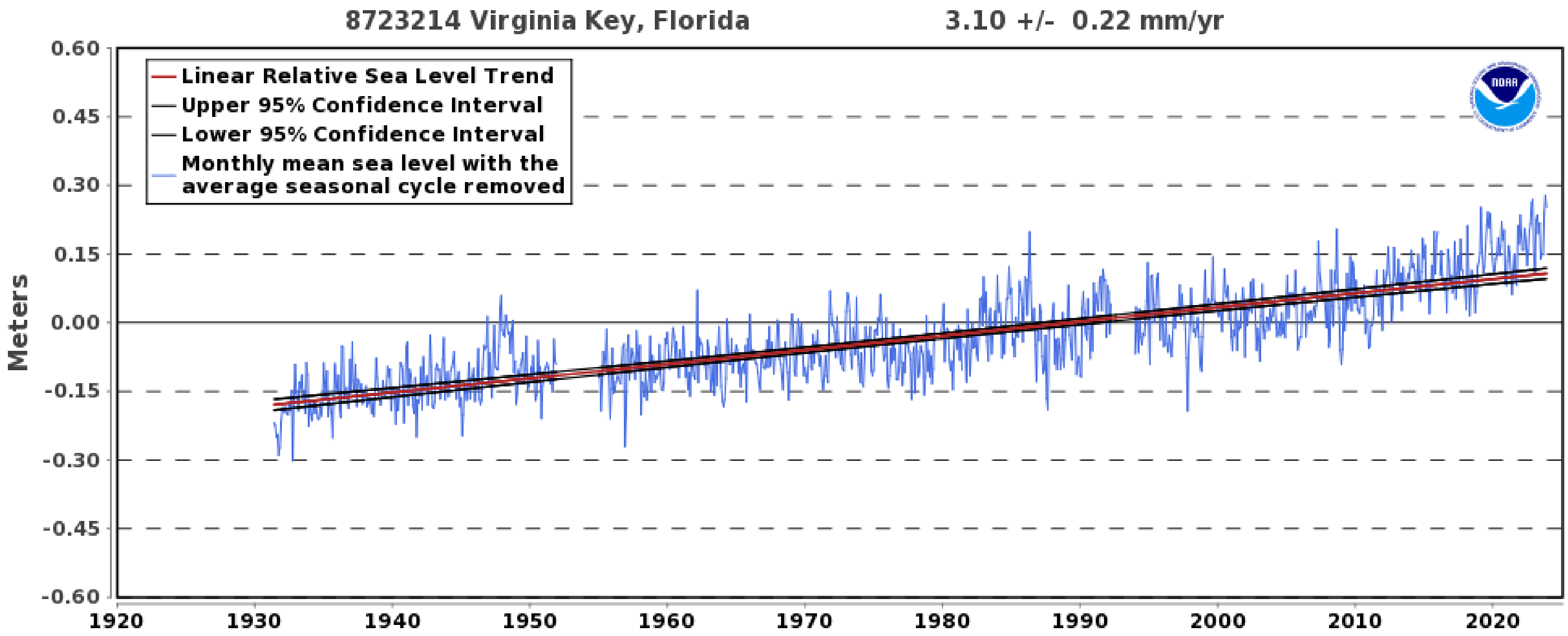

Figure 17. Sea Level Trend Data for Virginia Key, Florida, plotted values are relative to the most recent mean sea level datum produced by CO-OPS. (NOAA 2024b.)

I.F. Four Principal Land Uses in the FLWC

Understanding how the FLWC interacts with Florida's climate resilience first requires a basic understanding of the number of FLWC acres and their principal current land uses. The FLWC spans nearly 18 million acres of contiguous open space, encompassing almost exactly half of the state's land area (Florida Wildlife Corridor Foundation 2024). Currently, the FLWC comprises approximately 9,820,356 acres of protected land (56%) and 7,856,968 acres of opportunity areas[2,3] (44%) (Figure 18). This distinction between acres in the FLWC that are conserved versus are not presently conserved is important to keep in mind. The nearly 18 million acres constitutes the geography of the conservation envisioned by the law, even if only 9.7 million acres are currently protected.

For the purposes of this report, the FLWC is composed of five generalized land use types (Figure 19), four of which are of direct interest for the question of climate resilience. These include approximately 11,494,708 acres of natural lands (65%), 4,959,310 acres of working lands (28.1%), 332,681 acres of intensive agricultural lands (1.9%), and 462,614 acres of developed lands (2.6%). There are an additional 428,011 acres of open water (2.4%) in the FLWC. The remainder of this section summarizes the contemporary number of acres in, and geographic distribution of, the first four of these land use categories. The following descriptions of land use categories by acreage are illustrative but not exhaustive.

The ***natural lands*** (as defined in Section I.G.5) category is composed of uplands and wetlands. The upland ecosystems with the most acres in the FLWC include Mesic Flatwoods (1,078,368 acres), Sandhill (621,599 acres), Mixed Hardwood Coniferous Forests (409,123 acres), Sand Pine Scrub (217,102 acres), Upland Pine (179,755 acres), Dry Prairie (145,563 acres), and Scrub (113,520 acres). The wetlands ecosystem types with the most acres in the FLWC include Glades Marsh (1,386,394 acres), Mixed

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[2] The Florida Ecological Greenways Network (FEGN) defines opportunity areas as lands and waters within the Florida Wildlife Corridor that are not currently conserved, or green spaces within the FLWC that lack conservation status and/or that are between or contiguous with already-conserved lands (FDEP 2022).

[3] This report uses the Cooperative Land Cover (CLC) data set (https://myfwc.com/research/gis/wildlife/cooperative-land-cover/) to assess and discuss land cover/land use within the Florida Wildlife Corridor (FLWC) related to resiliency. Though the CLC is considered best available data for statewide natural community and many semi-natural land covers, there are other Florida specific options that could result in different estimates of some land use types within the state and the FLWC. These options include FLUCCS (https://geodata.dep.state.fl.us/datasets/FDEP::statewide-land-use-land-cover/about), the Florida Statewide Agricultural Irrigation Demand (FSAID) agricultural land cover data (https://www.fdacs.gov/Agriculture-Industry/Water/Agricultural-Water-Supply-Planning), and statewide parcel-based land use data (https://www.arcgis.com/home/item.html?id=683014d92d234ff7bcda79e9a3489042). All these sources of land cover and/or land use data have specific uses and identify land use coverage in different ways and can be better fits for some conservation and land use planning projects depending on goals. For example, the University of Florida Center for Landscape Conservation Planning used a hybrid land cover dataset combining the FSAID and CLC databases to identify potential impacts of projected future development and conservation significance of agricultural land cover classes. This hybrid land cover data set estimates that there are 2,667,539 acres of grazing/ranchland in the FLWC versus the 1,749,024 acres identified using CLC. For intensive agriculture, the hybrid land cover data set estimates 462,148 acres versus 322,681 acres using CLC. This hybrid agricultural land cover dataset using FSAID/CLC is focused on identifying agricultural land uses, therefore it is not surprising that it would identify more agricultural land than a more general land cover dataset. Finally, parcel-based land use is also relevant to the discussion of pros and cons of using various land cover/land use sources and especially in regard to resiliency and the role of working lands. Parcel data identifies land use based on how a property is taxed, so parcels that are primarily used for grazing or silvicultural purposes are identified as such. This means that natural systems and other land covers that are on such parcels are also included as "grazing" or "silviculture" in parcel data if that is the predominant use. However, identifying such parcels can then be a useful way to identify additional conservation or resiliency benefits of these working land parcels including acres and locations of wetlands, intact floodplains and surface water buffers, and other natural communities. Indeed, "working lands" parcels contain millions of acres of functional wetlands, floodplains, and other natural communities that are essential for facilitating resiliency, and approximately 80 percent of the currently unprotected Opportunity Areas within the FLWC are in grazing/ranch or silvicultural parcels.

Hardwood-Coniferous Swamps (835,567 acres), Mixed Scrub-Shrub Wetlands (772,142 acres), Mixed Wetland Hardwoods (582,588 acres), Marshes (502,603 acres), Cypress (454,525 acres), and Mangrove Swamps (408,614 acres) (Figure 20).

The ***working lands*** category (as defined in Section I.G.4) by acreage includes: Coniferous Plantations (2,607,332 acres), Improved Pasture (1,540,089 acres), Rural Open Land (273,967 acres), Unimproved Woodland/Pasture (208,935 acres), Orchards/Groves (40,898 acres), and Wet Coniferous Plantations (162,835 acres).

The ***intensive agriculture*** category (Figure 21) includes: Citrus (152,640 acres), Irrigated Row Crops (67,313 acres), Field Crops (49,236 acres), Sugarcane (39,980 acres), and Row Crops (22,661 acres). Most intensive agricultural lands that are within the FLWC are within specific corridors needed to make functional connections between high priority areas of ecological significance.

The ***developed lands*** category includes: Transportation – Highways (290,406 acres); Extractive (35,866 acres); Residential – Low Density, <2 Dwelling Units/acre (28,897 acres), Utilities (27,172 acres); Residential – Medium Density, 2-5 Dwelling Units/acre (10,463 acres); and Residential – High Density, >5 Dwelling Units/acre (1,436 acres). Figure 22 depicts the intersections between urban lands and the FLWC.

The precision of these land-use classifications belies some underlying technical challenges. Zooming in to a specific location in a small number of cases may reveal a discrepancy. For example, some developed lands are within the boundaries of conserved or opportunity portions for various reasons. Very low-density residential development is occasionally inconsistently classified in land cover data and therefore may or may not show up as developed depending on the source and version of land cover/land use data. Some developed facilities within conservation lands (such as military lands included as conservation lands in the Florida Managed Areas Database) are included within the FLWC since these facilities occur on protected lands. Extractive (mining lands) are included in southwest Florida phosphate mining region within the FLWC when they are part of the Integrated Habitat Network plan for this region. In addition, some development included roads (Figure 23), linear utility facilities, and some residential development can be added to the FLWC through the final FEGN spatial optimization process, where very narrow gaps less than 100-meters in width surrounded by the FEGN are added to the Network. Finally, there are time lags between the identification of developed areas in source data and new development after the last boundary delineation. These challenges are inherent to the field of land use classification and are as such unavoidable. Nonetheless, the quantitative values, and their geographic distributions, presented here are high quality characterizations of Florida’s contemporary land uses.

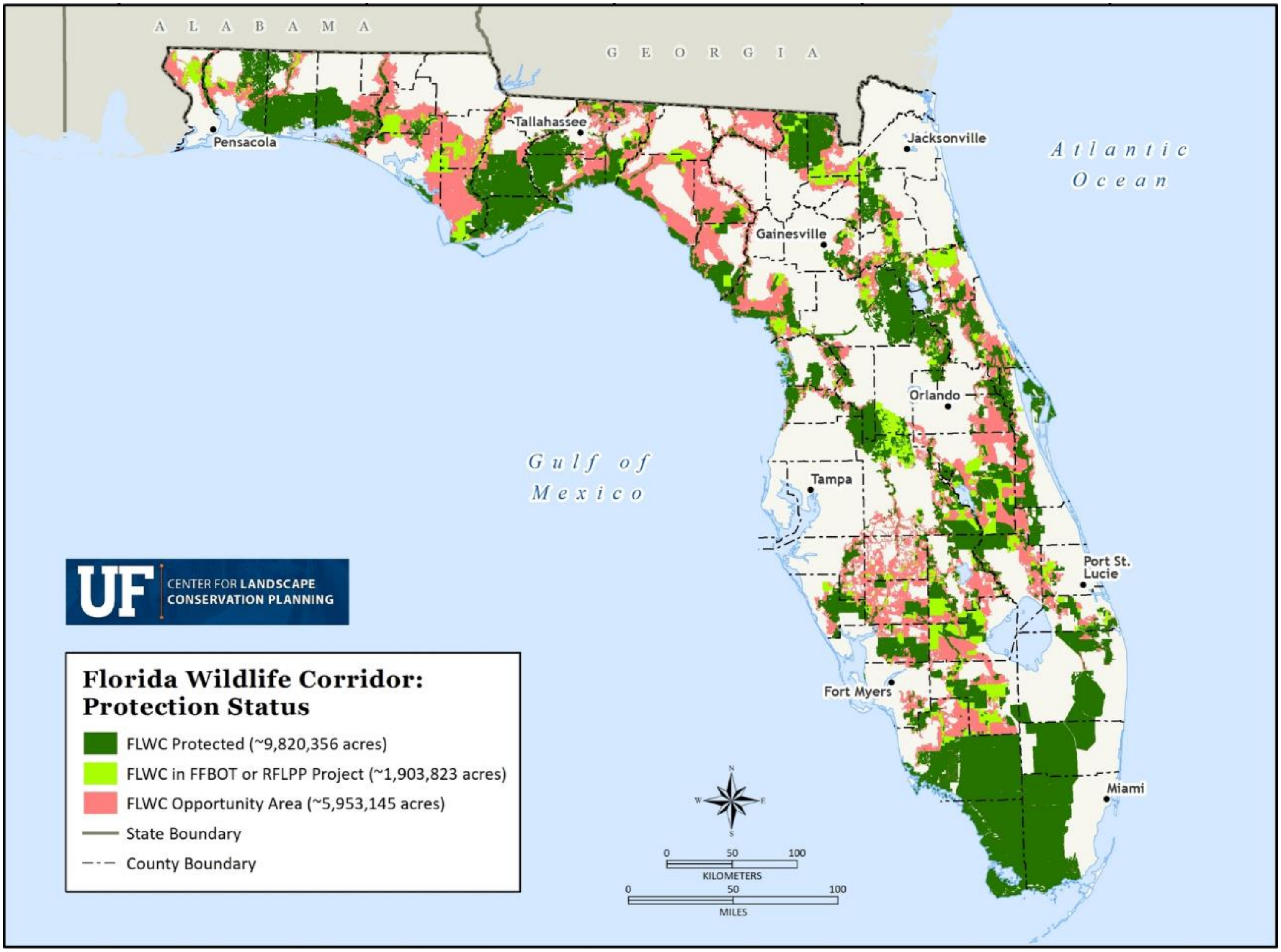

Figure 18. Protection Status of the Florida Wildlife Corridor. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2024c.)

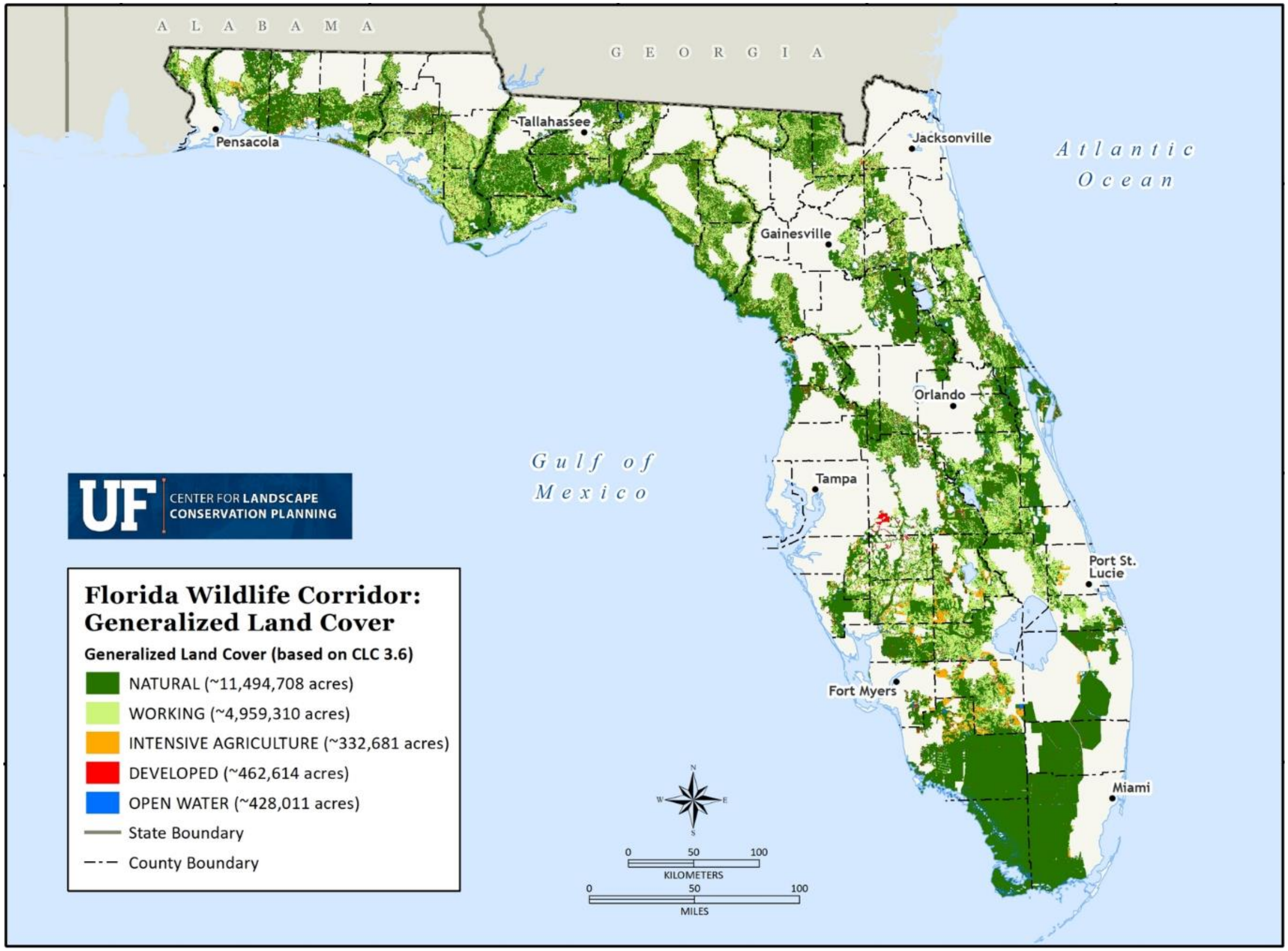

Figure 19. Florida Wildlife Corridor: Generalized Land Cover. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2024b.)

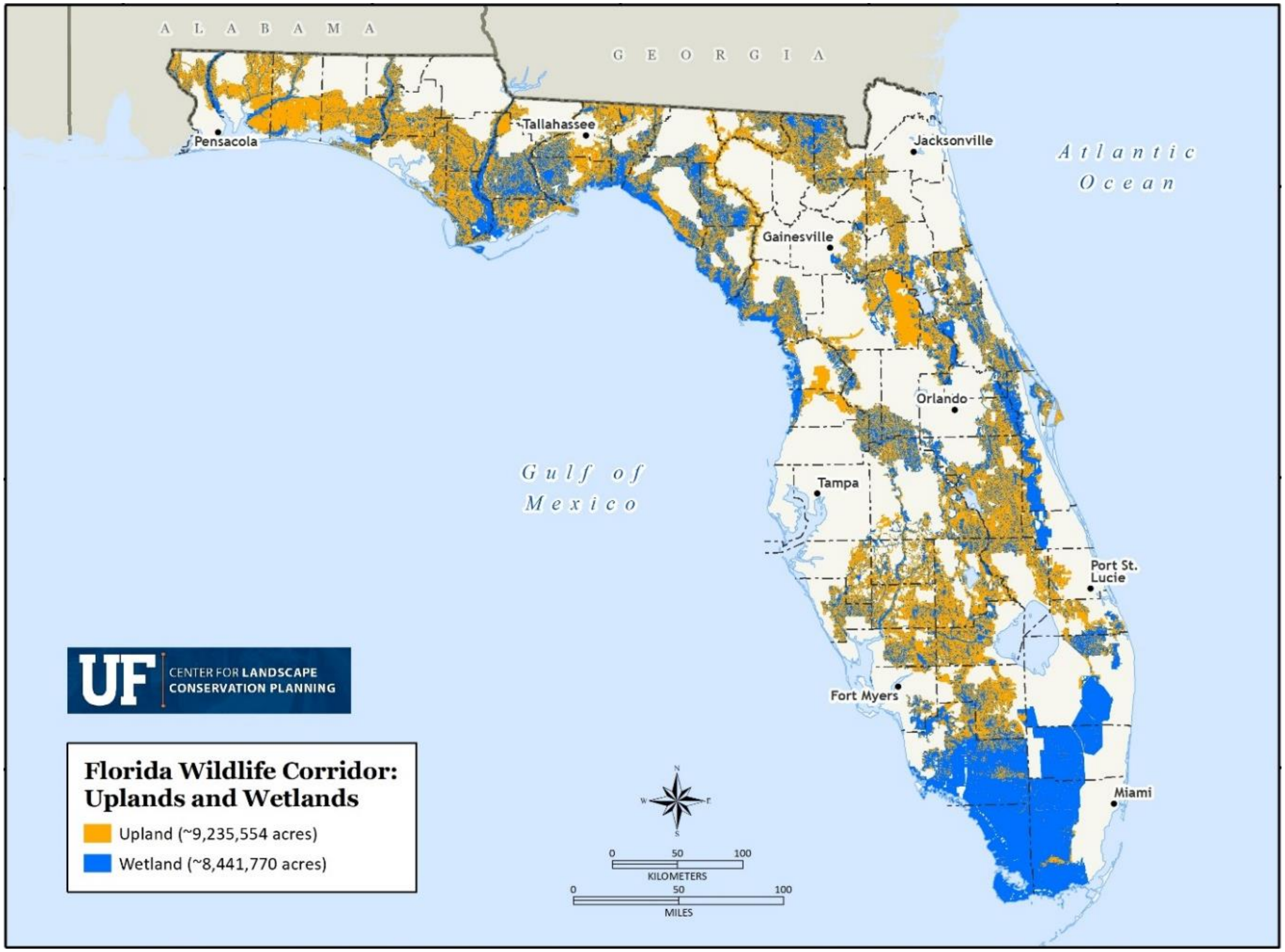

Figure 20. Florida Wildlife Corridor: Uplands and Wetlands. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2023c.)

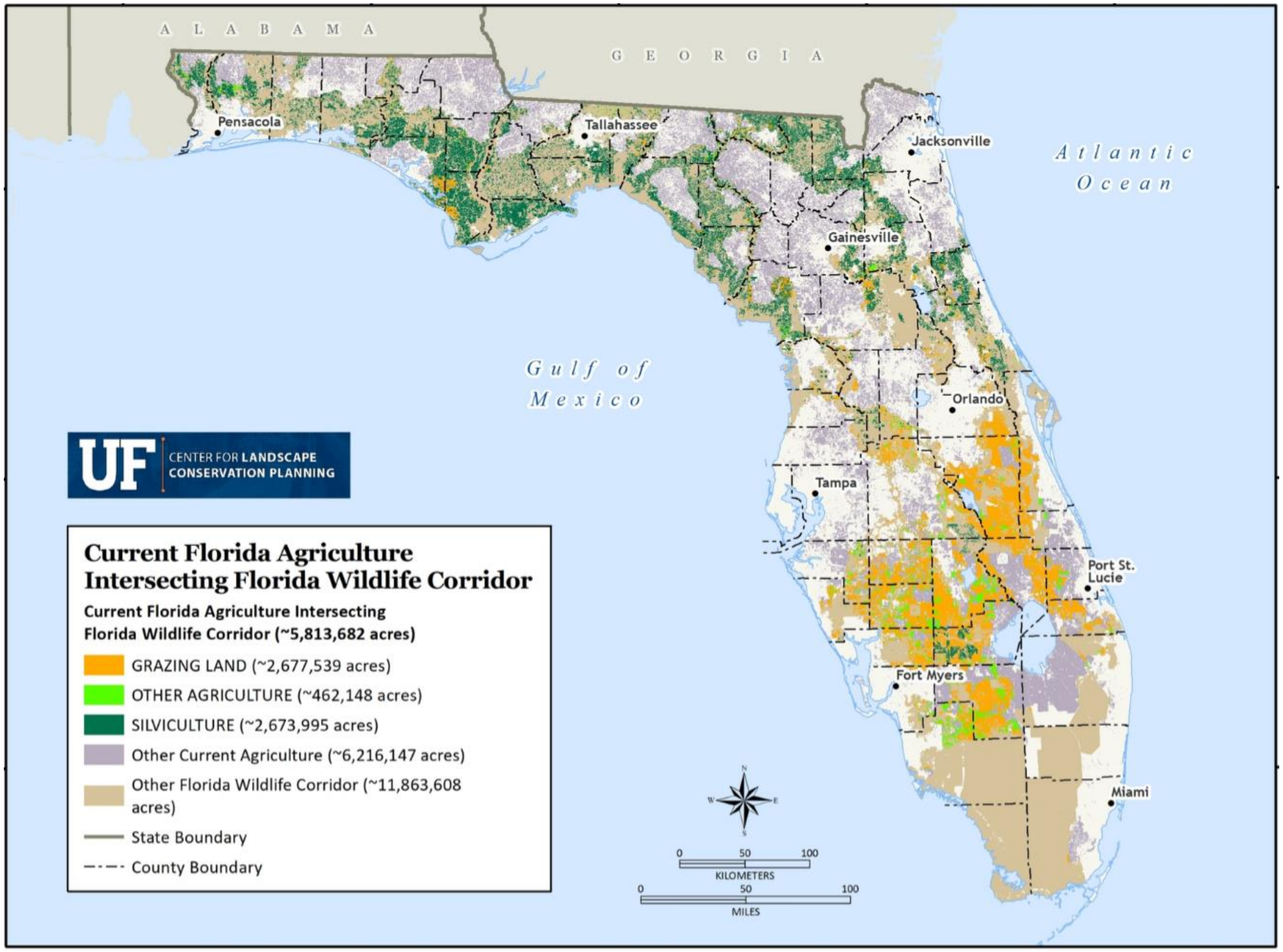

Figure 21. Current Florida Agriculture Intersecting Florida Wildlife Corridor. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2023a.)

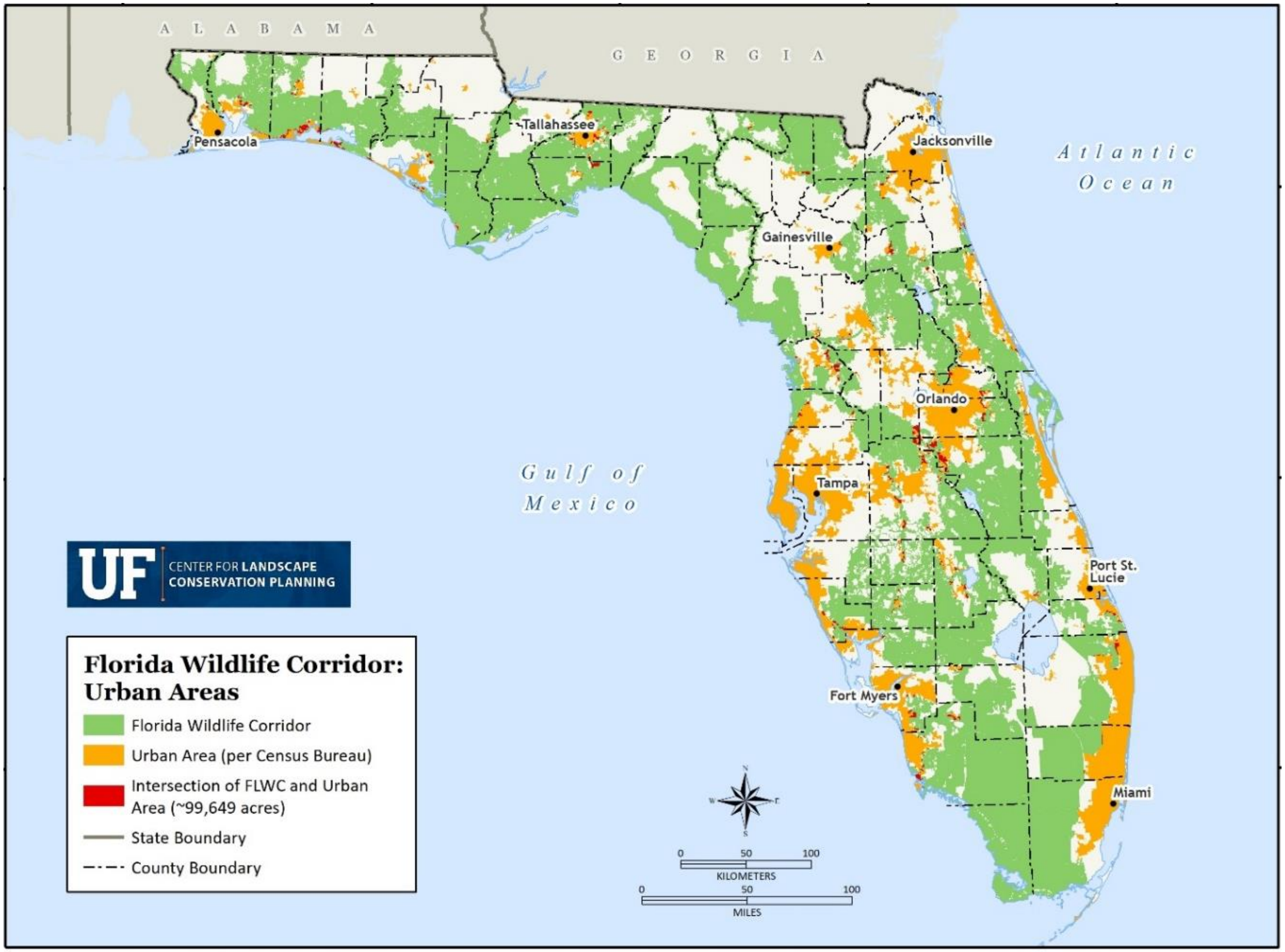

Figure 22. Florida Wildlife Corridor: Urban Areas. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2023d.)

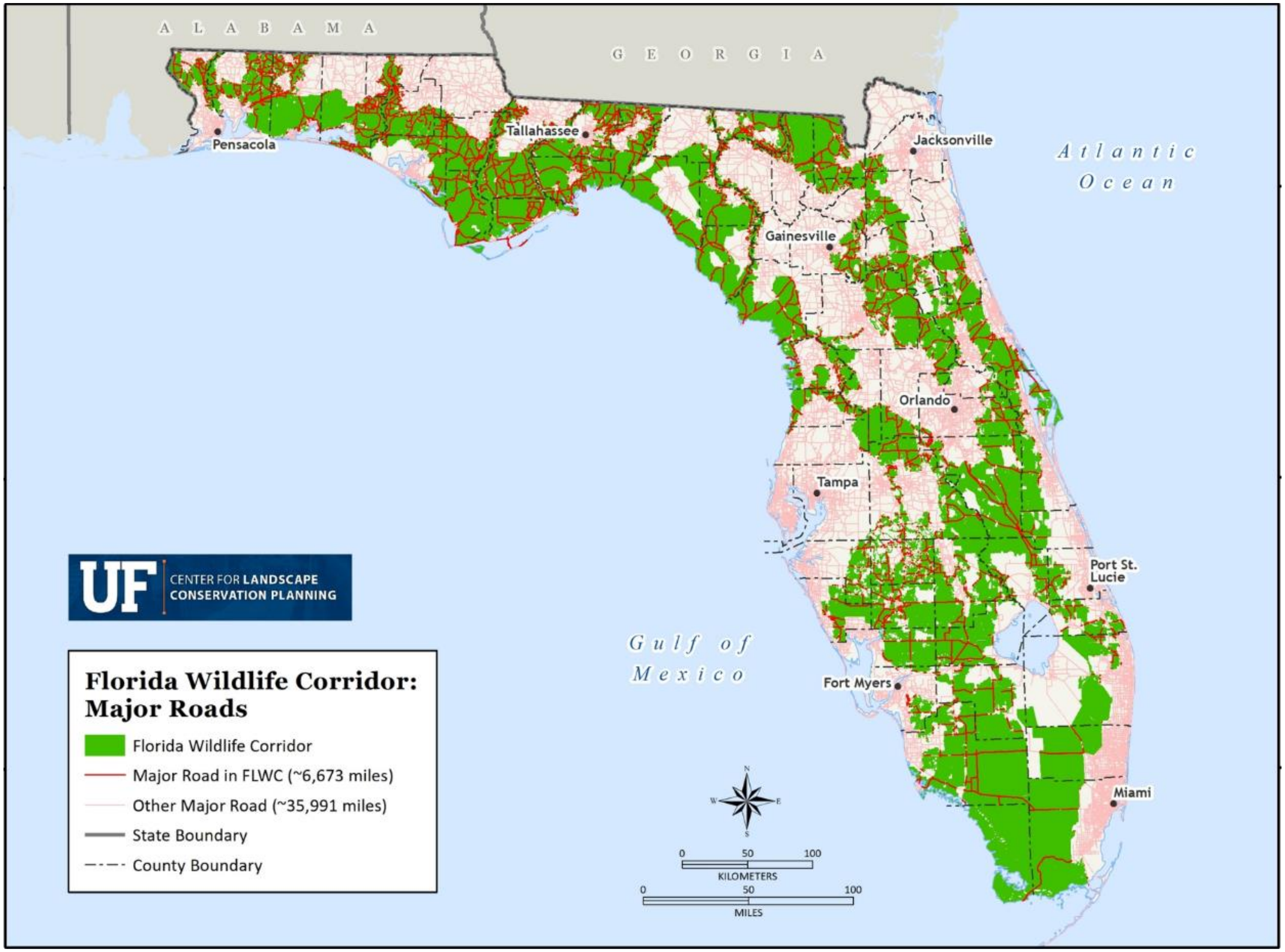

Figure 23. Florida Wildlife Corridor: Major Roads. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2022.)

I.G. The Region's Dominant Ecosystem Services and Values

The preceding sections on the history and status of the FLWC, and what kinds of land uses and economies are located in the FLWC, provide the backdrop for understanding how our environmental conditions may be affected by the twin developments of population growth and climate change. In this section, we connect the potential impacts from our double exposure to the general suite of benefits nature provides society. Specifically, we adopt the four-part "ecosystem services" schema common to conservation research for the past couple of decades.

I.G.1. Ecosystem Services Theory - Naming What Nature Provides That We May Try to Preserve

Land conservation initiatives, such as the FLWC, are largely grounded in a motivation to preserve ecosystem composition, structure, and function for the benefit of current and future human populations in places where urbanization is rapidly changing the landscape. To measure conservation policy and program successes or failures, it helps to identify which specific features of ecosystem dynamics are being proposed for conservation. These features are known as "ecosystem services," or simply put, the benefits humans derive from ecosystems (MIllenium Ecosystem Assessment 2005).

At the highest level of abstraction, ecosystem services are parsed into four main categories. ***Provisioning*** services relate to important products obtained from ecosystems, such as food, fiber, freshwater, and genetic resources. These services support human health and drive economic activity, and typically in turn underpin rural economies. ***Supporting*** services are foundational for the production of all other ecosystem services, such as soil formation and nutrient cycling. ***Regulating*** services are the moderating or stabilizing benefits on natural processes, like climate regulation, water quality, and pollination. ***Cultural*** services are the non-material benefits people realize from ecosystems, such as recreation, spirituality, and education. Cultural services contribute to human wellbeing both economically (e.g., ecotourism) and more broadly (e.g., sense of place).

Provisioning services are the most straightforward to measure either directly or indirectly. Both supporting and regulating services are vitally important to sustaining life and livelihoods, but these services are less easily measured than provisioning services. As such the supporting and regulating services are often overlooked, especially in traditional accountings of economic activity (e.g., Gross Domestic Product), because either the timescales are so great relative to economic cycles, or the elements involved are not owned by landowners such that assigning costs and benefits is difficult. Even more challenging to measure, and therefore more prone to being excluded from cost-benefit analyses and associated policy discussions, are the cultural ecosystem services, given their typical firm grounding outside of economic markets. Figure 24 from the most recent National Climate Assessment illustrates this concept in a bit more detail.

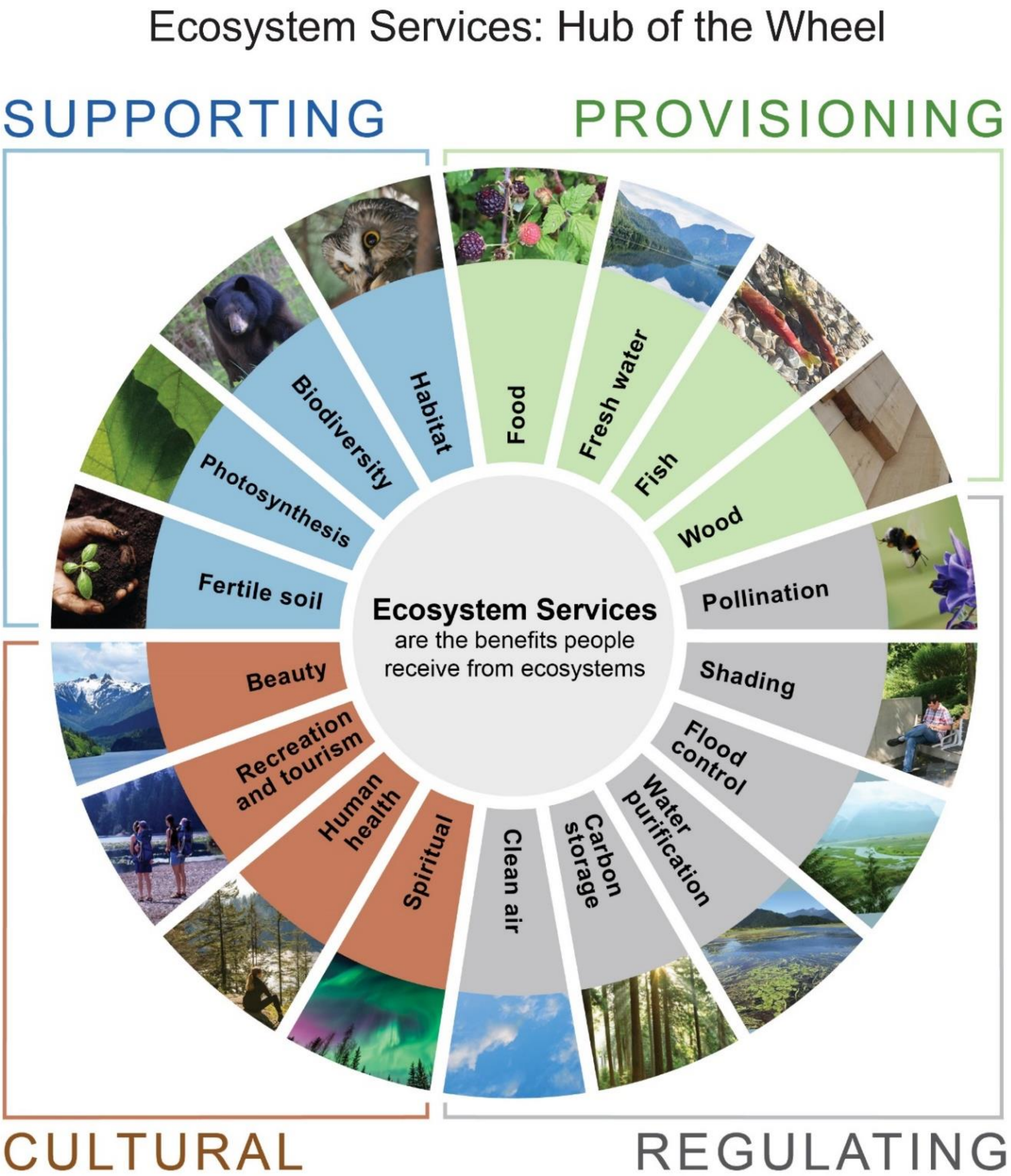

Figure 24. Ecosystem Services: Hub of the Wheel, ecosystem services have wide-ranging benefits for plants, animals, and human well-being. (Crimmins et al. 2023.)

We adopt this ecosystem services framework as a partial lens for understanding the interactions between the FLWC and the state's changing climate. The framework is useful because it is intuitive and widely employed among conservation and policy experts. Yet there are two potential limitations of this framework to keep in mind. First, this perspective is admittedly anthropocentric and subjective. It adopts a human welfare-centered approach that is inconsistent with viewpoints that place nature's inherent value or that of its non-human constituents (e.g., specific plant or animal species or even unique ecosystems) as the primary driver of decisions. By this definition, we presume that for a given ecosystem service to be considered for preservation, it must first be recognized as valuable to people. While the anthropocentric perspective is not without its flaws, we believe it best fits the realities of how conservation decisions are largely made by voters, lawmakers, and other contributors to our political and economic systems. By contrast, one could argue that certain ecosystem workings are intrinsically beneficial to the Earth even if there is no apparent human benefit. Regardless, in this report we focus on the benefits people derive from lands in the designated FLWC geography. Importantly, valuing nature for its instrumental benefits to people does not preclude protection of nature for its intrinsic value - the two approaches are complementary and not mutually exclusive.

Adopting an instrumental (how do the services benefit humans) rather than intrinsic (how is nature inherently valuable) grounding for ecosystem services means the discussion about which services to preserve is inherently subjective. What is a "valuable" environmental benefit for one person may be viewed as irrelevant or detrimental (i.e., ecosystem disservice) to another person. There is no escaping this subjective dimension to understanding what ecosystem services people benefit from (or not) and are willing to support preserving (or not). As a result, policy and program progress can stall when different stakeholders value the same ecosystem service differently. Such differences of opinion might be manageable for a case with a limited geography and similar kinds of soils and climates. But potentially insurmountable differences of opinion are likely when, as is the case for the FLWC, the lands in question are vast in number (nearly 18 million acres), and heterogeneous in terms of climates, soils, people, and livelihoods.

Second, the precise definitions of the four categories of ecosystem services are not universally agreed upon. Related, some of these concepts arguably overlap, raising the possibility of double-counting or inconsistent classification (Mengist, Soromessa and Feyisa 2020). For example, surface water flow to a farm's irrigation system can be viewed as a provisioning service, water quality through soil infiltration is a supporting service, and water supply is a provisioning service – these individual services are often aggregated under 'water quality and quantity', creating the potential for double-counting watershed services (Fu et al. 2011). In conclusion, the "ecosystem services" conceptual framework encompasses much more coupled human-environment system dynamics than the wildlife conservation-biodiversity link. Hence its utility for situating the ecosystem service changes linked with the FLWC in the broader context of climate change and climate resilience efforts.

I.G.2. Ecosystems Services Theory - Valuing What Nature Provides That We May Try to Preserve

The ecosystem services accounting challenge means that it is difficult to provide a clear rank-ordering of which services in a given place are more or less important. Yet prioritization is needed because there is a limit to the costs society has been willing to bear to preserve its lands, or to respond to climate change. Direct "oranges to oranges" comparisons require common measures, but it is evident from the definitions of the four ecosystem services categories that the elements in question differ in kind. The good news is there is a common currency for comparing dissimilar things – the U.S. dollar in our case – provided we have the technical means for translating ecosystem services into dollars.

There is a well-established environmental valuation literature in academia (e.g., from natural resource and environmental economics and ecological economics experts) and in professional practice (e.g., EPA policies, legal decisions on real estate disputes). This literature has enabled significant advances in our ability to include the value of ecosystem services into policy and land use decisions (Barbier 2012; Barbier et al. 2011; Boyd 2011; Chan et al. 2012; Chaudhary et al. 2015; Costanza et al. 1997; Department for Environment Food and Rural Affairs 2007; Finlayson et al. 2005; Gould and Lincoln 2017; Haines-Young and Potschin 2011; Johnston and Russell 2011; Johnston et al. 2013; Milcu et al. 2013; Mooney and Ehrlich 1997; Scholte, van Teeffelen and Verburg 2015; Wilson and Howarth 2002; Zaidi, Dickinson and Male 2015).

As valuable and advanced as this literature is, there are practical limitations to expressing ecosystem service values in dollars. For an economic value to be meaningful, in theory there should be well-defined ownership rights of the service, and an explicit market for the service – two criteria difficult to satisfy for some ecosystem services. For example, if someone wanted to purchase some additional summertime wind for their working lands operations, there is no market to turn to. Thus, while it is straightforward to measure for example the economic value of an acre of corn produced per year as a meaningful reflection of its 'provisioning' ecosystem services, it is difficult to assign a dollar value to other services such as wind, local soil formation, or nutrient cycling that helped enable the corn to be produced in the first place. Such difficulties make the overall economic valuation of ecosystem services less precise in some cases than one might wish.

Even though the science behind ecosystem services valuation is still evolving, it is important to include ecosystem services (and their economic valuation when feasible) when making conservation and climate decisions. Doing so gives us a chance to avoid greater societal challenges down the road. This is especially true as population growth has increased the demand for food, water, and other natural resources, which places greater strain on increasingly degraded and diminished ecosystems that provide these vital goods and services. Increased wealth and new technologies can amplify the demand for ecosystem services with each passing decade. Accordingly, the demand for characterizing the relative values of ecosystem services – in quantitative terms when possible or qualitative terms when not – is also growing. For example, cost-benefit analyses, commonly required in Federal regulatory affairs, now need to incorporate ecosystem services (Revesz and Prabhakar 2023).

I.G.3. Ecosystems Services Practice - Estimating Ecosystem Service Values in the FLWC

Not surprisingly, the FLWC, covering nearly 18 million acres, harbors a wide array of ecosystem types and accordingly ecosystem services and the services' economic values. A challenge for a FLWC-wide assessment such as this report is that ecosystem service valuations have not been conducted for the full region and range of services. As such, we need to draw estimates for the FLWC from reasonably representative locations with the most recent possible ecosystem services valuations. For example, in a recent study of the Tampa Bay region, researchers found mangrove forests had a per-acre value of $195.40 for carbon sequestration, whereas pine flatwoods had a relatively smaller value of $28.70, using values derived from adjusted 2020 Social Cost of Carbon rates (Todd et al. 2023). Similarly, McCormick et al. (2010) estimated the value of ecosystem services changes from restoring the Everglades through the CERP program to be approximately $46.5 billion, which included both values derived from verifiable transactions (such as $1.3 billion from park visitation fees) and more abstract estimated values (such as $13.2 billion for groundwater purification). Where such formal estimates are unavailable, we also draw from generic data sources reflecting relevant economic activity. In the following sections we paint an initial picture of the region's ecosystem services valuation using our four-part land use classification. We draw from recent studies that appear sufficiently relevant to mention. The reported economic values of the FLWC's ecosystem services below are intended to provide a rough idea of the likely economic impacts in the FLWC.

I.G.4. Working Lands and Intensive Agriculture

The FLWC supports a variety of working lands that span low to high intensity and that generate valuable agricultural and timber products, fisheries, and aquaculture. Low intensity working lands typically include agricultural operations conducted on land that remains semi-natural, and whose operations are less concentrated across the land and less input intensive. In Florida, this generally refers to rangeland and commercial timberland, which often contain embedded patches and corridors of natural habitat such as cypress domes, depression marshes, riparian forests, and other communities. Ranches and timberland are also good facsimiles of natural ecosystems in Florida because they approximate the structure of grasslands or prairies and forests, respectively. They can be burned effectively–applying the most important land management technique in the state–without damaging the agricultural operation. Lower intensity working lands are also important sources of provisioning ecosystem services such as food, fuel, and fiber. In this report, we focus on the following specific working lands and intensive agriculture provisioning services: crops, livestock, wild plant and animal products, timber, wood fuel, biochemicals, natural medicines, freshwater, and ornamental resources.

There are 5,291,991 acres of low intensity working lands and intensive agriculture land use types intersecting or within the FLWC. The intensive agriculture and working lands within the FLWC represent 45% of the total farm and farmlands in Florida (United States Department of Agriculture 2022). In 2019, the agricultural industry (including livestock production), natural resources, and food related industries contributed over $182 billion to Florida's economy (University of Florida Intitute of Food and Agricultural Sciences 2022). Looking only at agricultural products, Florida's cash receipts from 2020 total to $7.4 billion, with crops accounting for 80% and livestock and poultry/eggs accounting for 15% of these receipts. These agricultural, natural resource, and food related outputs are not possible without the services provided by the ecosystems where the production takes place. For example, without pollination services, the availability and diversity of Florida's agricultural crops would decline leading to food and economic insecurity. Therefore, it is critical to conserve lands that support pollinators.

Intensive agricultural lands, as compared to well-managed natural and low intensity working lands, typically produce less supporting, regulating, and cultural ecosystem services because the ecosystems are vastly altered to conditions that usually do not support high levels of biodiversity or ecosystem functions and stability (e.g., from disturbances like invasive species). However, there are efforts by individual landowners to improve ecosystem services to improve production (Zamora-Re et al. 2020) and consumer satisfaction (Delmas and Gergaud 2021; Palm et al. 2014). For example, some farmers install riparian buffer strips to enhance the aesthetic value (cultural ecosystem service), protect biodiversity (supporting ecosystem services), and improve water quality (regulating ecosystem service) (Cole, Stockan and Helliwell 2020; Jayaraman et al. 2021). To date, there are more studies valuing the negative impact on ecosystem services of intensive agricultural operations than on the potential positive impacts (Davari et al. 2010; Emmerson et al. 2016; Power 2010). This gap could be filled with a focus on ways the FLWC enhances ecosystem services.

Aside from the agricultural outputs that are accounted for in Florida's Gross Domestic Product (GDP), there is a significant non-market value of the cultural ecosystem services that working and intensive agricultural lands cultivate from the agricultural heritage and sense of place generational landowners have with their lands. There are relatively few valuation studies that place a dollar sign on agricultural heritage in Florida. One study conducted in Chile found the public is willing to pay $50.50 per person to conserve Chile's agricultural heritage, as it is a large part of Chile's national identity (Barrena et al. 2014). Additionally, although provisioning services are the main ecosystem service produced in working lands, significant supporting and regulating services are also generated from these lands. For example, a study conducted in 2021 that quantified ecosystem services in working landscapes in southern Georgia and south-central Florida found that the Florida subregion was critical for wildlife habitat (especially imperiled species), landscape stabilization, and biodiversity (Coffin et al. 2021).

A large portion of lands (1,749,024 acres) in the FLWC are working lands related to beef cattle ranching. Production from the beef cattle industry and farms generated over $446 million of gross revenue in 2017, but also provides a variety of supporting, regulating, and cultural ecosystem services. A 2017 study conducted by the University of Wyoming investigated the economic value of three ecosystem service classifications (private forage, general ecosystem services, and wildlife value) in Florida. They found that between these three ecosystem service classifications, the total per acre worth of private beef cattle ranching lands was $85.25. The highest valued ecosystem service was wildlife value at $56.56/acre, followed by private forage at $15.50/acre, and general services at $13.19/acre (Maher et al. 2020). This example underscores the importance of working lands in the climate resilience equation. These lands are areas where nature and human needs intersect, producing tangible outputs while maintaining some ecosystem services.

The biodiversity values of working lands are often considerable. Perhaps surprisingly, pastures managed for livestock production in Florida are preferred over native grasslands by some of our most iconic and imperiled bird species, including the crested caracara (*Caracara plancus*), Florida sandhill crane (*Antigone canadensis pratensis*), and Florida burrowing owl (*Athene cunicularia floridana*) (Morrison and Humphrey 2001; Noss 2012). These birds appear to find more suitable foraging habitat and prey in grazed pastures than in ungrazed grassland; a plausible hypothesis is that they evolved with Pleistocene megaherbivores (Noss 2012).

I.G.5. Natural Lands

Natural lands provide the most regulating ecosystem services across a forest-wide landscape scale (Coffin et al. 2021). The natural land category includes forests, pine savannas, various wetland communities, coastal communities, and inland water. Coastal areas are the interface between marine water and land, which includes estuaries, coastal aquaculture, and seagrass communities. Inland waters are defined as permanent water bodies such as rivers, floodplains, lakes, and wetlands.

There are over 6,323,248 million acres of forests and savannas (including both uplands and wetlands) within the FLWC, the second largest ecosystem type comprising the current FLWC. Forest and savanna ecosystems produce regulating ecosystem services, such as air quality, climate regulation, erosion control, flood hazard risk, and water filtration. The economic value of erosion control was studied by Taye et al., (2021) who analyzed 261 global ecosystem service studies, using an approach that controlled for wide variations in ecosystem characteristics, human preferences, and standardized methods across the studies. They found erosion control in forests is the most highly valued at $1,672, and flood hazard risk reduction is valued at $368 per acre (although these values can contextually vary; FEMA 2021).

Coastal ecosystems play an integral role in climate regulation, flood and storm hazard risk reduction, water filtration, and species nursery habitat. Despite representing a modest share of the FLWC, coastal areas (approximately 707,811 acres) provide a significant benefit to the region's inland and marine functioning, and therefore should not be overlooked based on their relatively small extent.

Inland waters are important for water storage and filtration, regional climate regulation, and flood control. There are over 210,379 acres of inland waters within the FLWC. FEMA aggregated economic values for various ecosystem services that inland wetlands produce (note that there are other water bodies included in the inland water categories other than wetlands). These studies were based on global analyses, as well as national analyses that aggregated many inland wetlands of the United States (Brander et al. 2006; Ghermandi et al. 2010; Adusumilli 2015). For inland wetland systems, a monetary value of $1,906/ac/year for recreation and tourism, $1,584/ac/year for water filtration, $1,416/ac/year for habitat, $1,264/ac/year for flood and storm hazard risk reduction, and $643/ac/year for water supply supported through inland water systems, were estimated.

Wetlands are a major landscape feature, with an estimated 11.3 million acres of wetlands covering almost 30% of the state (Haag and Lee 2010). Approximately 90% of the wetlands in the state are freshwater wetlands (of which 55% are forested, 25% are marshes and emergent wetlands, 18% are scrub-shrub, and 2% are freshwater ponds) and 10% are coastal wetlands (Haag and Lee 2010). Wetlands play a key role in the water cycle by influencing groundwater recharge, evaporation, low flows, and floods (Brody et al. 2007). In general, freshwater wetlands are classified by their landscape location and the key water supply mechanism (how the wetland is fed by a water source) where many wetlands have more than one route by which water is supplied to them (Acreman and Miller 2007). It was recognized early in the literature that wetlands are an important feature for flooding mitigation by their ability to store large amounts of water and by reducing peak water flows by 40-60% (Novitski 1985; Conger 1971).

One ecosystem service from natural lands that may not be offered as extensively in the other land use types discussed is providing outdoor recreation opportunities. There are many conserved natural lands within the FLWC that currently provide these opportunities, such as Ocala National Forest, Everglades National Park, and some 75 state parks like Jonathan Dickinson State Park in Palm Beach County. These areas are vital to connecting humans to nature, which has been shown to increase pro-environmental attitudes and increase local activism in upkeep and conservation policies of an individual's local natural area (Larson, Whiting, and Green 2011; Kil, Holland, and Stein 2014). Protected areas with recreation access are one of the most studied and reliable ecosystem service values available, as they represent a market value (i.e., people are willing to pay to travel to these areas and forgo the income they may receive from work; people are willing to pay travel expenditures, like lodging fees and entrance fees, etc.). Recreation areas are a ‘double-whammy’ when it comes to ecosystem services, because they provide a market-based economic value and conserve other types of ecosystem services, like carbon sequestration, water quality, and others.

Sutton, Duncan, and Anderson (2019) investigated the monetary value of national parks within the contiguous U.S. They implemented a benefit transfer method to analyze the impacts of 17 different ecosystem services. Everglades National Park, which is within the FLWC, had the greatest annual ecosystem services value at $50 billion per year (Sutton, Duncan, and Anderson 2019). This was not only due to its size (it is the third largest national park by acreage), but because of its massive extent of mangrove and tidal marsh ecosystems. These ecosystem types provide a myriad of benefits, like water quality and storage, wildlife habitat, climate regulation, pollination services, and even provisioning services like genetic material.

I.G.6. Developed Lands

Typically, this land use type produces the least amount and variety of ecosystem services (Geneletti 2013). As is the case with intensive agriculture lands, economic research related to developed lands is largely focused on the negative impacts that development has on ecosystem services. Development of infrastructure, industries, residential areas, and the like generally decreases all types of ecosystem services (Turner et al. 2016). There are certain urban planning methods that can mitigate these impacts (e.g., urban tree cover policies), but, for the most part, impervious surfaces are the least compatible with ecosystem services. Concentrated development can reduce tree and other vegetation cover, compact soil, hydrologically disconnect important water recharge zones, trap heat, reduce biodiversity, increase waste, and concentrate pollution. See Section II.C Adaptive Capacities for a more detailed discussion.

Advancing new specific FLWC policies and programs would benefit from an ecosystem services valuation study specifically focused on only the FLWC. Two approaches are available for such an advance. The most comprehensive and accurate approach is to commission a thorough study of the region's ecosystem services values. A less time- and resource-intensive approach (but also of necessity less complete and precise) is to conduct a benefit-transfer study, which averages ecosystem services values from prior studies derived in other contexts (e.g., elsewhere in the state -- for example North Florida conservation forestry; Kreye et al. 2014). It aggregates previous ecosystem service valuation studies into a single value range that (with some precautions and careful interpretation) can be applied, as a placeholder, to the same ecosystem services in our study location. Finally, these studies should be commissioned regularly. By definition, ecosystem services valuations are a function of the biophysical and socio-economic conditions of the moment. For a coupled human-environment system such as the FLWC that is evolving so rapidly in climate and population terms, the magnitude of services should be expected to vary significantly over time, with potentially important implications for policy and private land-owner decisions. This hypothesis can be tested by regularly conducting ecosystem services valuations.

I.H. A Socio-Economic Portrait of the FLWC's Working Lands

The FLWC spans most of Florida and is home to a diverse range of residents representing various economic livelihoods and social and demographic backgrounds. As such, we expect the sensitivities and adaptive capacities to climate exposures to differ at least in part with the differences in human profiles. The research literature often references this composite concept as "social vulnerability." Specifically, measures such as population size, age, race, gender, poverty rate, employment by industry, and unemployment rate are commonly taken as proxies for social vulnerability. For the purposes of this report, social vulnerability as such can be meaningfully viewed as the inverse of resilience as introduced in Section II.

The expected directional effects of each of these variables are typically what one would expect. For example, a household with a lower annual income should, *ceteris paribus*, have a lower ability to invest in anticipatory or reactive adaptations to cope with environmental stresses. That said, in practice the social effects are not always so simple to predict. The effect of a given social vulnerability variable may depend on values of other variables, which may in turn vary over time and with location. In some cases, the relationships may be non-linear. For example, age may be positively linked with social resilience for adults between 18 and 55 if their incomes are rising with levels of work experience, but negatively linked with social resilience at older ages when their incomes may stagnate upon retirement, and health challenges become more common. Similarly, children may be more vulnerable than adults. So, the resilience relationship with increasing age may be negative for youth, positive for working-age adults, and negative again for older citizens.

Given this largely intuitive yet contingent composition of social vulnerability, in this section we first present profiles of a few of these variables independently, and second present a composite index of local likely social vulnerabilities to changing environmental conditions via the Social Vulnerability Index (SoVI; Cutter et al. 2003). The SoVI is one of a growing number of such measures adopted by scholars and practitioners including for instance the World Bank, the Centers for Disease Control, and the Federal Emergency Management Agency (FEMA). The SoVI analysis presented below is intended only as a first-cut insight to animate preliminary conversations about climate vulnerability and resilience in the FLWC. Additional work is needed to tailor the SoVI to suit the needs of FLWC stakeholders for specific investigation and action.

I.H.1. A Quick Socio-Economic Snapshot of the FLWC

To profile the residents intersecting both the current protected and opportunity areas of the FLWC, we organize the state into 5 regions: Central, North Central, Northeast, Northwest, Southeast, and Southwest (Figure 25). These regions are drawn from the 2021 American Community Survey (2021a) data from the U.S. Bureau of the Census. The following variables are reported here: population size; age, race, and gender; employment by industry; poverty rate; and household income.

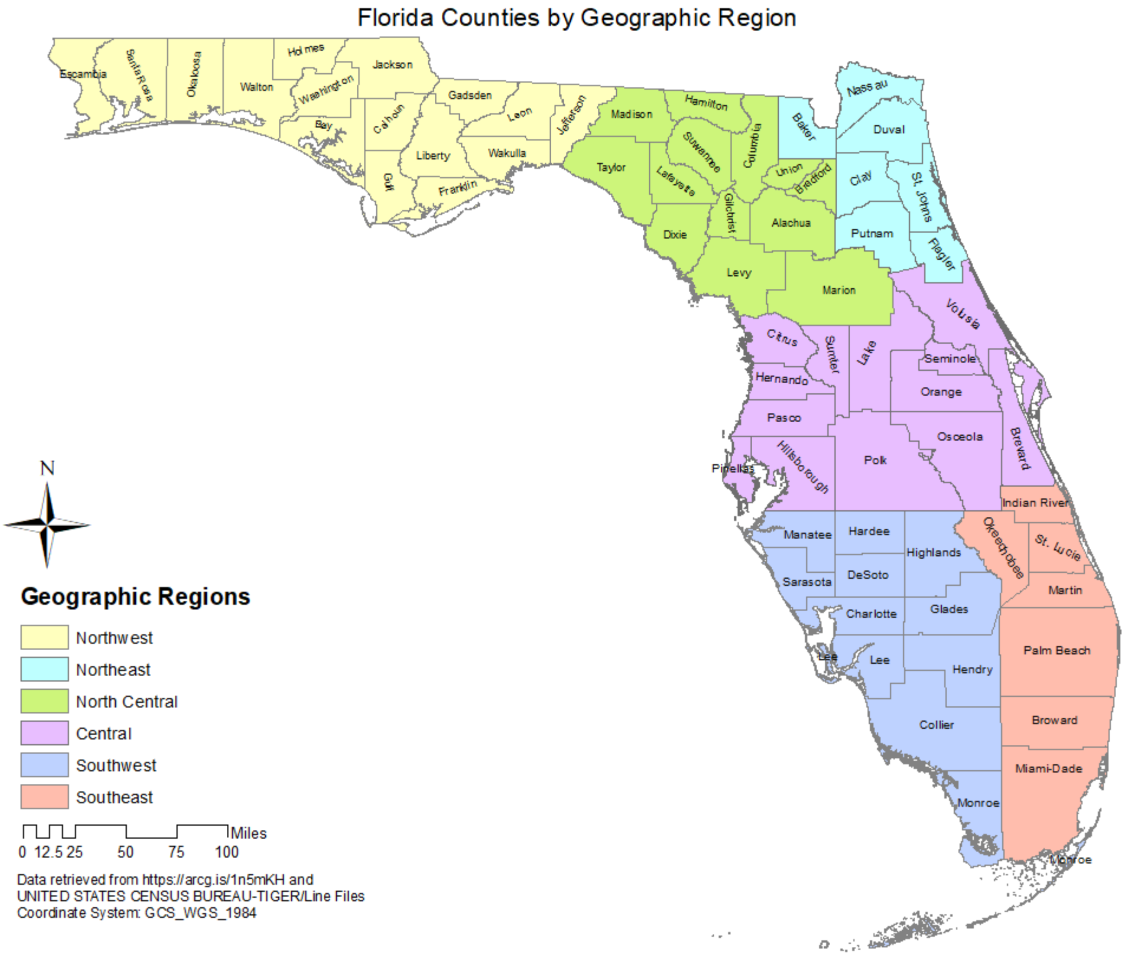

Figure 25. Florida Counties by Geographic Region. (Data retrieved from https://arcg.is/1n5mKH and credits United States Census Bureau-TIGER/Line Files; CES 2024f.)

We examined the total ***population size*** of areas intersecting the FLWC, both in the current protected lands and opportunity lands across different geographic regions (Table 1).

Regarding ***age, race, and gender***, the median age of FLWC residents is in the mid- to high-40's for all regions. The majority of residents intersecting the FLWC are white. The most racially diverse region is the Southeast region, with the intersecting population consisting of 29% Hispanic, 14% Black, 2% Asian American, <1% Native American, and 55% white. Racial profiles are not much different in the protected versus opportunity areas. All regions are fairly uniform in gender distribution, more or less half females and half males.

To understand residents' ***employment by industry***, we focus on two industries that intersect with those that residents in the FLWC are working in. We analyzed how many residents are working in extractive (i.e., agricultural and natural resource careers like mining, farming, etc.) and service careers. More residents in or near the FLWC work in services (18-22% across the regions) than in extractive industries (<7% across the regions).

Poverty rates are estimated as the ratio of people in a certain age group whose income falls below the poverty line of that specific county (i.e., half the county's median household income). The region with the highest poverty rate is North Central at 18%, with the lowest poverty rate in Central Florida at 12%. Poverty rates in opportunity lands were higher than those in protected lands for the North Central (+1.5 percentage points), Southeast (+0.9), and Southwest (+5.1) regions.

Households with annual incomes >$200,000 are considered high income. The region with the greatest share of high-income households intersecting the FLWC is the Southeast (9.2%), and the lowest is the North Central (2.7%).

Table 1. Number of Residents Living within or adjacent to the FLWC. (UCF 2024a.) [4]

	Total Intersecting FLWC	**Protected Area**	**Opportunity Area**
Central	1,104,357	782,845	321,512
North Central	343,731	277,072	66,659
Northeast	234,565	194,840	39,725
Northwest	617,554	499,309	118,245
Southeast	334,316	288,605	45,711
Southwest	508,353	366,017	142,336

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[4] There is not a perfect mapping between Census Tracts and the FLWC boundaries. In fact a number of Tracts that intersect the FLWC only overlap a small amount. An analytical judgment call was needed. We elected to count all residents in a Census Tract even partially intersecting the FLWC as representing some of the population count for the FLWC.

I.H.2. A Preliminary Social Vulnerability Index (SoVI) for the FLWC

As noted above, since multiple factors contribute to the social vulnerability to environmental conditions, it may help to combine the several commonly inspected variables in the section above into a single value. An index that reflects the abstract concepts leading to higher or lower abilities to prepare for and respond, recover, and adapt to environmental challenges might provide a more streamlined and efficient perspective on priority locations for monitoring or aid vis-a-vis the FLWC. The Social Vulnerability Index (SoVI; Cutter et al. 2003) is perhaps the most well-known of such indices. This data-driven method allows for each geographic unit, such as a census tract or county, to have its own vulnerability value. The scores are normalized and unitless such that the numbers are meaningful in comparison not in isolation. A higher score means higher social vulnerability, i.e., lower climate resilience.

Our SoVI analysis for the FLWC identifies high SoVI areas (census tracts) intersecting protected areas and opportunity areas (Table 2; Figure 26). Across all regions, significantly more higher-vulnerability census tracts are located in FLWC protected areas than in opportunity areas. Yet due to variations in the geographic sizes of the census tracts, the high versus low SoVI scores are evenly divided (in acres) between protected and opportunity lands (51% and 49%, respectively). However, the population in high SoVI areas is strongly weighted to protected lands.

The principal influences on the high SoVI scores are largely driven by three factors each with a few component variables. The access barrier and poverty factor includes the poverty rate, access to automobiles, and mortgage burden measures. The age and dependence factor includes measures of the median age, percentages of young (under 5) and aging (over 65) residents, and percentages of social security recipients. The wealth factor includes house values, percentages of people earning over $200,000 per year, and median income measures. In conclusion, the preliminary, first-cut takeaway message from this inspection is that the data-driven and partially overlapping concepts of ‘access barrier and poverty,’ ‘age and dependence,’ and ‘wealth’ deserve further examination to understand the extent to which the FLWC may affect the vulnerabilities signaled by these variables for people living in or near the FLWC.

Clearly, the SoVI as constructed from prior applications and implemented above is weighted towards social over biophysical variables. This emphasis is the intentional result of needing to balance the analysis in a literature that excluded social factors. For the SoVI to have maximum salience for the FLWC context, additional detail on the ecological priority measures, and associated ecosystem services values, should be incorporated.

Table 2. Social Vulnerability Index (SoVI) Per Region, Protected Lands and Opportunity Lands within the FLWC. (UCF 2024b.) [5]

	Total High-SoVI Census Tracts Intersecting FLWC (Population)	**High-SoVI Census Tracts Intersecting Protected Land (Population)**	**High-SoVI Census Tracts IntersectingOpportunity Land (Population)**
Central	52 (189,924)	40 (148,480)	12 (41,444)
North Central	41 (143,103)	34 (116,345)	7 (26,758)
Northeast	11 (53,131)	9 (42,504)	2 (10,627)
Northwest	30 (104,688)	25 (89,161)	5 (15,527)
Southeast	18 (66,170)	15 (58,451)	3 (7,719)
Southwest	49 (174,066)	36 (122,272)	13 (51,794)

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[5] There is not a perfect mapping between Census Tracts and the FLWC boundaries. In fact a number of Tracts that intersect the FLWC only overlap a small amount. An analytical judgment call was needed. We elected to count all residents in a Census Tract even partially intersecting the FLWC as representing some of the population count for the FLWC.

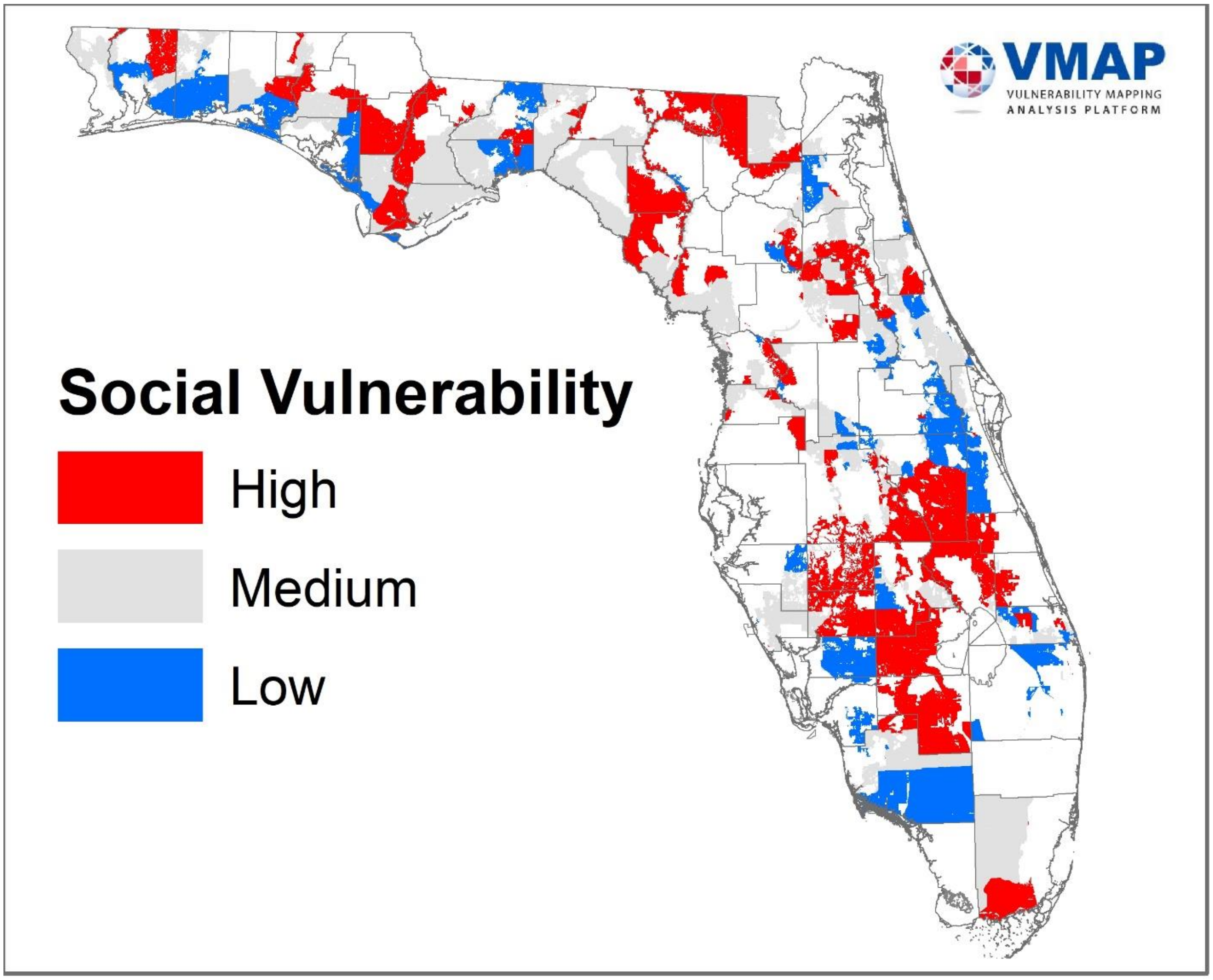


Figure 26. VMAP, Social Vulnerability of the Florida Wildlife Corridor, tracts were appraised for their overlap with the FLWC to determine if they either intersected with or were within the FLWC boundaries, including the opportunity areas. However, because there were no census tracts entirely within the FLWC, the data reflects census tracts that only partially fall within the FLWC. (Data for this SoVI analysis utilized census tract socio-demographic data from UCF's Vulnerability Mapping and Analysis Platform (VMAP) and was sourced from the American Community Survey 5-Year Estimates (2021-2022); University of Central Florida (UCF) 2022.)

II. Florida’s Climate Resilience Intersected with the Florida Wildlife Corridor (FLWC)

II.A. Exposures: The Stresses Acting on FLWC lands

As described in Section I.C., Conceptual Framework, the climate resilience equation begins with *Exposure.* This concept describes the intersection of the specific climate stresses, including their approximate geographic and temporal boundaries, with the coupled human-environment systems experiencing the stresses. These systems are readily identifiable assemblages of people and things people value, plus the dominant environmental features of the place (Kates 1985; Polsky and Eakin 2011; Turner et al. 2003). For this report, there are two broad categories of stresses to which our state is exposed: changes in temperatures and precipitation. We assess how these changes may matter using the lenses of land use and ecosystem services. Four land use types are identified as characteristic of the FLWC: Developed (Urban/Suburban), Conservation Lands (Natural), Intensive Agriculture (e.g., Row Crops), and Working Lands (Seminatural; Ranching and Timber). Four classes of ecosystem services are examined: provisioning, supporting, regulating, and cultural.

II.A.1. Climate - Future Climate Scenarios Salient for the FLWC

Average annual temperatures are projected to exceed historical records by as early as the middle of the century. Based on a lower emission scenario, temperature increases will likely be slightly warmer than historical averages. Under a higher emissions scenario, the projection is higher still (Figure 27; Runkle et al. 2022). By 2050 the state will likely experience >50 days with temperatures that exceed 95 °F and, with a projected increase of 8° to 15 °F heat index increase, which is higher than any other region in the country (Runkle et al. 2022).

Extreme heat days are defined as days at or above 95 °F (Figure 28). By 2050, the state's eastern coast should experience up to 30 more extreme heat days than 1991-2020 averages. Locations directly adjacent to the coast will experience increases by a range of 10-20 days annually (Zierden 2023). In the Panhandle, coastal locations will likely experience up to 30 more extreme heat days annually, while inland areas may see as many as 40 more extreme heat days by the year 2050 (Zierden 2023). It is also anticipated that inland regions of the peninsular portion of the state will experience the most significant changes, with as many as 40 more extreme heat days and over 50 days in some isolated regions by 2050 under the NCA5 high scenario (Zierden 2023). The last three years have tied or broken the previous record of the number of “hot” days in Tampa, FL (Zierden 2023) which supports the trend indicated on the chart (Figure 29).

Overnight minimum temperatures are rising more than daytime highs are, particularly during summer months (Figure 30). In South Florida, the number of “hot” nights (nights where the temperature does not fall below 75 °F) has increased threefold in South Florida. The number of “hot” nights is projected to continue to increase across the state by the late 21st century (Hayhoe et al. 2018).

Annual precipitation is anticipated to rise as global temperatures rise (Zierden 2023; Figure 31). Additionally, average annual precipitation in general is projected to increase in North Florida and decrease in South Florida, with high confidence for the estimates in North Florida (Zierden 2023).

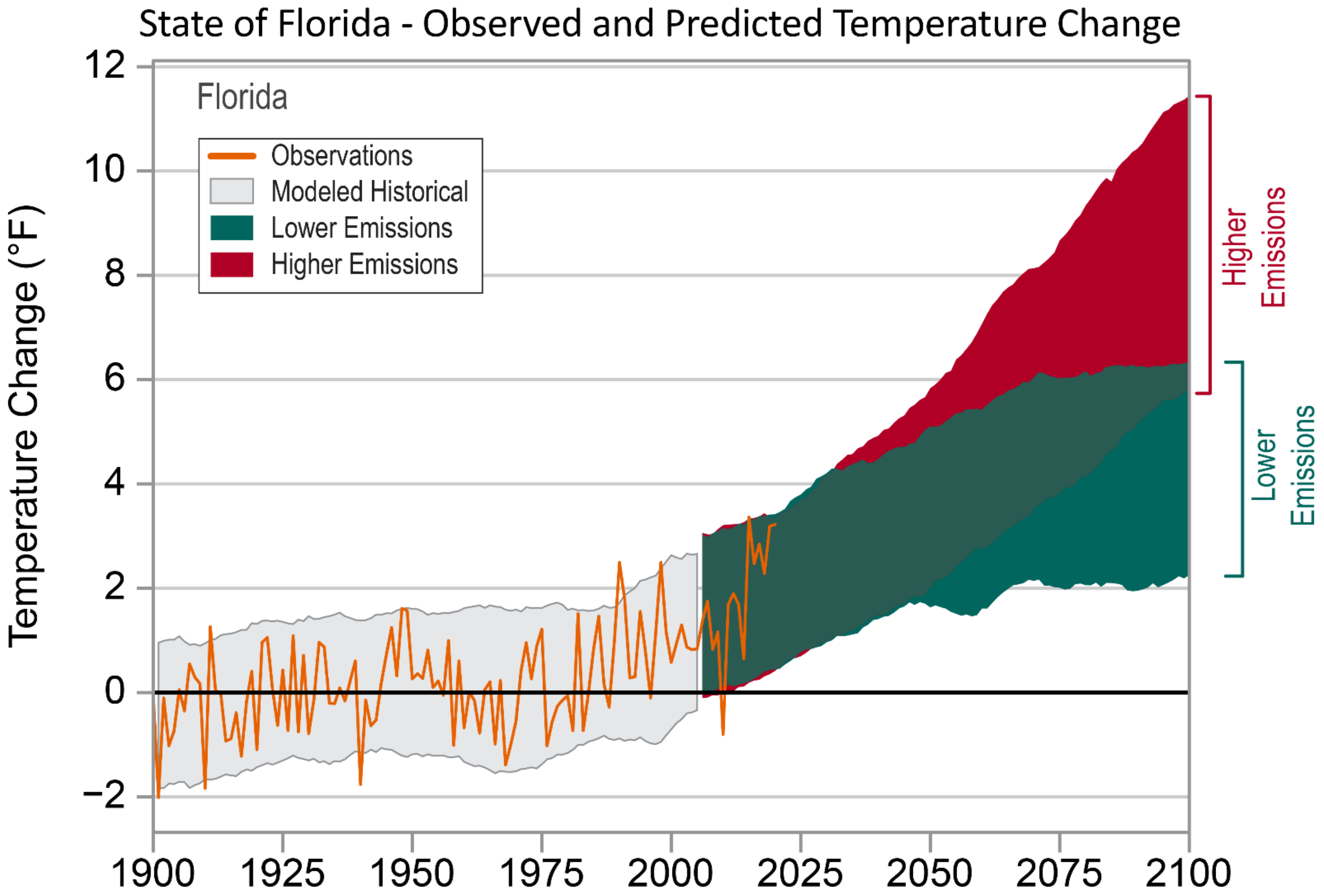


Figure 27. Near-Surface Air Temperature in Florida, the chart shows two global climate model scenarios for future trends - in red, the projection is based on a global higher emissions scenario using current rates of increase. In green, trends are based on a slower rate of increase of global emissions of greenhouse gases. Orange lines indicate observed average temperatures from 1990-2020, 2023. (Data from NOAA National Centers for Environmental Information – State Climate Summaries, using CISESS and NOAA NCEI; Kunkel et al. 2022.)

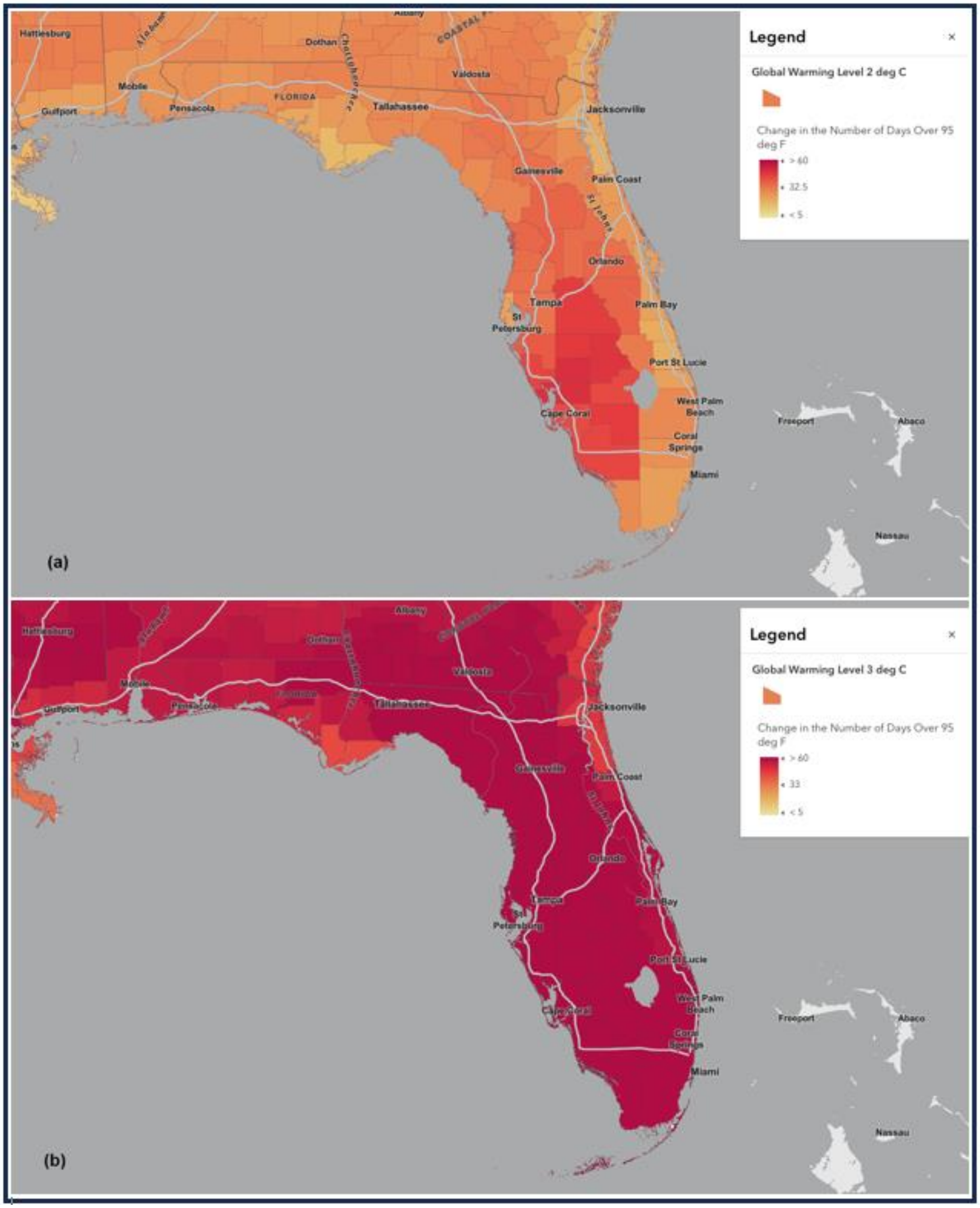


Figure 28. The Change in the Number of Days by 2050 Over 95 °F Under (a) 2 °F Global Temperature Change and (b) 3 °F Global Temperature Changes Above Pre-Industrial Levels Measured From 1851-1900, based on the SSP5-8.5 scenario. (Generated using the Fifth National Climate Assessment (NCA5)/U.S. Global Change Research Program; Zierden 2023.)

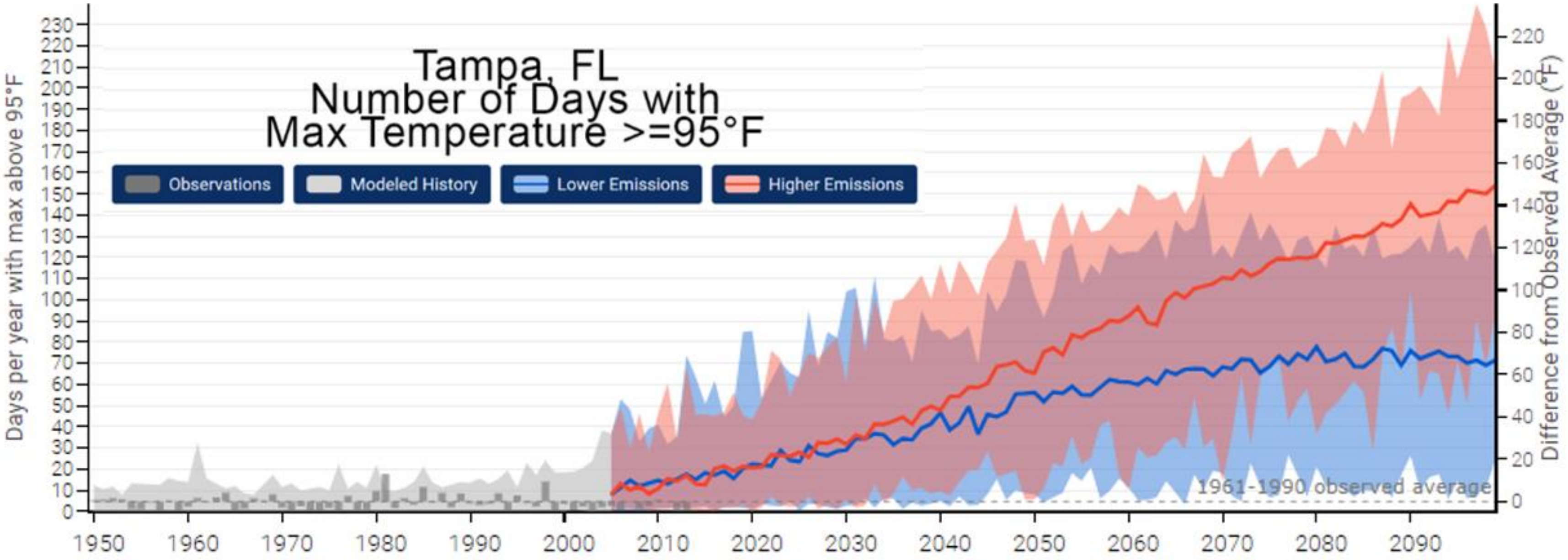


Figure 29. Tampa, FL Number of Hot Days with Max Temperature >=95 °F, the dark gray “observations” are observed averages for each year from 1950-2013. The horizontal line is the average from 1961-1990. Years where the bars extend above the link were higher than the long-term average. Gray bars that extend below the line are lower than the long-term average. The lighter gray band shows modeled values (hindcast) for 1950-2005 where the top of the band shows a maximum value at each time period. The blue band shows projections from 2006-2100 where humans stop increasing global emissions of greenhouse gases by 2040 and then reduce them through 2100. The red band shows the same projections if humans continue to increase greenhouse gas emissions through 2100, 2023. (Created with National Environmental Modeling and Analysis Center (NEMAC) Climate Data Tool - Tampa, Florida; CES 2023c.)

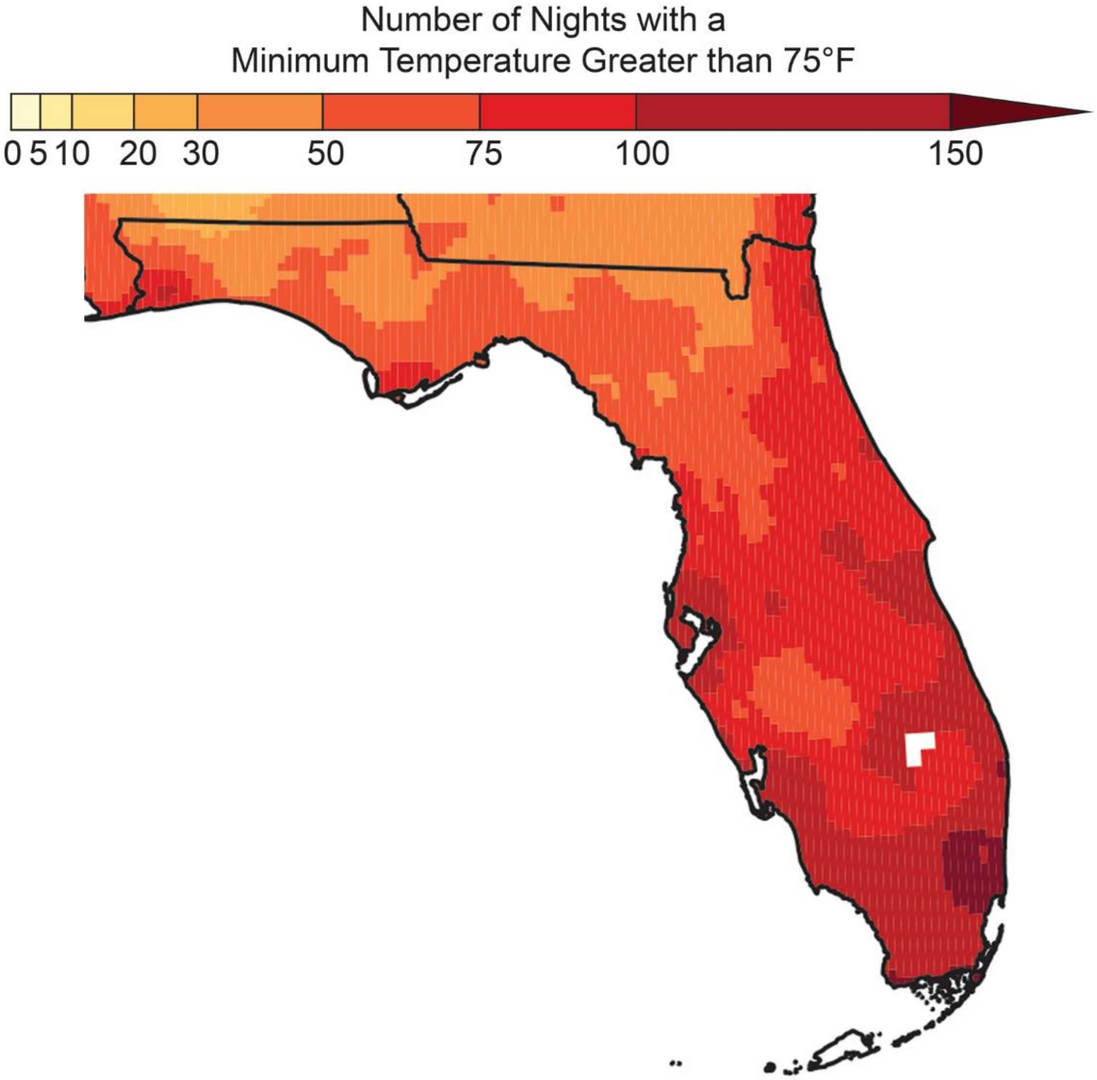


Figure 30. Projected Number of "Hot" Nights for 2070-2099 Using the Low Scenario Fourth National Climate Assessment (NCA4). (Lewis et al 2018.)

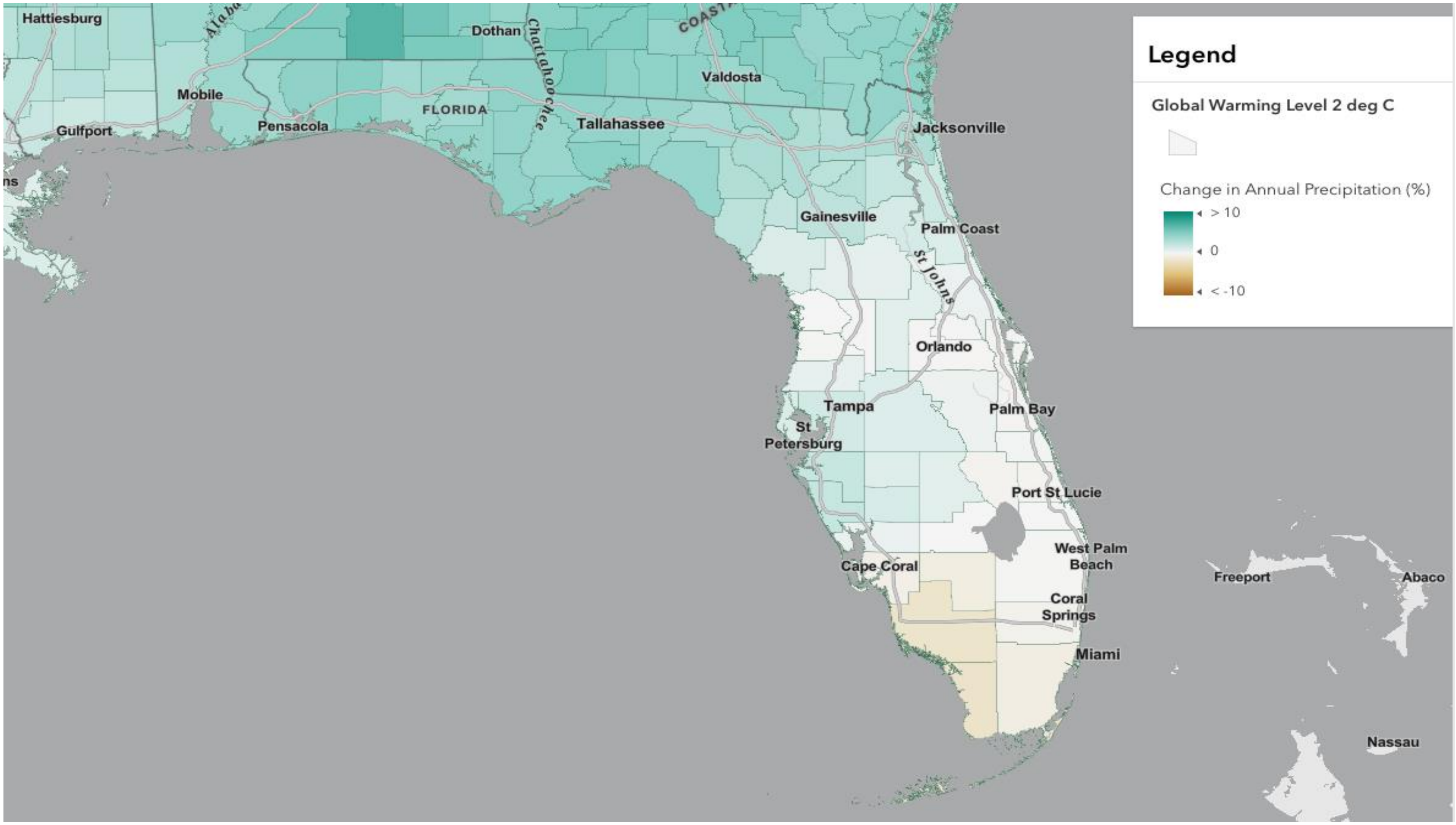


Figure 31. Change in Precipitation Projected Under a 2 °C (3.6 °F) Increase of Temperature by 2050 above Pre-industrial Levels from 1851-1900. (Generated using the Fifth National Climate Assessment (NCA5)/U.S. Global Change Research Program; Zierden 2023.)

Sea-Level Rise. Sea levels continue to rise around the world, with 10-12 additional inches expected over the next 30 years along the U.S. coastline (Sweet et al. 2022). Long-term sea-level rise projections depend on estimates of greenhouse gas emissions. Global temperatures would rise more (see temperature section above) under higher emission scenarios, which would lead to greater sea level rise (Zierden, 2023), but lower emission scenarios would lead to less sea level rise. Projections for the Virginia Key, FL station are highlighted in Figure 32, showing the potential for sea-level rise from low to high emission scenarios. The Sweet et al. (2022) report provides sea-level rise estimates for various regions around the U.S. coastline, with the two nearest to Florida being the estimates for the southeastern U.S. and for the eastern Gulf of Mexico. These estimates range from conservative, the Low scenario, to extreme, the High scenario. The data provided in the Sweet at al. (2022) report shows that the difference in the sea level rise scenarios between the Southeastern region and the eastern Gulf of Mexico region average less than 1 inch for time horizons from 2040 to 2070 across all 5 sea level rise scenarios, which means that the average of these two regions is a reasonable first estimate for what Florida will experience. Compared to sea levels in 2000, using the 'intermediate' scenario, these projections indicate Florida ocean level increases of approximately 10.9 inches by 2040, approximately 14.6 inches by 2050, and approximately 23.8 inches by 2070. The Florida Flood Hub at the University of South Florida is working on a more careful analysis of the data just along the Florida coastline; the results of that analysis are not expected to deviate much from these results.

The potential impacts of sea-level rise include increased saltwater intrusion and impacts on groundwater supplies, impacts to gravity-flow drainage infrastructure due to increases in high tide flooding levels, and higher storm surge levels with more inundation during storm events. A recent hurricane event, Idalia, is an example of this phenomenon. The 2023 storm damaged many homes in low-lying neighborhoods in the Tampa Bay region due to a storm surge depth of about four feet. This occurred during a King Tide event. It is estimated that the inundation would have been at least two feet higher (Mitchum as cited in Mulligan 2024) if the storm surge had occurred during high tide rather than low tide. This illustrates the relationship between sea-level rise, high tide flooding and storm surge.

Sea-level rise has the potential to impact the FLWC. Figure 33 highlights areas of the FLWC that would be inundated with water given 3 feet of sea-level rise. Impacts are particularly evident along the Southwest, Northwest coasts, and the Northeast. Approximately 1,498,500 acres of the total FLWC (roughly 5%) are intersected by a 3-foot rise in sea level.

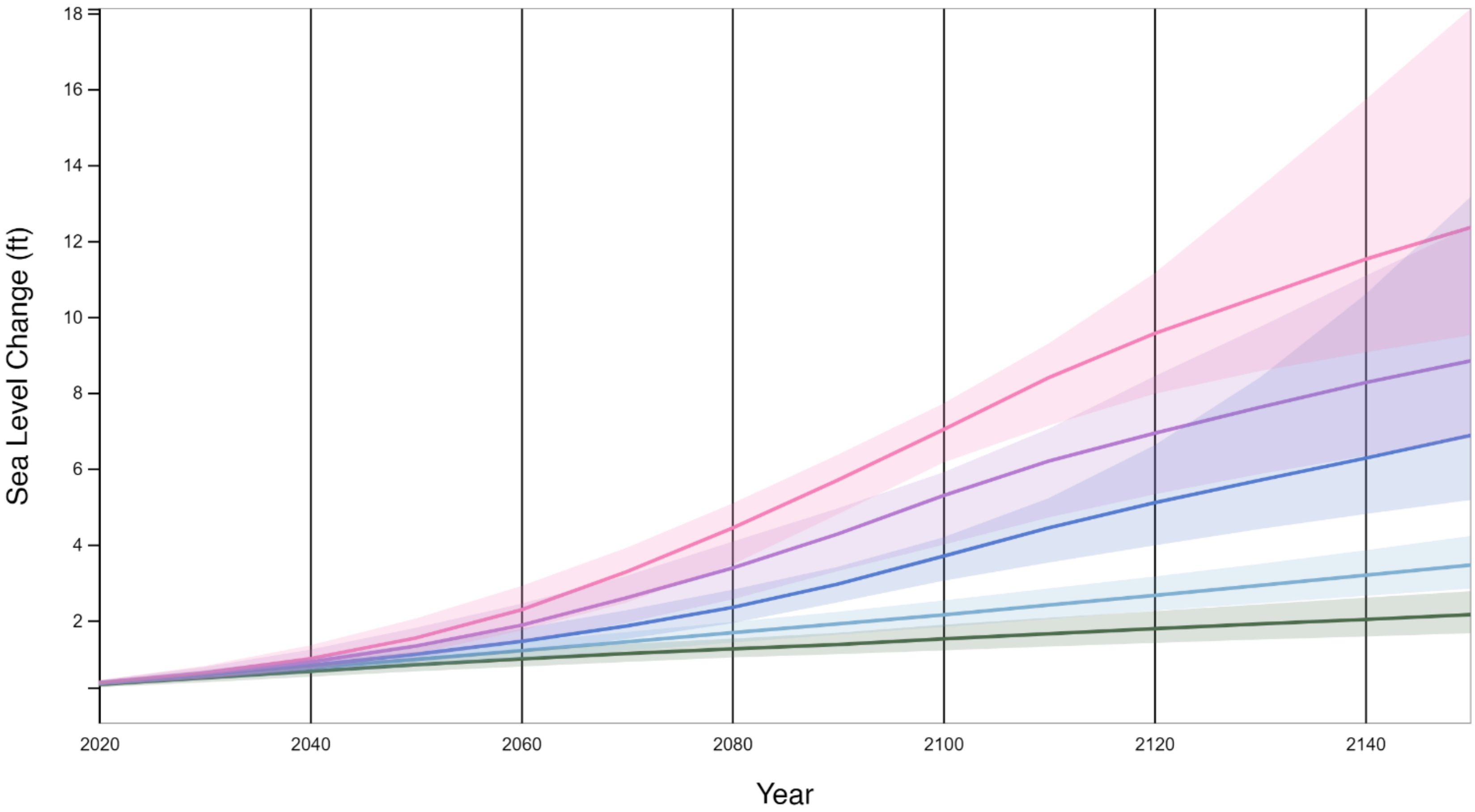


Figure 32. Sea Level Rise Scenarios. Virginia Key, FL Station. (Produced using the Interagency Sea Level Rise Scenario Tool, NASA Sea Level Change (2020 – 2140); CES 2024h.)

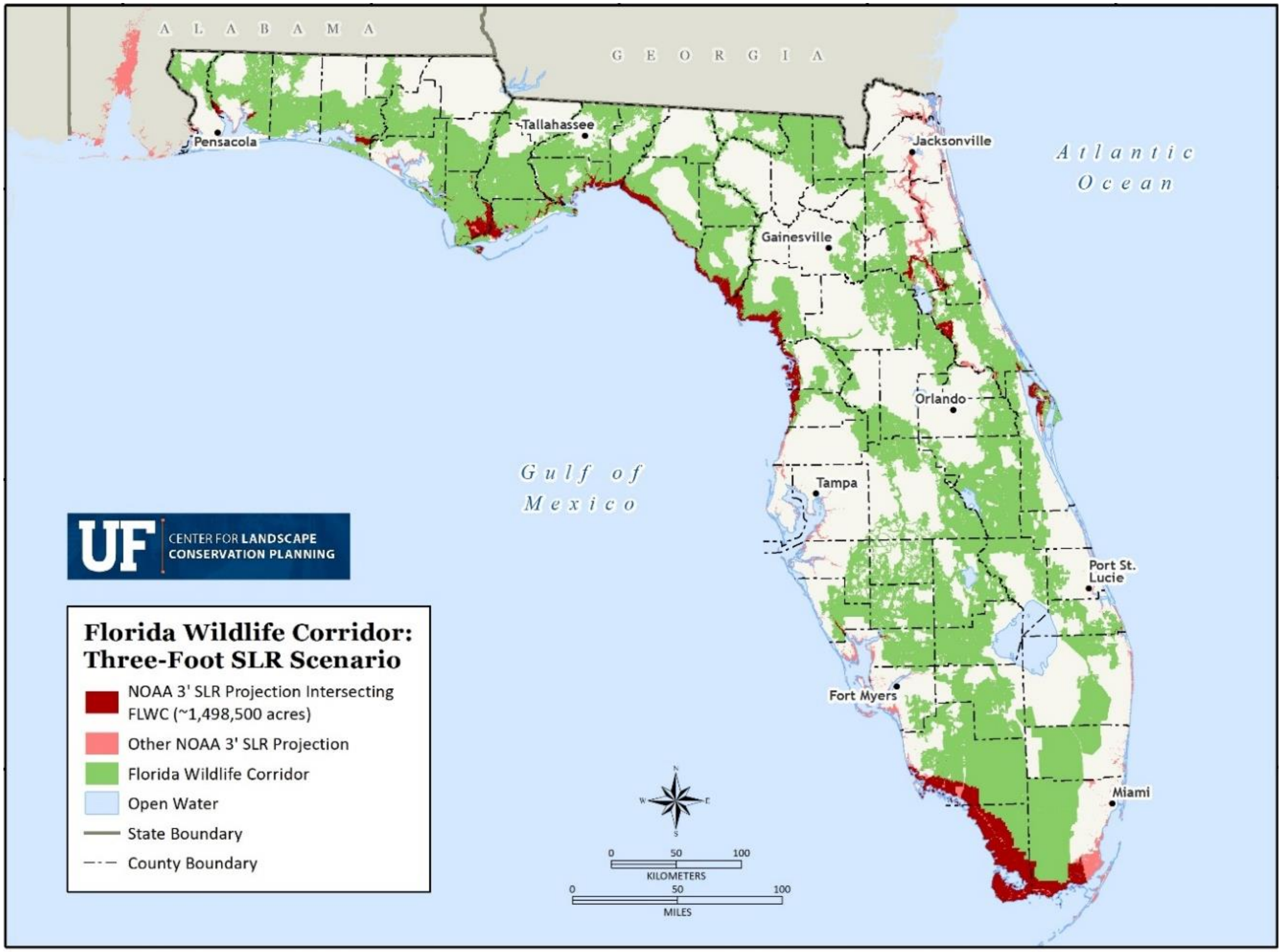


Figure 33. Three-Foot Sea-Level Rise Projections in the Florida Wildlife Corridor. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2023e.)

As Florida and the Southeast are prone to tropical storms, it is important to also recognize the potential changes to tropical cyclone activity associated with climate change. As the oceans and land cover continue to warm, it is anticipated that hurricanes will both increase in intensity and reach major category strength (at least Category 3) when they do occur. Rapid intensification, due to pockets of hot ocean water, can also be exacerbated by the increase of global ocean temperatures. Hazards associated with tropical cyclones are also expected to worsen, such as global storm surge inundation, high wind activity and precipitation flooding (Zierden 2023). Increased storm activity, coupled with sea-level rise (a projected increase anywhere between 1-3 feet by 2100 (Runkle et al. 2022) and on-land torrential rainfall, can lead to increased coastal and inland flooding in the future as well.

While projected summer precipitation changes remain uncertain, particularly in regions of North Florida, including the Panhandle (Runkle et al. 2022), higher temperatures are likely to increase the rate of soil moisture loss (via elevated evapotranspiration rates) and an associated intensification of drought activity. This, coupled with population growth and continued land use change will likely contribute to reduced water availability, impacting the economy and Florida's unique ecosystems (Runkle et al. 2022). Increased drought activity may also cause more frequent wildfire events.

II.A.2. Population - Florida's Likely Future Settlement Patterns and Densities

In Florida, population growth is one of the biggest factors that could negatively impact the state's climate resilience (Iler et al. 2021). From July 2021 to July 2022, Florida had the highest rate of net migration nationwide, with approximately 1000 people moving to the state per day (Tampa Bay Economic Development Council 2023). From a regional perspective, we can see the largest growth in population occurring between 2010 to 2020 in Southeast, Southwest, Central, Northeast and North Central regions (Figure 34). This growth should increase in the coming decades. The Bureau of Economic and Business Research at the University of Florida estimates Florida's population will increase by 7-24% by 2050, resulting in as many as 31 million total residents (compared to 21.8 million in 2023) (See Table 3 for regional specifics).

Population growth estimates for 2050 provided by the Bureau of Economic and Business Research (2023) provide low, medium, and high ranges. In this report, we focus on the low and high estimates (Table 3). For low estimates, the Northeast, Southeast, and Southwest regions are anticipated to have negative or no population growth, with minimal population growth (0.9%) in the Central region and minor growth (6.4%) in the North Central region. For high estimates, the Northeast and Southwest regions are anticipated to have the highest growth at 65% and 61%, respectively. The regions with the lowest population growth are North Central and Central, at 40% and 41%, respectively.

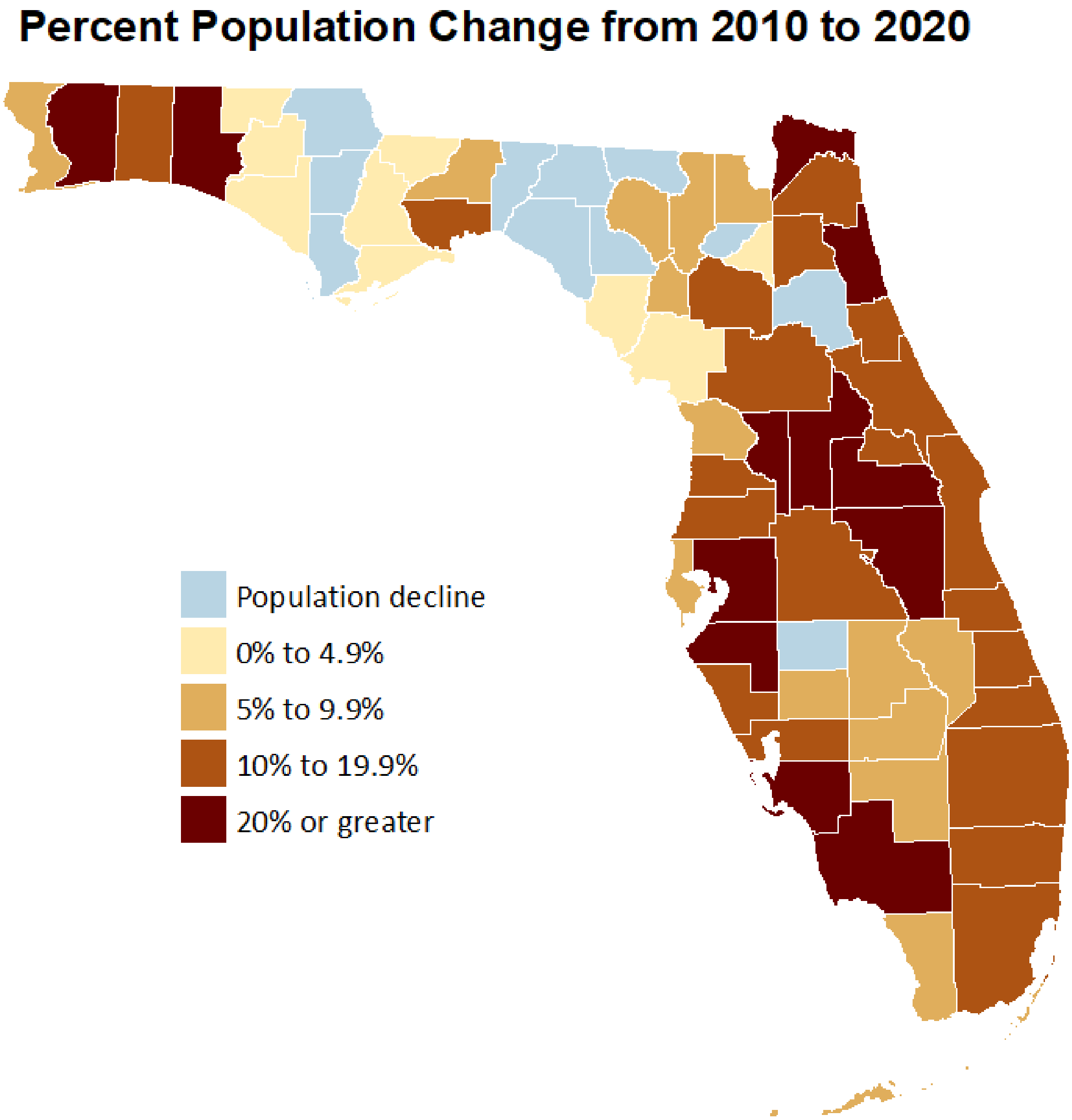


Figure 34. Percent Population Change From 2010 to 2020. (Data from Bureau of Economic and Business Research, 2023 (https://bebr.ufl.edu/population/) and FGDL (https://fgdl.org/ords/r/prod/fgdl-current/catalog) Albers projection; CES 2024g.)

Table 3. 2050 Population Projections per Region. (Bureau of Economic and Business Research 2023.)

Region	2022 Population	Total Low Estimate Per Region	Total High Estimate Per Region	Population Change Low Estimate (%)	Population Change High Estimate (%)
Central	8,349,242	8,420,300	13,376,400	0.9	37.6
North Central	587,781	535,300	824,500	6.4	40.3
Northeast	1,878,146	1,878,100	3,102,200	-0.002	65.2
Northwest	1,542,781	1,416,900	2,268,400	-8.2	47.0
Southeast	6,961,960	6,510,100	9,861,700	-6.5	41.7
Southwest	2,564,239	2,563,800	4,148,700	-0.02	61.8

These population projections are an area of concern for Florida’s climate resilience in the midst of climate change. No one expects Florida’s population to stop growing. If this growth is distributed in a geographically compact way, then its impacts on ecosystem services will be minimized. Such a growth management outcome is one of the intended effects of the Florida Wildlife Corridor (FLWC). The Florida Department of Agriculture and Consumer Services (DACS), in conjunction with the University of Florida’s GeoPlan Center, and 1000 Friends of Florida, have teamed to project population growth across the state (1000 Friends of Florida 2016, 2023). Estimates from the report indicate a projected increase of developed land in the Central region up to 48.2% based on current development patterns, and a population increase of 14.9 million people across the state. This is in comparison to a statewide percentage of 33.7% developed land and far greater than other regions such as the Florida Panhandle (17.8%), Northeast Florida (34.5%), and South Florida (30.4%).

Estimated impacts on the FLWC are also anticipated to be most significant in the central region of the state indicating that approximately 206,365 acres of Florida Wildlife Corridor land could potentially intersect sprawl by 2040, using the 2040/2070 Sprawl (Trend) Development Projections. Additionally, 985,882 additional acres of the FLWC could intersect sprawl by 2070, as depicted in Figure 35 and includes areas of critical linkages.

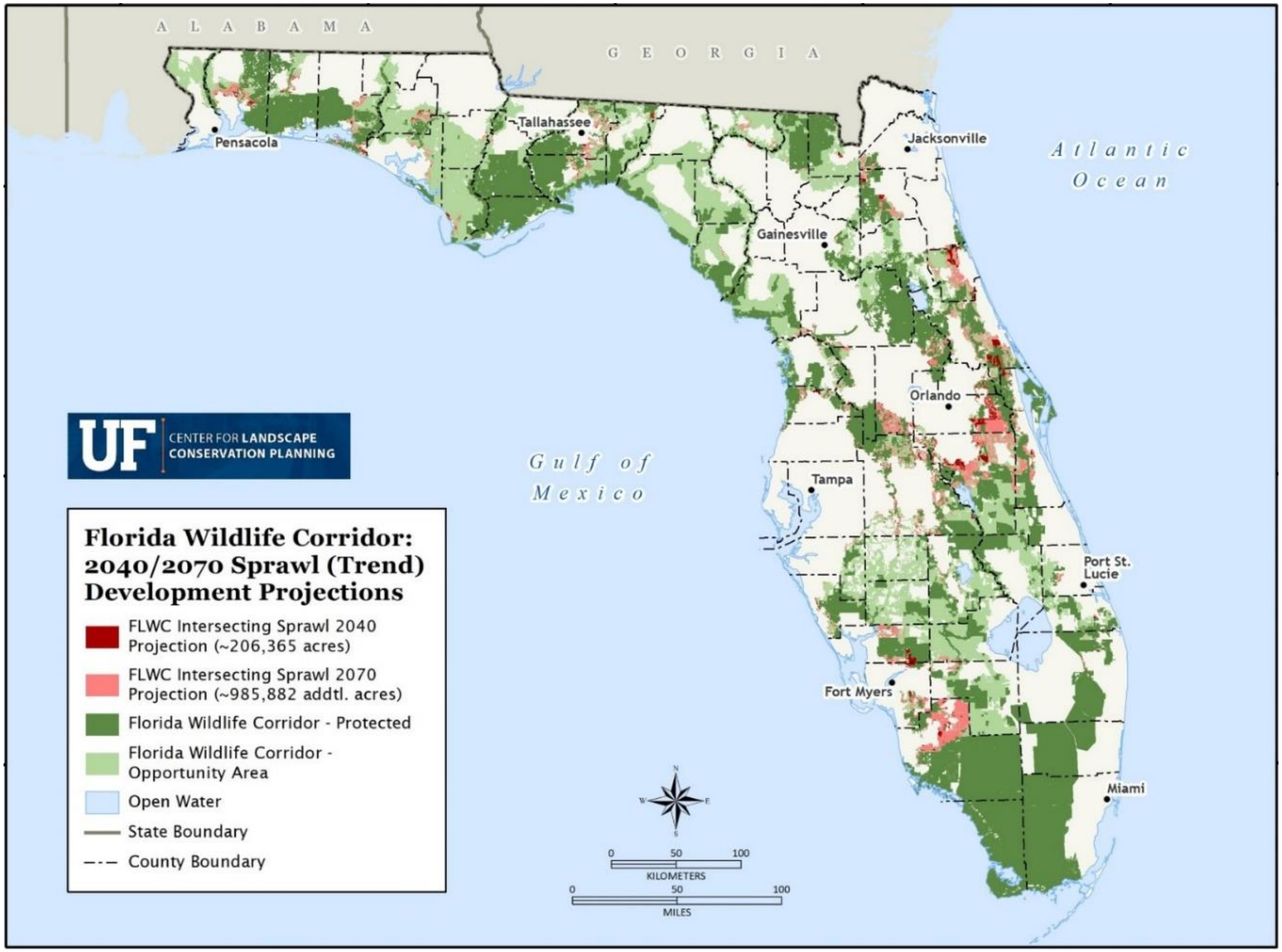


Figure 35. Florida Wildlife Corridor Areas of Projected Sprawl in 2040 & 2070. (Data from Environmental Systems Research Institute, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, Florida Geographic Data Library, Florida Natural Areas Inventory, University of Florida Center for Landscape Conservation Planning, U.S. Census Bureau, U.S. Geological Survey; Projection: Albers Conical Equal Area; University of Florida 2024a.)

II.B. Sensitivities: The Twinned Climate-Population Effects on the FLWC's Dominant Ecosystem Services

This Section II.B on Sensitivities applies the Exposures described in Section II.A to the overarching framing presented in Section I. Our motivation is to understand how the FLWC might affect, directly or indirectly, the impacts, both positive and negative, on our lands and livelihoods from the twinned exposures of a rapidly growing human population and a changing climate. We define climate-population sensitivities as the expected changes for people and ecosystems in response to the changes in climate and population (outlined in Section II.A, Exposures). Where possible, we tie the expected changes to our four principal land use categories.

To recall from Section I.F, the four land uses examined in this report are developed (urban/suburban), natural land, intensive agriculture, and working lands (seminatural; ranching and timber). The future climate conditions are divided into two overarching categories: more heat, and changes in precipitation. Where possible we quantify the potential impacts, in other cases we offer qualitative assessments. We evaluate the changes under two assumptions: first, a future Florida where the conserved acreage in the Corridor does not change relative to the present day, and second, a future where all the FLWC acreage is conserved. The acreage extent considered therefore ranges from today's approximately 10 million acres conserved to the maximum potential of nearly 18 million acres (Figure 1). Not knowing today how much of the FLWC will be conserved in the future, these two scenarios bracket the range of potential future outcomes.

II.B.1. More Heat

The best understood climate change is heat. In response to rising levels of atmospheric greenhouse gases, average temperatures will increase. This will occur in most places worldwide, offsetting scattered instances of unchanged or reduced temperatures. Generally, average nighttime temperatures are expected to increase more than daytime temperatures, winter more than summer, and high latitudes more than low latitudes (as outlined in Section II.A. Exposures). In Florida the expected temperature increases are likely to be larger. Averages across multiple climate models project that by 2050-2074, Florida months may warm approximately 3 to 5 °F relative to a 1981-2010 baseline (USGS 2023; Figure 2).

With the FLWC as our exposure unit, the most salient effects of this heat increase on our four land uses should manifest in four principal ways: changed fire risks, changes to plant and animal communities, modified food and fiber output, and physiological stress on outdoor workers and recreational visitors.

In terms of ecosystem service impacts, we speculate that fire stabilization from natural lands, working lands, and in some aspects, intensive agricultural lands is critical to Florida's climate resilience. Regular fire regimes improve ecosystem efficiency, and therefore, ecosystem services. Restricting development to denser geographies that do not remove natural or working lands would increase regulating services like temperature regulation, air quality, and carbon sequestration that may mitigate some heat related exposures that harm human health. Additionally, implementation of a full FLWC could contribute to supporting services like pollination and nutrient cycling, as well as regulating services like water quality and quantity, that support production in food and fiber lands. In conclusion, fully conserving the FLWC and limiting urban sprawl will help conserve natural, working, and intensive agricultural lands that will contribute to ecosystem services that reduce fire and heat impacts that adversely impact ecosystems and people.

II.B.1.a. Heat-Related Changes to Fire Risks

In the theoretical absence of population growth and the FLWC, climate change would likely lead to increased fire in Florida leading to some recovery of the open, grassy ecosystems, pine savannas, and scrub that dominated Florida's landscapes pre-settlement. Heat, plus drought and lightning, are among the essential ingredients for fire (Platt, Orzell, and Slocum 2015), and all of these are expected to increase with climate change over the coming decades. Some climate models predict global increases in lightning frequency on the order of 50% within the current century (Romps et al. 2014). Some of the narrowest parts of the FLWC correspond with some of the state's highest lightning frequency zones (Collins et al. 2017: Figure 20.8). With higher temperatures and increased moisture stress, vegetation generally will be more combustible. Warmer temperatures also favor C_4 (warm season) grasses (Morgan et al. 2011), which are mostly highly flammable. Potentially countering a projected trend of increasing grassiness, however, is the direct effect of enhanced atmospheric CO_2, which favors C_3 woody species over C_4 grasses and could potentially release woody plants from control by fire (Midgley and Bond 2015). Effects of increasing drought severity could affect tree-grass competition, however. Diverse grasslands and savannas are likely to be resilient to climate change-induced drought through the local expansion of more drought-tolerant grass species (Craine et al. 2013).

A smart strategy toward ensuring Florida's climate resiliency is therefore to maintain its savannas and other open grassy ecosystems. The FLWC will be most resilient to climate change – and contribute most to Florida's overall climatic resilience – when it maintains a fire regime characteristic for its climate and vegetation. The grasslands, savannas, and other open, grassy ecosystems that once dominated Florida, and still make up a considerable portion, are likely to be more resilient to climate change than closed-canopy hardwood forests. In general, grassland species are more tolerant of fire, wind, drought, heat, disease, and defoliating insects than the hardwood forests that have often replaced them due to fire exclusion. Grassland fires tend to travel quickly and do not have the long flame lengths or residency times of severe forest fires. Compared to closed-canopy forests, grasslands have low water consumption, which leaves more water resources for human uses (Hanberry and Noss 2022). In sum, considered in isolation from population growth and the FLWC, more heat likely means more short-term fire risk for Florida, opening the door to an eventual transition to more open, grassy ecosystems with relatively calm fire regimes better aligned with local conditions.

However, adding the realism of Florida's rapid human population growth to the picture modulates this projection. In general, people demand fire suppression to protect urban areas against fire-induced loss of life, property damage, and health impacts from smoke. Reduced prescribed burning, however, increases wildfire risk (Hunter and Robles 2020). Thus, the more that new housing, businesses, schools, and highways are scattered on the landscape versus geographically compact, the more difficult it becomes to manage fire risk through regular prescribed burning. Therefore, if Florida's new developed lands are not proactively shaped to maximize contiguous area that facilitates regular fire management sufficiently far from the new human developments, then the long-term climate change benefit of favoring more open, grassy ecosystems described above should be limited. The resulting forest cover would mean greater fuel loads and higher fire risk given the higher temperatures.

This risky situation would be further compounded if a contemporaneous increase in drought severity and duration compels agencies to impose longer bans on controlled burning (Mitchell et al. 2014). The net result of these human-environment interactions may be a growing number of Florida landscapes with mounting fire risks. Modeling suggests that fire risk in Florida is projected to increase due to general climate warming, higher winter temperatures, increased frequent heat waves, and decreasing soil moisture. Southern regions such as the Everglades are likely to experience earlier problems, due to their advanced favorable atmospheric conditions. These conditions include anticipated warmer winters and a decrease in precipitation compared to prior years (Barbero et al. 2015).

This anticipated outcome in Florida echoes the tenuous situation unfolding in California and elsewhere in the U.S. West in recent years (Hagmann et al. 2021; Parks and Abatzoglou 2020; Reilly et al. 2017). Florida has advance notice of this likely outcome if development is not planned with fire management in mind, thus avoiding the California/U.S. West outcome, and should continue to be a high priority for Florida. Given the above theoretical backdrop, it stands to reason that in principle the FLWC would be beneficial for fire risk in the context of Florida's twinned population growth-climate change stressors. More geographically compact development patterns requiring absolute protection from fire means a greater feasibility for effective fire suppression. By contrast, more dispersed land development means a lesser feasibility for proactive fire suppression, translating into higher fire risks.

However, simply conserving existing opportunity areas in the FLWC alone, as measured by the number of acres in conservation, would not suffice to manage fire risk to socially acceptable levels. The fuel load on the conserved land still needs to be actively managed. Instead, implementing dedicated, sustained annual fire management practices to lands inside the FLWC borders is needed. This approach seems to hold the most promise for balancing the dynamics of shifting climate conditions, a growing population, and the predictable and understandable human demand to live without fear of fires. In sum, simply conserving existing opportunity areas in the FLWC without a thorough fire management plan may not lead to net fire risk reductions in the long-term, though it would greatly improve the ability to manage fire efficiently and effectively.

In conclusion, the degree of fire risk change from a warmer Florida is not easily identifiable between the land use categories of natural and developed lands. Population growth means more developed land, but the extent and geometry of the development appear to dictate the change in fire risks on the natural lands. The more geographically compact the new developments are, the greater the *potential* is for proactive fire management on natural lands. The less geographically compact the new developments are, the more likely it is that prescribed burning in the natural lands will be eliminated, which ultimately leads to higher fire risks on both the natural and developed lands. Thus, compact development per se does not suffice to reduce fire risks; it simply provides the opportunity to launch a proactive fire management regime on surrounding natural lands.

II.B.1.b. Heat-Related Changes to Plant and Animal Communities

Plants and animals have always needed to adjust and adapt to changes in environmental conditions and will continue to do so. There is a lot of ongoing research into climate change's effects on plant and animal communities in Florida. Improving the fate of Florida's plant and animal communities assuming a continued human population boom has been among the original principal motivations for the FLWC and other conservation efforts for years. The focus of this section is how heat-related changes to plant and animal communities be additionally impacted by the combined changes in human population growth and conservation of existing opportunity areas in the FLWC.

Regardless of human population growth and/or additional opportunity areas of conserved area within the FLWC, we can expect higher average temperatures to likely manifest as more frequent, lengthy, or intense drought conditions, rather than a simple increase in daily averages (Perkins, Alexander and Nairn 2012). Given the wet-dry seasonality of much of Florida's climates, this change in the hydrologic cycle likely translates into lower soil moisture and conditions favoring drought-tolerant insects, grasses, and vertebrates (Schwalm et al. 2017).

Temperature affects all biological processes, with impacts scaling from the metabolism of individual cells to the migration of flora and fauna. For each process, there is typically an optimum temperature around which the process slows, and if the temperature deviates too cold or too warm from the optimum, then the process may stop. In approaching this stopping point an organism needs to adapt or it may miss a crucial life function, be weakened, or die. For fauna, adaptive actions could be migration, seeking shelter, or altering the timing of movement or reproductive activity. Flora can employ metabolic, structural, and phenological adjustments to cope with temperature deviations, and may 'migrate' as temperature change creates better reproduction frontiers at the margins of an existing range.

Averages across multiple climate models project that by 2050-2074, Florida months will warm between approximately 3 to 5 °F relative to a 1981-2010 baseline (Alder and Hostetler 2013) (Figure 36). This range reflects scenarios with different levels of greenhouse gas emissions reductions. Under a scenario of minimal emissions reductions, average June, July, and August temperatures could be near 87 °F throughout Florida. Worrying aspects of 'peak temperatures' are hidden by averaging, as extreme high temperatures could cause organisms to cross metabolic thresholds that imperil their viability in Florida. One issue is that some of the models predict warming as great as 7 °F, reflecting a temperature dynamic more similar to tropical environments. Moreover, the daily amplitude of temperature is historically approximately 15 °F which means that the average daytime high for temperature could be as much as 94 °F during summer months. Considering that the global climate warming and cooling cycles (e.g. El Nino) are expected to continue (Cai et al. 2021), it is possible that Florida will have years where temperatures are well above these average values.

The FLWC is designed to allow fauna and flora to cope with these temperature changes in the face of population growth better than a future without a strong brake on suburban sprawl. The envisioned geographic continuity of the FLWC will allow fauna to more easily move to suitable habitat types within a season, seasonally migrate among habitat types, or potentially relocate to new areas within Florida. A notable case where this movement might be critical is for black bear (*Ursus americanus*) in Florida (Costanza et al. 2020). The Florida black bear is the sole black bear found in a subtropical environment, at a latitude and average temperature only paralleled by black bears found in northern Mexico. As a species apparently living at its climatic edge, Florida black bears could be more dependent on avenues of 'escape' from excessive temperature change at different temporal scales than other species. However, allowing movement within the continuous vegetation cover offered by the FLWC would likely be important to multiple plant and animal species.

In addition to facilitating organismal movement, the FLWC will moderate temperatures for organisms within and near its boundaries. This will be directly related to vegetation coverage within the FLWC, which should be more extensive and voluminous than in developed areas. The process of evapotranspiration cools the surrounding air as the sun's energy hits the earth's surface. Cooling during drought periods can be further facilitated by deep-rooted plants as these can access subsurface water sources and continue to transpire even as surface soils dry and evaporation is slowed. The importance of the FLWC will also reflect its moderating effect on temperature relative to nearby urban-suburban regions. Land surfaces covered by relatively 'dark' colored human infrastructure and homes convert this energy into heat, further warming the near environment. This urban warming, or Urban Heat Island (UHI) effect can be substantial. Notably, from 2004-2014, the average UHI effect across 60 cities in the

United States increased temperatures by 2.4 °F relative to nearby rural areas (Kenward et al. 2014). If Florida landscapes are fragmented by development, the edge effects from UHIs could further challenge organisms trying to adapt to a changing temperature regime. It is likely the FLWC will moderate this effect, but by how much requires further research.

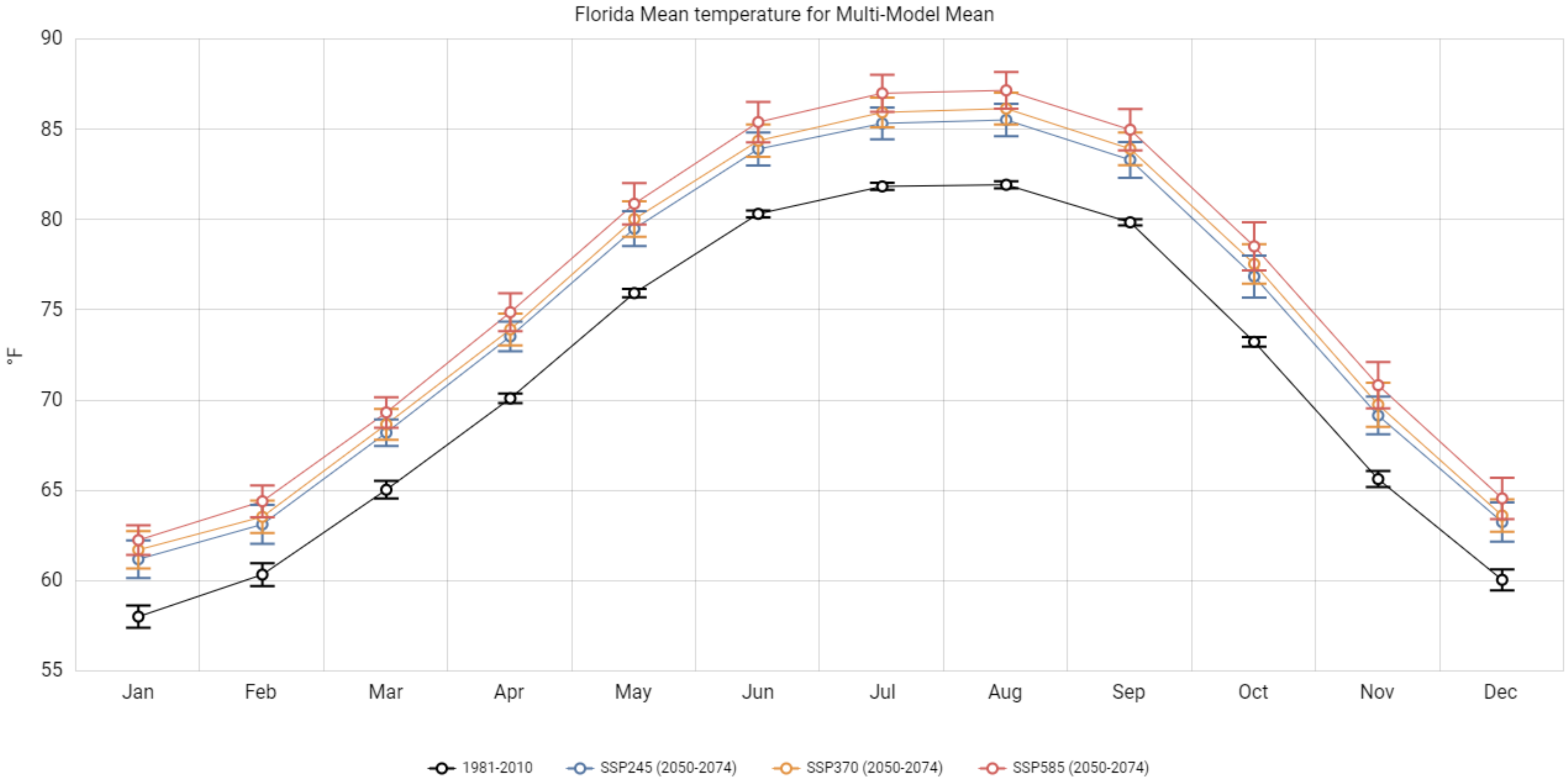


Figure 36. Florida Average Monthly Temperatures for 1981–2010 and Projected Temperatures for the 2050–2074 Timeframe, as estimated from multiple climate models, the Shared Socioeconomic Pathways (SSP) reflect graduated levels of societal success in reducing greenhouse gas emissions, with SSP245 reflecting the greatest effort and SSP585 the least. (Graph generated using Climate Change Viewer Tool at https://www.usgs.gov/tools/national-climate-change-viewer-nccv last accessed 12/1/2023; Alder and Hostetler 2013.)

Warming and heat extremes may also increase the value of the FLWC to the people of Florida who use it for outdoor recreation. It would be expected to find higher diversity and densities of plants and animals in the more natural areas of the FLWC, if it provides the more optimal temperature regimes needed for organismal life processes. The cooler temperatures in the FLWC could also make it a more enjoyable experience for recreational users than other locations (Evans 2019), especially for those urban and suburban Floridians looking to escape the UHI. Without this escape opportunity, the health of Floridians could be compromised as studies have found a correlation between outdoor activities in cooler temperatures and metrics of human well-being (Mullins and White 2019).

In conclusion, the changes in plant and animal communities from twinned climate-population changes should be moderated by a full implementation of the FLWC. This high-level outcome should apply to all four land use types, even if the degree of changes varies with land use type. Moreover, whatever moderating effect the FLWC has in this context, it is likely to be less pronounced in intensive agricultural and working lands than in natural or developed lands. The professionals managing lands for food and fiber output (see also Section II.B.1.c.) already strive to optimize for specific biological-economic outcomes, and as such likely possess the skills, tools, and incentives to adapt to maintain their outcomes in the face of the changing baseline conditions, at least for the coming few decades.

II.B.1.c. Heat-Related Changes to Food and Fiber Output

The two ecosystem changes due to more heat discussed above – increased fire risk, and changes to plant and animal communities – will manifest, if in varying ways, in all four of Florida’s main land uses. By contrast, Florida’s intensive agricultural lands and working lands are the land use categories where we expect to observe potential changes in food and fiber output (heat effects in the fourth land use category, developed lands, are described in Section I.G below). Farmers, ranchers, and timber producers are experts at actively managing their lands. These professionals routinely respond to changing conditions fundamental to their operations, including not only weather variations and extremes, but also variations in commodity prices, labor availability, and consumer demand.

The question for this report is how proactively these expert land managers may respond to changing heat conditions linked with climate change. Due to climate change, adaptation is required in the environmental, social, and agricultural fields (USDA 2024). Reducing risks, building resilience, and sustaining productivity all depend on local responses. The agriculture sector will have to modify their management, and conservation techniques, such as maintaining soil health. Artificial intelligence is one of the upcoming techniques to maintain a healthy soil, reduce the impacts of natural hazards and have a reliable yield.

Producers and landowners can mitigate climate change by undertaking climate-smart conservation efforts with the help of organizations like USDA's Natural Resources Conservation Service (NRCS). The USDA provides technical and financial support for the adoption of climate-smart agricultural management practices. These funds will help farmers and ranchers implement conservation methods that help adapt their operations, but also support climate change mitigation. Projects with support include nutrient management, cover crops, decreased tillage, wetland restoration, and reforestation, all contributing to greenhouse gas reduction and carbon sequestration goals. See Section II.C - Adaptive Capacities for more discussion.

Florida lands currently used for food and fiber production are at significant risk of being converted to urban land use (1000 Friends of Florida 2023; Volk et al. 2017; Daskin et al. In review). This applies to the land utilized for orchard crops such as citrus and for field crops like watermelons, sweet corn, and tomatoes (Florida Department of Agriculture and Consumer Services 2024). The payoff for selling land to developers can be too high to resist. We are observing some of this process today with the citrus greening disease leading to apparently sustained economic crop failures. The result is the widespread sale of citrus lands for urban development (Peng et al. 2021). Not having a vision such as that represented by the FLWC to incentivize keeping these working lands in production in the face of twinned climate-population change means Florida may lose much of its food and fiber lands. Once converted to urban land use, it is difficult to conceive of the lands being converted back to food and fiber uses.

The impact of this conversion will not likely be felt in the abilities of state, national, or global populations to feed themselves. The global agricultural system should be able to accommodate the loss of Florida food and fiber production acreage to still provide consumers adequate calories and nutrition. Instead, the impact of this trend on Florida's coupled human-environment systems within the FLWC boundaries would be felt more in the abilities of our rural communities to sustain themselves economically and socially. This impact would manifest, as has been unfolding for decades across the U.S. grain belt and Great Plains regions, as a depopulation not only of the farmers and ranchers but also of their support workforce and businesses. This process typically means lower local incomes, increasing unemployment, declining public health, and a loss of young families (Lasley 2016). We observe this in Northern Florida in recent years. In other Florida areas, such as Central Florida, the departure of land's economies may be replaced by suburban and urban uses. In general, such an outcome would result in the loss of a way of life for Floridians in many of our current rural communities.

The FLWC is designed to reduce biodiversity loss, specifically wildlife, that failing to manage our human population boom and climate change would generate. Potential co-benefits of the FLWC include a greater economic viability of our food and fiber lands compared to the scenario of those lands being outbid for conversion to urban uses, with the associated reversal of the negative trends hypothesized above. This discussion highlights a feature of the land conservation process that may seem obvious but is often unstated and therefore may be overlooked: the wildlife improvements (plus any co-benefits) will not be lasting if the conservation programs are not lasting. If the conservation is enacted but then lifted, with the lands then converting predictably to urban uses, then the program's ecological, social, and economic benefits will cease, but the initial costs of keeping the land temporarily out of urban use will be unrecoverable.

II.B.1.d. Heat-Related Physiological Stress on Outdoor Workers and Recreational Visitors

For people, hotter conditions for Florida should bring more challenges than benefits. The state's current climates do not include areas with strong winters such that warmer winters would mean a climate change benefit for human well-being. The challenges in Florida include more human health risks from physiological heat stress, and less ability to spend time outdoors. The heat increase will translate for many of Florida's residents and tourists as longer and hotter summers, with less nighttime relief from daytime highs (Crimmins et al. 2023).

In natural lands areas, this outcome likely means a longer recreational season for hunting, kayaking, etc., but with diminished participation during the peak heat weeks. In intensive agriculture and other working lands, this hotter future means shifting farming and livestock practices to reduce crop and animal stress. In all four kinds of land use settings, the hotter future means outdoor workers will face a greater risk of dehydration, heat stroke, and other heat-related illnesses, and will be available for fewer work hours per week (Kjellstrom et al. 2010). Of note for Florida is the combination of elevated heat with our familiar humid air. The resulting heat index (how hot the body feels, which increases with higher humidity) will be even more unsafe than what is suggested by the thermometer reading (Fischer and Knutti 2013).

Finally, the magnitude of the increased risks noted above will be larger in developed areas due to the urban heat island effect (Rizwan, Dennis and Liu 2008). Vegetated surfaces cool local temperatures by providing shade and through evapotranspiration, and urban areas have smaller vegetated surface areas. Replacing vegetation with concrete and asphalt significantly increases local temperatures. As a result, urban outdoor workers will experience even greater well-being challenges from outdoor heat exposure than outdoor workers in natural or working lands. It will be difficult enough to tend the fields or animals in a warmer Florida; the temperatures will be even higher for resurfacing a city road or repairing a rooftop air conditioning system. The same concern extends to non-working populations vulnerable to high heat, such as infants and the elderly, especially those who live with limited access to air conditioning or who rely more on public transportation with the needed long outdoor wait-times for buses or train (White-Newsome et al. 2009).

In sum, this heat-related human physiological stress impact of climate change appears to pose different risk levels across our four land use categories. Qualitatively speaking, the greatest threat is associated with developed lands, followed by intensive agricultural lands and working lands, and finally natural lands. The impacts should scale roughly in proportion to the numbers of outdoor workers and tourists. Adding population growth to the picture means an increase in exposed people, likely mostly (but not exclusively) in developed areas.

Interestingly, in the FLWC's developed lands, fully implementing the FLWC would not necessarily alleviate the increase in heat-related physiological stress on outdoor workers and recreational visitors from a warming Florida compared to the present extent of the FLWC. If anything, the act of conserving land from development in the FLWC likely means the FLWC's current developed lands will become more intensively urbanized. Accordingly, these areas would, if developed and managed in the traditional way, exhibit more concrete and asphalt, less vegetative cover, and therefore an enhanced urban heat island effect. Thus, a fully implemented Florida Wildlife Corridor would likely reduce the geographic expansion, but not necessarily the incidence or magnitude, of human heat stress in Florida measured as a function of the total number of people exposed.

This outcome is not preordained, however. There is a well-developed literature plus a good number of case studies on how to develop urban areas that are compact and cool (see Section II.C. Adaptive Capacities). For the incidence or magnitude to be reduced, the FLWC would need to be accompanied by a set of best practices, and ideally incentives to implement the practices, for reducing the urban heat island effect in existing urban areas likely to become more intensively urbanized. A common illustration of cooling cities is to increase the extent of tree canopy in urban areas. Another more cutting-edge example is to vegetate building rooftops. Further discussion is presented in Section II.C. Adaptive Capacities. This needs to consider not just the presence or absence of the FLWC in evaluating our future prosperity, but also the kind of ancillary management goals pursued alongside the FLWC, echoes what we recount in Section II.B.1.a., 'Heat-related changes to fire risks.'

II.B.2. More Rain

In Section II.B.1. above, we provide an outline of what the best understood effect of rising atmospheric greenhouse concentrations – more heat – is likely to mean for the lands in the designated FLWC. Here in Section II.B.2. we describe the other of the two principal expected changes in climate – precipitation. With heat, we can specify the direction of the expected change: more, as opposed to less, heat. By contrast, for precipitation the net effect of changing our atmosphere is nuanced and relatively uncertain at present for Florida. These nuances and uncertainties are briefly summarized here. The bottom line is that climate change should, in the aggregate, bring more rain and elevated flood risks to Florida, as described in Sections II.B.2. and II.B.3. Vignettes #1 and #2 provide examples from recent flooding events in Florida.

As with Section II.B.1 for future temperatures, in this section we evaluate our state's expected precipitation changes under two scenarios: first, a future Florida where the conserved acreage in the FLWC does not change relative to the present day, and second, a future where all of the legislated FLWC acreage is conserved. Not knowing today how much of the FLWC will be conserved, these two scenarios bracket the likely range of potential future outcomes. Where possible we quantify the potential impacts, in other cases we offer qualitative assessments.

Despite being unable at present to predict precisely how precipitation will change, scientists do know enough about these processes to provide useful information today until future research gives more precision. Specifically, as the layer of the atmosphere where life unfolds (the lowest layer, called the troposphere) warms, two physical properties of the hydrologic cycle will change. First, the water vapor carrying capacity of the air will increase, and second, evapotranspiration will increase. This means in theory that the warmer air *can* hold more water vapor before the water's mass becomes too heavy to remain aloft and then returns to the surface in the form of rain. It also means in practice the air *will* become more moist compared to before the added heat, because the warmer air will transfer more water from surface waters, oceans, and vegetation to the atmosphere. As a result, a warmer planet means that future rain events should on average contain a greater volume of water.

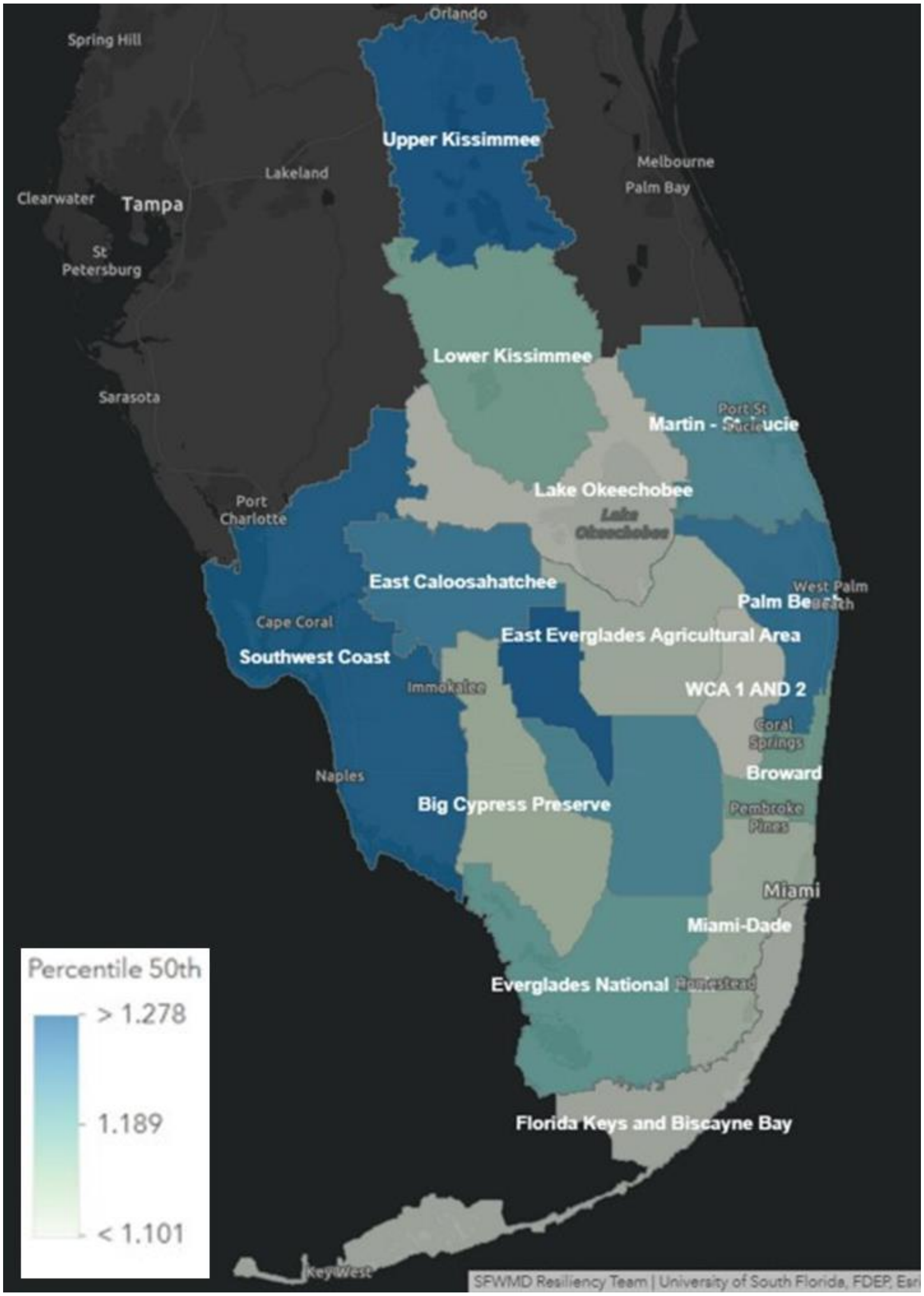
These predictions are supported by the most recent national climate assessment. In Florida's region, the Southeast, during the period 1958-2021 total precipitation falling on the heaviest 1% of days increased by 37%, and the annual heaviest daily precipitation amount increased by 9% (Crimmins et al. 2023). Similar positive trends are seen in all regions of the contiguous United States.

However, a place that experiences more intense rainfall events does not necessarily also experience more aggregate rainfall per year. Indeed, while virtually all of the United States (especially east of the Rocky Mountains) has seen more intense rainfall in recent years, the eastern half has seen more aggregate annual rainfall, whereas the west has experienced less. Thus, the singular stimulus of warmer air could result, depending on where the focus is, in opposite hydrological changes in different places. Some places or seasons will become wetter, others drier. The more pronounced cases will result in more floods or more droughts. The reasons for these differences include a location's proximity to a large lake or ocean, whether it is positioned leeward or windward of nearby mountain ranges, and its latitude and elevation.

Predicting Florida's climate conditions is arguably more challenging than for most locations in the U.S. Its near-tropical latitude means influential weather systems come from not only the west as for most of the contiguous U.S., but also from the south and east. Its being a peninsula means climate changes may be slower to materialize but more long-lasting when they do. Given these unknowns, it is not yet clear whether Florida's annual rainfall amounts will increase, decline, or remain unchanged under climate change. Recent data show that eastern Florida has experienced a slight decline in annual rainfall, while western Florida has experienced a slight increase. Winters and summers appear to be getting wetter, and falls and springs drier, during the period 2002–2021 (Crimmins et al. 2023: Fig 2.4).

The United States Geological Survey (USGS) and the South Florida Water Management District (SFWMD) have recently explored how climate change may affect extreme precipitation in South Florida. Results demonstrate that while significant uncertainties remain, the most consistent outcome across a range of scenarios is a projection of increased extreme rainfall (Irizarry-Ortiz et al. 2022). They developed a change factor, which could be applied to current rainfall accumulation to estimate future rainfall accumulation with the same likelihood of occurrence. For example, a 1-percent exceedance event (a rainfall event with a 1 percent probability of being equaled or exceeded, also commonly called a hundred year, or 1-in-100-year rainfall event) with a future change factor of 1.1 would be 10 percent wetter (10% more rainfall accumulation) in the future, than a 1-percent exceedance event today.

The report shows that the change factor differs by location and by likelihood of occurrence of the event. The authors acknowledge the significant uncertainty in their results but concluded that a positive (change factor higher than 1.0) change factor indicating wetter extreme events would be expected for much of Florida. Moreover, the change factor appears to increase with the return period of the rainfall event. Figure 37 shows results from the study summarized by the SFWMD for 14 rainfall areas in South Florida. It shows the spatial distribution of the computed change factor for the 72-hour, 100-year event based on multiple scenarios of climate futures. The Florida Flood Hub at the University of South Florida is extending this work to cover the entire state of Florida.



SFWMD Resiliency Team | University of South Florida, FDEP, Esri

Figure 37. Map of Computed Change Factors for the 14 Rainfall Areas Within the SFWMD Boundaries, as well as Everglades National Park, and a Combined Florida Keys and Biscayne Rainfall Area for the 3-day duration and 100-year Return Frequency, based on the 50% confidence interval (within the 25th and 75th percentile of models spread) for the ensemble of all model results and combined emissions scenarios (RCP 4.5 and RCP 8.5). (SFWMD 2022.)

In sum, we expect future rainfall in Florida to be more intense. More specifically, the most salient effects of expected changes in precipitation for the FLWC's four land uses should manifest in three principal ways: more runoff (flash) flooding, more river flooding, and more coastal flooding. The principal importance for the FLWC of the increased water delivery from the atmosphere described above is any associated changes in flood risks. Floods are generated by not only the quantity and intensity of rainfall but also by the characteristics of the land on which it lands. These characteristics include among others slope, soil quality, dryness, and extent of impervious cover. Considered collectively, these factors contribute to an overall flood risk. With the launch of the National Flood Insurance Program (NFIP) in 1968, the Federal government has estimated the flood risks for different locations across the U.S. The goal of this program is to guide location decision-making and to inform insurance risk calculations.

In effect, the NFIP results in a binary qualitative classification of each location as being known to have either "high" or "low" flood risk. In quantitative terms, these categories refer to whether or not a place is in the "100-year floodplain." These zones represent areas with an annual exceedance probability (AEP) of 1 percent, or that have a 1% chance of a flood of that magnitude (or higher) occurring in any one year. If a place is located within such designation, then it is known as "high" risk. Figure 38 shows the distribution of lands inside versus outside the 100-year floodplain across the FLWC. The figure also shows the relative shares of floodplain lands between conserved (65%) and opportunity (35%) areas, and of non-floodplain lands between conserved (44%) and opportunity (56%) areas.

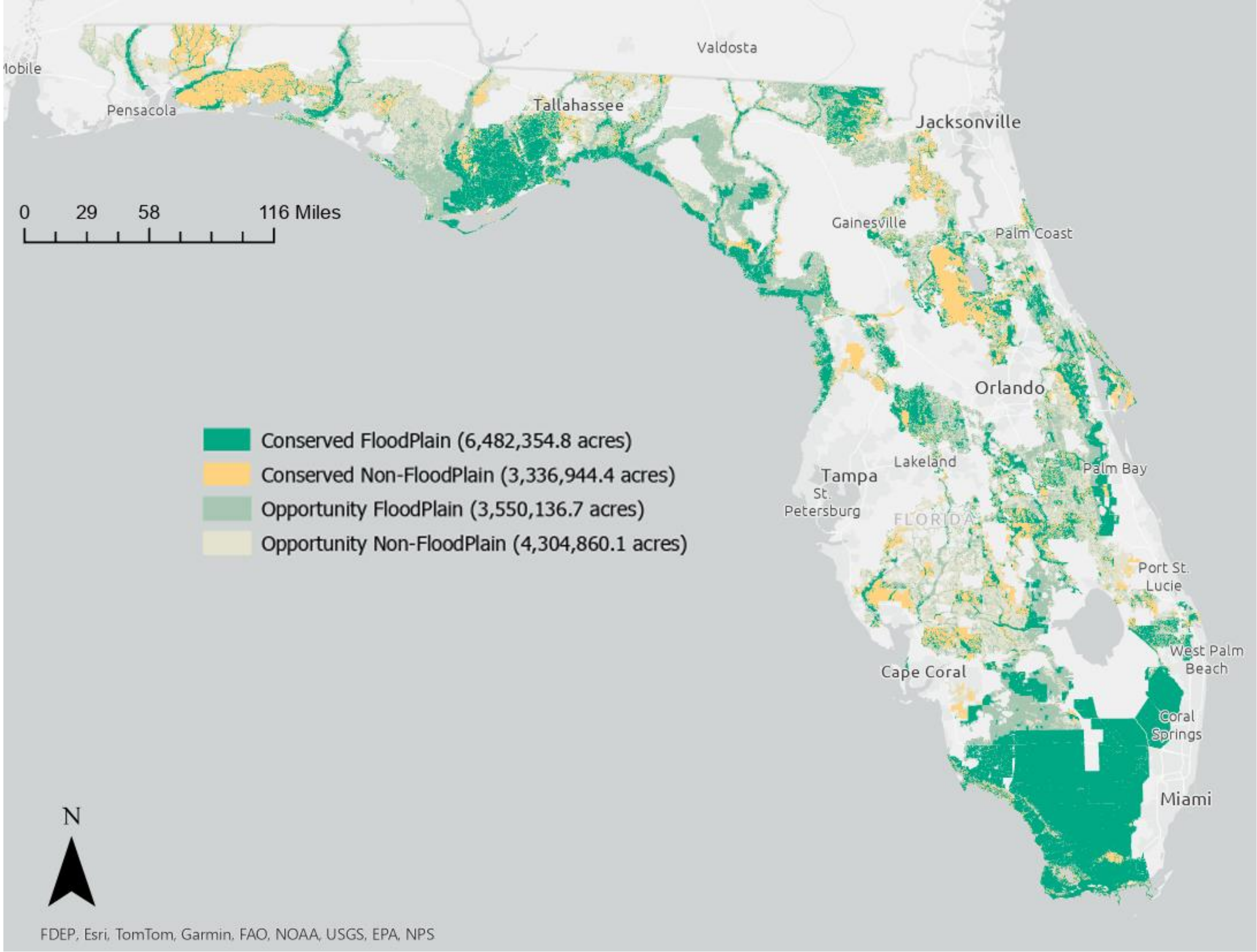


Figure 38. Floodplains of the Florida Wildlife Corridor. (CES 2024d.)

II.B.2.a. More Runoff Flooding (Pluvial Flood Risk)

Pluvial flooding, or runoff from rain, occurs when precipitation intensity exceeds the capacity of the human-made and natural drainage systems within an area (Rosenzweig et al. 2018). This can be especially problematic when the sea level is high, such as during daily high tides or annual King Tides, which reduces the ability of the drainage system in low lying areas of Florida to drain the water to sea by gravity. Additional challenges for drainage of intense rainfall include clogged storm drains, a lot of impervious surfaces often associated with urban development, or when the soil is saturated thereby preventing water removal from the surface to the subsurface. We characterize extreme rainfall events with depth, duration and frequency statistics. For example, we might specify the maximum number of inches of rain we can expect in a 24-hour period with a probability of occurrence in any one year. These numbers, though, are based on analyses of historical data, so it is difficult to project these estimates to the future since the climate is changing. To do that requires that we analyze the data from climate models.

Vignette #1: Pluvial Flooding in Broward County

On April 12th, 2023, a significant amount of rain fell across Southeast Florida, with especially heavy rainfall in the cities of Fort Lauderdale, Hollywood and Dania Beach (Figure 39). Over a 12-hour period, 25 inches of rainfall (a rate of 3 -6 inches per hour) fell in some locations, causing widespread flash flooding. The storm was characterized by a slow-moving front, coupled with an intensifying area of low pressure in the Gulf of Mexico (National Weather Service 2023).

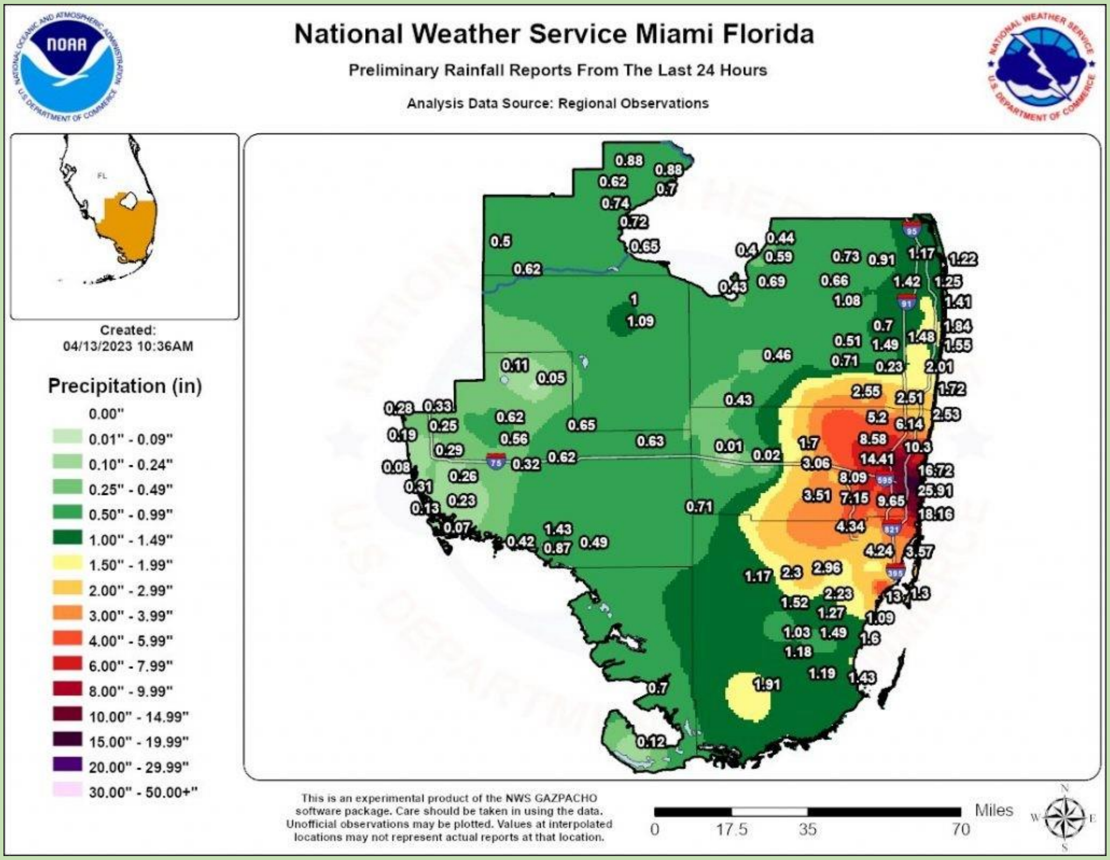


Figure 39. 24-Hour Estimated Rainfall and Observed Precipitation for the 2023 Fort Lauderdale Torrential Rainfall Event on April 12, 2023. (National Weather Service 2023.)

Many roads were inundated and unusable, with many cars remaining stranded without drivers due to the height of the water. The Fort Lauderdale-Hollywood International Airport canceled all flights and was closed through Friday, April 14th (Ives and Hauser 2023). Some residents were instructed to even use canoes or kayaks to avoid wading through the water. Even after the rain stopped, roads remained flooded throughout the region (Figure 40). This event totaled $1.1 billion in damages to homes, businesses, and vehicles (NOAA 2023a).

Figure 40. Roads Remained Flooded after Rainfall Stopped. (CES 2023d.)

Throughout the event, there was one instance where Fort Lauderdale received 1.5 inches of rain within 10 minutes, closing in on a record for the most rain in that short of a time (Ortiz and Bacon 2023). The ordeal, with record rainfall in the area again in November, contributed to the various climate-related records set in 2023 with 40 inches of rainfall above the annual average. 2023 hit a milestone as one of the wettest years on record for Fort Lauderdale. It was only the second time in 111 years of record-keeping that South Florida exceeded the annual 100-inch rain mark (Prociv 2023). The storm was all the more unusual given its timing in the spring. Major storms in south Florida are typical in the wet (summer) season, not during the dry season.

II.B.2.b. More River Flooding (Fluvial Flood Risk)

Fluvial flooding, or river flooding, is a function of rainfall accumulation (a combination of the intensity and duration) in or near rivers. When there are heavy and sustained rains, the ability of watersheds to up-take the water by evaporation, transpiration, interception, or infiltration is exceeded and surface runoff is generated which flow to streams, these streams flow into canals and rivers which in turn discharge into lakes or to the ocean or gulf. Where the flows in the streams, rivers or canals exceed the conveyance capacity of these water bodies, the water level rises and if it exceeds the bank elevation overbank flooding occurs.

Fluvial flooding can occur well after the rainfall event as runoff or stream flow wends its way towards the coast with the water bodies cresting sometimes days after the storm has passed. For example, the Peace River crested well over its record highs and flooded Arcadia not during but following Hurricane Ian (Figures 41 & 42). The worst of the flooding occurred after the storm had passed as runoff from record rainfall inland made its way to tide.

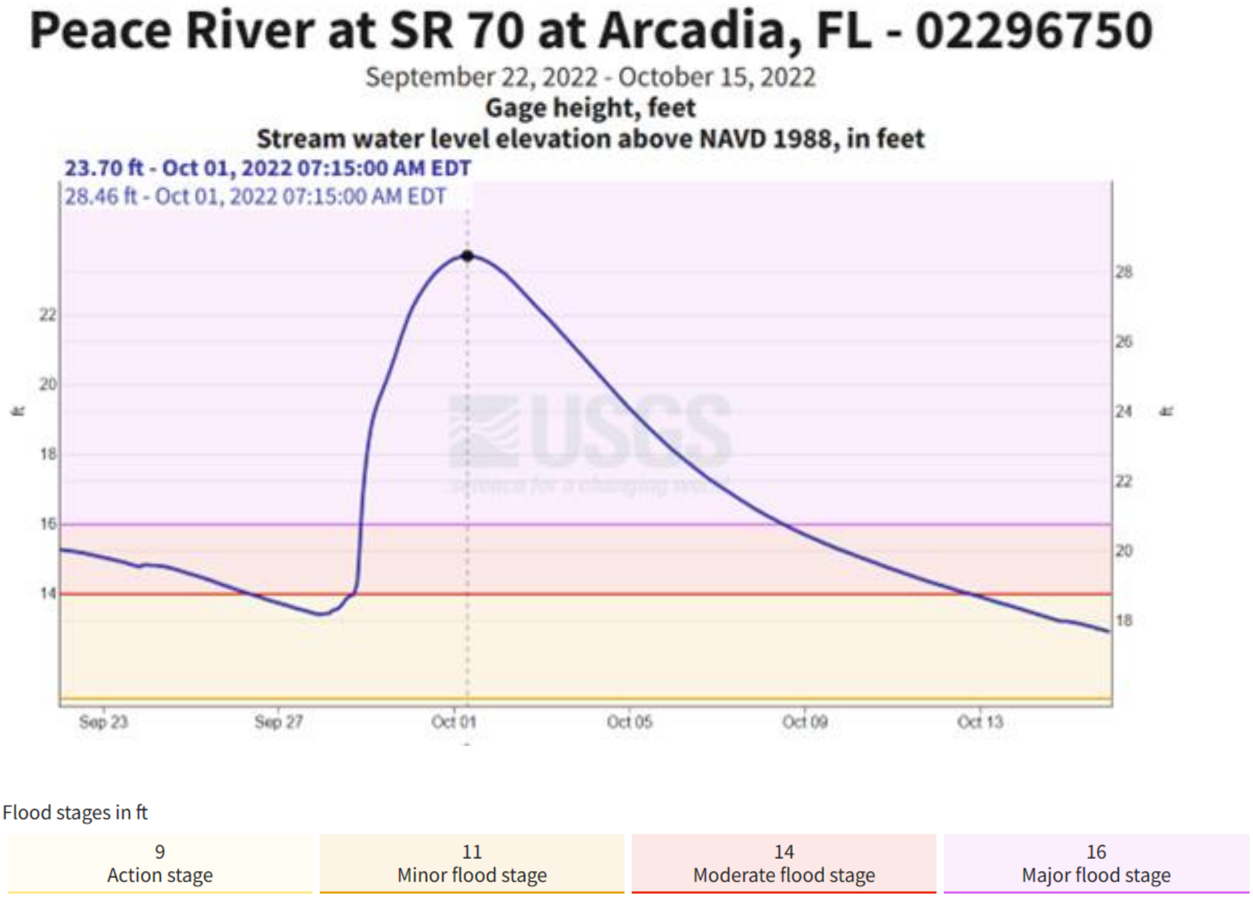


Figure 41. Observed and Forecasted Stage (in NAVD 88) on the Peace River at Arcadia Following Hurricane Ian Compared to Historic Record and Flood Stages, Peace River at this gauge exceeded the historic record of 20.5 feet NAVD 88 and was well above major flood elevation of 16 feet NAVD 88 at the gauge location. (USGS 2023.)

Figure 42. Peace River Campgrounds Near Arcadia Flooding After Hurricane Ian. (Reprinted from Treasure Coast Newspapers; Weit 2022.)

Vignette 2: Fluvial Floods From Hurricane Irma in Jacksonville

Hurricane Irma struck Florida on September 10, 2017, making landfall in the southwest and traveling north throughout the following days (Figure 43). As a Category 1 hurricane, the storm passed through Jacksonville overnight, bringing enough rain to flood the St. Johns River (Hong 2017). On September 11, the city of Jacksonville flooded to historic levels (Figure 44). This record was partially the product of an influx of water in the St. Johns River Basin from the storm's rainfall elsewhere on the peninsula that drained towards the city, compounding the effect of rain falling directly on the river (White 2022).

Moreover, the storm's effect on the St. Johns River was also exacerbated by a Nor'easter storm that had preceded Irma, bringing high pressure from the north that mixed with the low pressure from Irma to cause 40 to 60 mph winds and significant rainfall. The storm surge in areas by the river reached heights between 3 and 5 feet (Monroe 2017). The floods cost the city of Jacksonville an estimated $85 million in damage (Hong 2017).

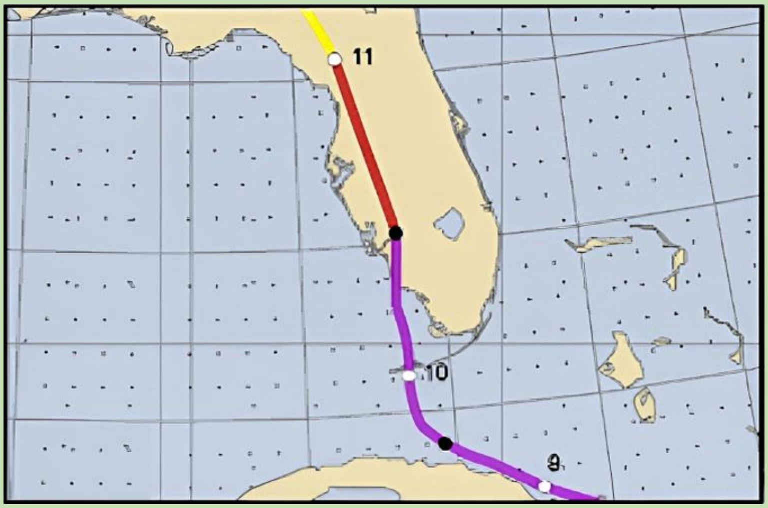


Figure 43. Hurricane Irma's Track through Florida, 2017. (NWS 2017.)

Figure 44. Man Standing in Downtown Jacksonville on September 11, 2017, as Hurricane Irma Floodwaters Remained in the Streets. (Reprinted from Florida Times-Union; Self 2018.)

II.B.3. Changes in Storms and Sea Levels

As outlined in Section II.A.1., Florida should expect tropical storms to intensify, and sea levels to continue their recent significant rise from recent decades. These trends will result in *more coastal flooding (storm surge and tidal flood risks).* The amount of rainfall, how quickly it falls, where it falls, and what water management or flood control assets are available to manage the resulting stormwater will often determine if there is a flood or not and how severe and sustained the flooding could be. Tropical storms and hurricanes are arguably the most common cause of damaging floods in Florida. Florida is hit by more tropical events than any other state in the union (Figure 45), which typically result in 1-3 feet of rain delivered in a short period of time (Henry 1998). Recent Hurricanes including Irma and Ian in Florida, Dorian in the Bahamas, and Harvey in Texas combined strong winds and the resulting surge with significant rain. Hurricanes, however, are not the only causes of rain-induced flooding in Florida. Heavy rains due to interactions between cold fronts and humid subtropical conditions in northern Florida result in flooding during winter and early spring in the Panhandle and northern part of the state. In the late spring and through the summer, all of Florida is subject to almost daily thunderstorms from the interaction of sea breezes and tropical climate (National Weather Service 2019). The intensity of the thunderstorms or their occurrence in rapid succession could result in flooding along rivers and lakes or in low lying and/or poorly drained areas.

We place hurricanes and storms in the coastal flooding section because even if some such events bring water damage inland, all such events that make landfall (and some that do not) bring flood risks for the coastal zone. The coastal flood risk from storms is largely driven by storm surge. These events are caused by strong winds blowing surface water (and often rain) towards the coast along with run-up caused by large waves forced by these same strong winds.

When a storm coincides with normal daily high tides, then the effect is amplified, and further amplified if the storm coincides with the annual highest (“King”) tides. This chance occurrence explains the unusual damages from Hurricane Sandy in the New York-New Jersey region in 2012.

We claim that coastal flood risks are increasing for Florida for two reasons (Knutson et al. 2020; Gori, Lin and Emanuel 2022). First, future tropical events will likely move more slowly as the atmospheric mean circulation slows in response to global surface warming (Hall and Kossin 2019). This matters for coastal flood risk if, for example, a hurricane producing rain at 10 inches per hour remains overhead for 3 hours instead of 30 minutes. This is what explains the extensive flooding in Houston from Hurricane Harvey in 2017.

Second, global sea levels are rising (Sweet et al. 2022). This means that the natural King Tides phenomenon mentioned above is producing more flooding today in low-lying locations, such as is already the case in many coastal Florida locations and will produce even more flooding in the coming years. Indeed, this trend manifests not only annually with the King Tides but also twice per day with the usual daily tidal cycle, albeit at lower levels than during King Tide season. Crucially, this tidal flooding sometimes occurs even when it does not rain (hence the common term for these events as “sunny day flooding,” even though tidal flooding can also of course occur when it rains). When a large rain event strikes a coastal location experiencing rising sea levels, the rain cannot drain away as quickly as it might in the present or would have done in the past.

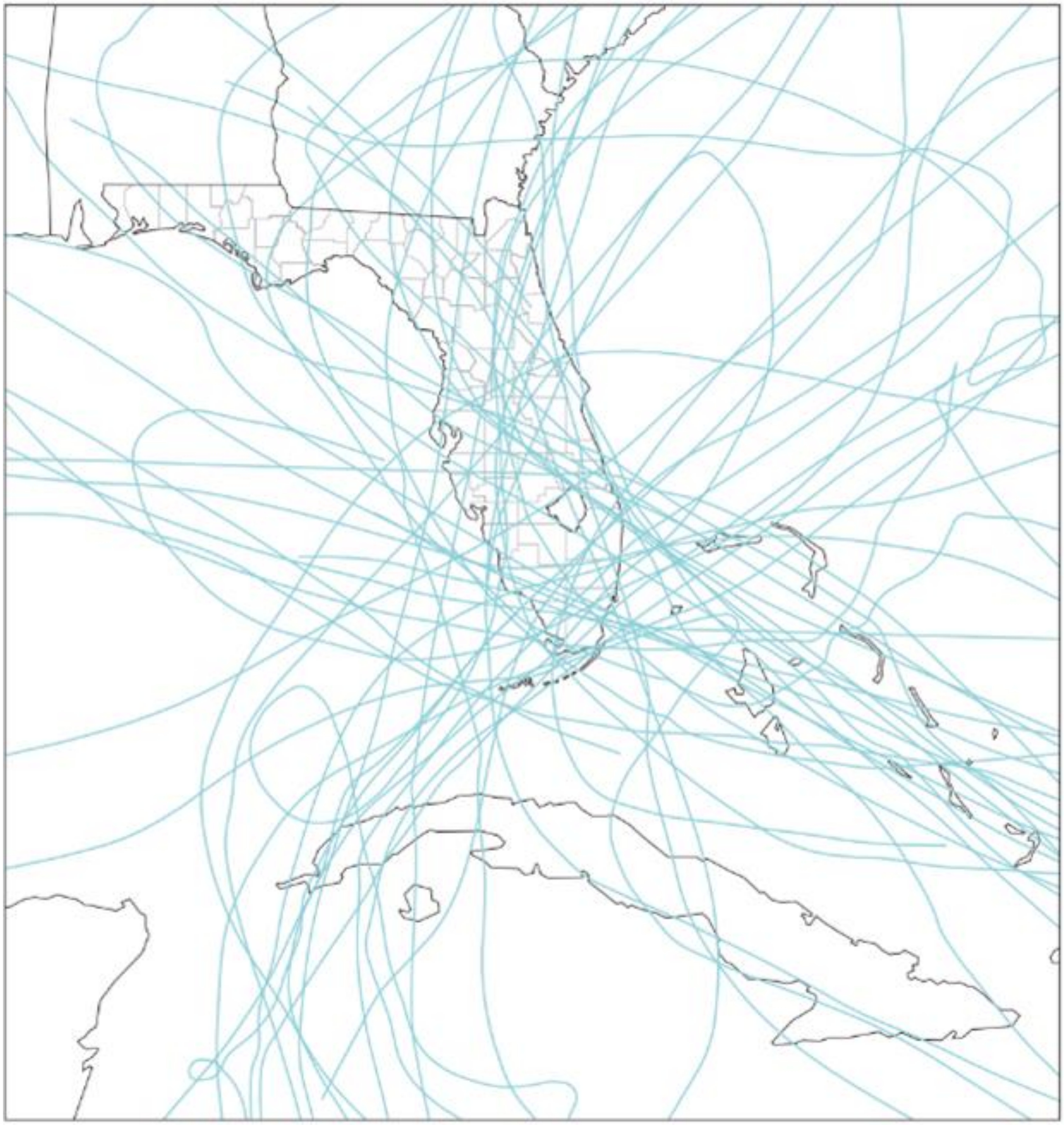


Figure 45. Hurricane Tracks, 1886-1996, Florida experiences more hurricanes than any other state, NOAA data for the period 1851 to 2022 show that of over 300 hurricanes hitting the coastline of the United States between Texas and Main, 120 or just over 40% made landfall in Florida. (Image source: Henry 1998; Purdum 2002.)

These increasing coastal flood risks present an urgent challenge for Florida and the FLWC. An important factor to consider is the speed at which these flood risks are rising. The recent alarming increase in tidal flooding in Florida should accelerate in the coming few decades, for two reasons. First, the earth's oceans are expected to heat more quickly in the coming years than in recent years (Knutson et al. 2020). Second, the recent increase in tidal flooding has been dampened due to a natural periodic decline in the effect on tides from how the Sun, Earth, and Moon are aligned. This alignment naturally shifts back and forth approximately every 19 years. To give one example, in St. Petersburg, Florida, the number of low-intensity tidal flooding events will increase from the current approximately 7 events per year to approximately 70 events per year by mid-century (Thompson et al. 2021).

The FLWC can reduce these mounting pluvial, fluvial, and coastal (surge and tidal) flood risks in Florida. The mechanism for this risk reduction is modified land uses. Fewer acres of urban/suburban development means lower flood risks due to fewer acres of impervious cover. In such a future, Florida can absorb more of the flood waters, diminishing the flooding impacts. As noted above in Figure 42, there are today approximately 3.5 million acres of FLWC opportunity lands in the floodplain. As wetlands make up a portion of the total land area in the FLWC, protection of this landcover type may yield increased resilience in this regard. The Adaptation of Coastal Urban and Natural Ecosystem (ACUNE) study led by University of Florida estimated that wetlands in Collier County provided damage avoidance to critical assets in Collier County by approximately $13 million and $200 million during Hurricanes Irma and Ian, respectively (Peter Sheng, in review). Furthermore, scientists at the University of Florida found that mangroves and marshes along Biscayne Bay reduced the maximum inundation behind the Bay by two thirds during Hurricane Andrew (Sheng and Zou 2017). Vignettes #3, #4, and #5 provide examples of wetland loss impacts, heightened tidal flooding and storm surge events in Florida.

The flood risk reduction of conserving those approximately 3.5 million acres has not been calculated but it is surely a large reduction. The urgency of this concern is even more pronounced when we acknowledge that, due to the changing climate conditions described above, the map of Florida's current floodplains is an underestimate of Florida's future floodplains. This means that some of the approximately 4.3 million acres of FLWC opportunity non-floodplain lands will shift to the floodplain category in coming decades. This shift adds to our flood risks, but also adds to our opportunities for flood risk reductions.

Vignette #3: Wetland Loss Impacts from Hurricane Irma in 2017

Hurricane Irma made landfall as a Category 4 storm across the Florida Keys and as a Category 3 storm in Southwest Florida on September 10th, 2017, bringing strong winds, intense rainfall, and storm surge (Cangialosi, Latto and Berg 2021; Figure 46). This resulted in an estimated $62 billion in damages (2023 CPI-Adjusted dollars; NOAA NCEI 2024).

Coastal wetlands, including their well-adapted vegetation such as mangrove trees, protect nearby communities by reducing storm surge flooding and damages during hurricanes (Al-Attabi et al. 2023). It is estimated that the median annual global value of coastal wetlands for storm protection is $447 billion per year (2015$US), with an estimated 40 million hectares of coastal wetlands located in storm prone areas providing $11,000/ha/yr in avoided storm damages on average (Costanza et al. 2021).

From the period of 1996 to 2010, total wetland coverage within potential flooding areas across 19 counties of Southwestern Florida decreased by an estimated 500 square kilometers (123,552 acres), which is approximately 2.8% of wetland coverage (Sun et al. 2020). This estimate is compounded by Florida's total wetland coverage reductions of more than 260,000 acres lost before 1996 (equivalent to 44% coverage reductions across the state) (Florida Fish and Wildlife Conservation Commission 2022; Figure 47). A loss of 1 square kilometer of wetland coverage increases the probability of experiencing property damage by storms by 0.02% in a county with average flooding area, wetland cover and winds, however this number increases to 0.6% in coastal communities (Sun and Carson 2020).

Sun and Carson (2020) indicate that reduction of wetlands across 19 counties that experienced tropical storm wind speeds upon landfall resulted in a $430 million increase in property damage by Hurricane Irma in 2017 (Figure 48). It is likely that with projected future sea-level rise, coupled with urban sprawl (Carr & Zwick 2016; Romañach, Benscoter and Haider 2020), wetlands could continue to be impacted, which may lead to a reduction in storm surge protections in the future that results in billions of dollars in additional landfall damages.

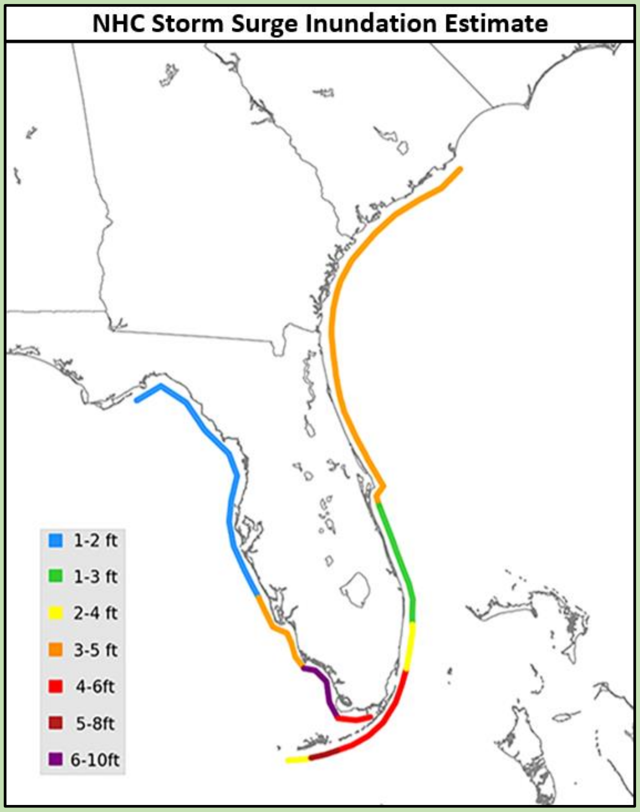


Figure 46. Storm Surge Inundation, (Feet above Ground Level), due to Hurricane Irma. (Cangialosi, Latto & Berg 2021.)

Vignette #3: Wetland Loss Impacts from Hurricane Irma in 2017 *(continued)*

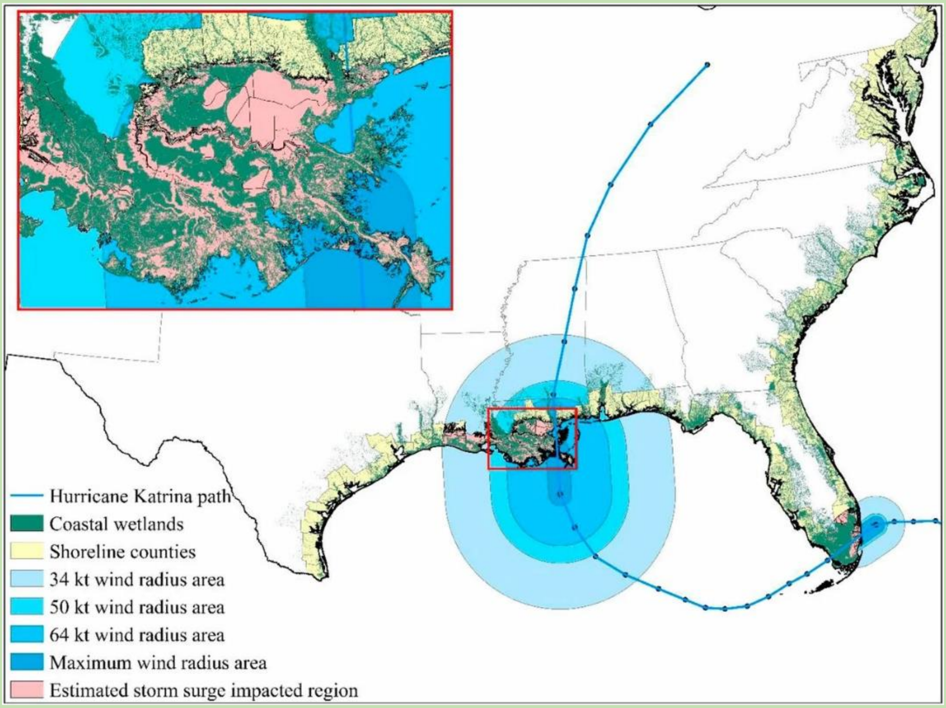


Figure 47. Hurricane Irma: Storm Surge Area and Coastal Wetlands Distribution. (Sun and Carson, 2020.)

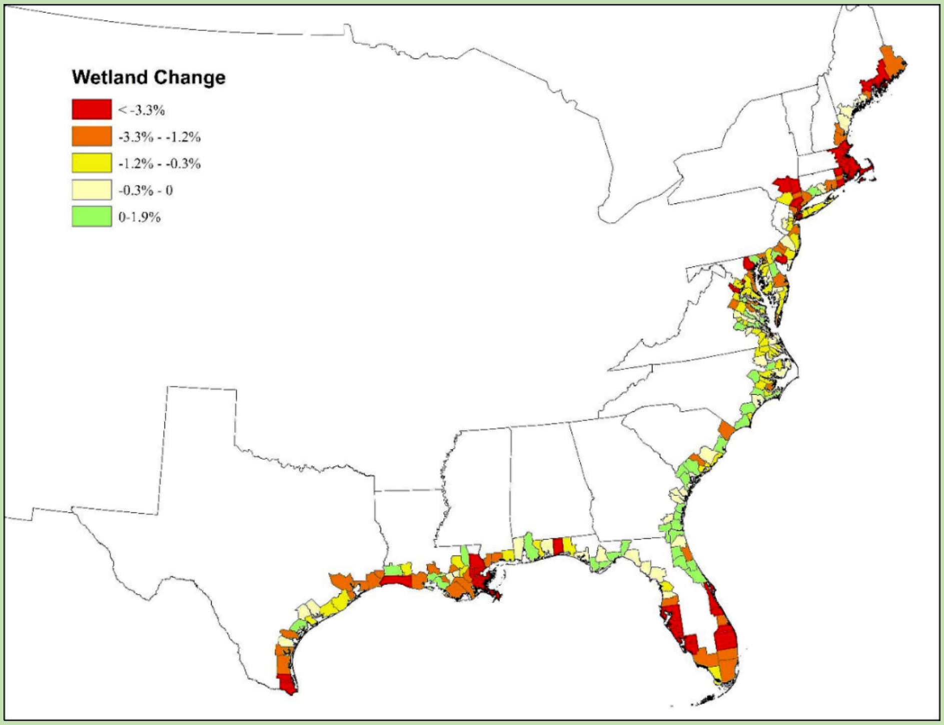


Figure 48. Coastal Wetland Change from 1996 – 2010. (Sun and Carson, 2020.)

Vignette #4: Heightened Tidal Flooding from Sea-Level Rise in Miami-Fort Lauderdale and Tampa Bay

The Miami-Fort Lauderdale area is extremely vulnerable to tidal flooding due to its coastal location and low elevation. Tides are a naturally occurring phenomenon, with for most places worldwide two high and two low tides each day. Due to the annual paths of the sun and the moon, the heights of the tides vary predictably throughout the year. The so-called King Tide season is the time of year when tides are expected to be highest. This season typically occurs in the fall, delivering water onto the landscape at times even when it’s not raining. As global sea levels continue to rise (due not to sun-moon-earth dynamics but to climate change from human activities), the region’s tidal flood risks also rise. King Tides can exceed 12 inches above average sea level heights (Miami Beach 2017). Weekly forecasts were issued for expected heightened tidal levels in the Southeast Florida region beginning in August 2023 and occurring every Monday during the King Tide season (SFWMD 2023).

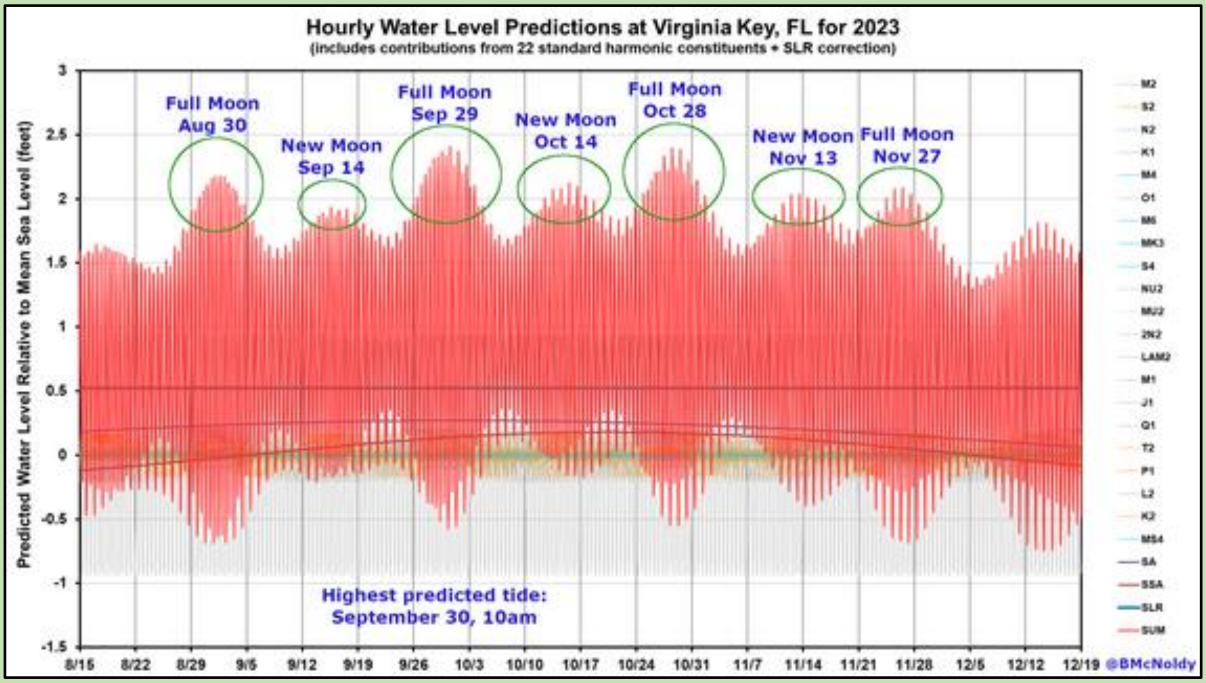


Figure 49. Water Level Predictions, Virginia Key, FL for 2023. (Image source: University of Miami; Reprinted from South Florida Water Management District (SFWMD) 2023.)

On the West Coast of Florida, Tampa Bay experiences fewer King Tide events than in the southeast. However, these events still present substantial risks for people and property in the region. At present, tidal flooding in the Tampa Bay area is expected 4-5 times per year (Mulligan 2024). St. Petersburg and Clearwater Beach are projected to experience an increase in tidal flood days over the next few years (Berardelli 2023; Sampson and Rhone 2021). On August 30, 2023, St. Petersburg experienced its highest water level of the year due to the heightened tides occurring just days after Hurricane Idalia struck the area (NOAA 2024; Figure 50). Future increases in high-tide inundation in Tampa Bay are attributed to sea-level rise and its compounding impact on shifts in weather and tidal patterns, according to a recent study by the University of Hawaii (Thompson et al. 2021). This form of nuisance flooding could become more than just an inconvenience, with local planners already worried about the implications of frequent high tides. Degradation of mechanical, electrical, and infrastructure systems is imminent due to the saltwater flooding projected to occur about 70 times per year over the upcoming decades, compared to the current average of 6 times per year (Sampson and Rhone 2021).

Figure 50. Water Pushes onto the Streets of Shore Acres, a St. Petersburg [Florida] Neighborhood in 2019. (Photo by Martin, S.; Reprinted from the Tampa Bay Times; Mulligan 2024.)

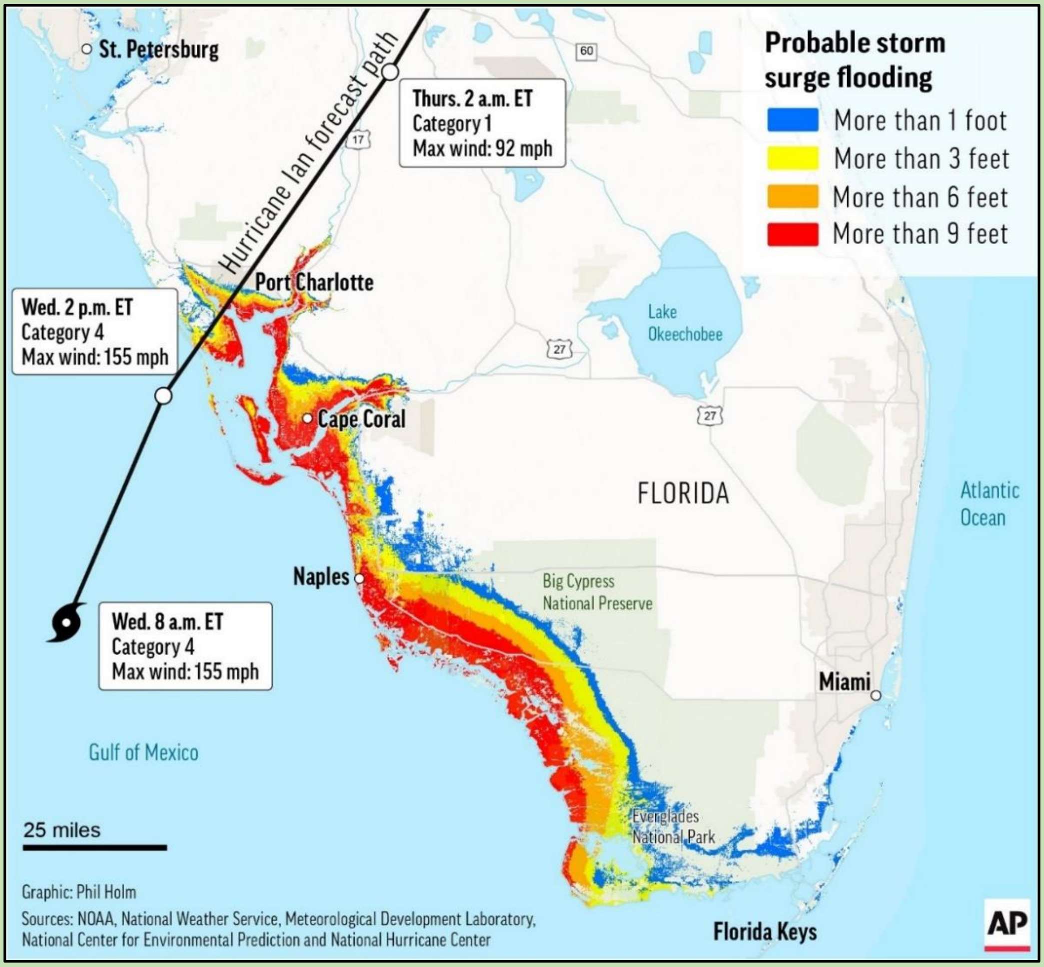
Vignette #5: Storm Surge from Hurricane Ian in Fort Myers

On September 28th, 2022, Hurricane Ian made landfall in Lee County, Florida as a Category 4 storm, slightly reduced in intensity from the preceding hours (Schwartz and Bravender 2022). Fort Myers Beach and nearby barrier islands and shorelines experienced major destruction from the storm surge that reached heights of 12-15 feet (Luciani 2022). The hurricane was recorded as the fifth-strongest tropical cyclone to make landfall in the United States and fourth-most powerful to hit Florida. The surge contributed to one of the deadliest natural disasters in decades, claiming 152 lives (Luciani 2022). Most of these deaths were attributed to drowning. The intensity and height of the surge caused debilitating damage to the region, destroying the Sanibel Causeway, cutting off multiple Leon County Islands (Figure 52).

Figure 51. Aerial View of Sanibel Causeway, Destroyed by Ian, Cutting Off Sanibel and Captiva Islands (Reprinted from Fox 13 Tampa Bay; Lee County Sheriff's Office 2022.)

Vignette #5: Storm Surge from Hurricane Ian in Fort Myers

The intensity of the surge was caused by multiple meteorological and geographic factors. According to Meteorologist and storm surge specialist Cody Fritz, Hurricane Ian had a large wind field and was slow-moving. The Florida west coast is also more vulnerable to storm surge than the east coast due to the shallower depth of the waters in the Gulf. The counterclockwise motion of Ian resulted in greater surges on the southern barrier islands such as Sanibel Island than those further north of the storm's center like Boca Grande (Devitt and Seaver 2023). The storm traveled further south as it approached land, and multiple storm surge watches were issued from Englewood to Bonita beach, which included Fort Myers. The final forecast predicted an anticipated storm surge range of 12 to 18 feet AGL (Bucci et al. 2023; Figure 53).



Graphic: Phil Holm

Sources: NOAA, National Weather Service, Meteorological Development Laboratory, National Center for Environmental Prediction and National Hurricane Center

Figure 52. Map of Probable Storm Surge Flooding in Southwest Florida Regions due to Hurricane Ian, as forecast two days in advance. (Graphic by Phil Holm/AP News; Reprinted from E&E News by Politico; Swartz & Bravender 2022.)

II.B.4. More Rain Across the FLWC's Four Land Uses

The concern about flooding for **natural lands** is often relatively low. In uninhabited areas, plants and animals should be able to cope fairly well with this kind and degree of climate change. Along Florida's coastline, and especially on its islands, species face a high risk of extinction from sea-level rise. As of 2012, 268 species of conservation concern tracked by the Florida Natural Areas Inventory were projected to have 50% or more of their local populations inundated by at least 50% under a scenario of 2 m (6.6 feet) of sea-level rise (Reece et al. 2013). Among the species highly likely to go extinct in the wild under this scenario are the Miami blue (*Cyclargus thomasi bethunebakeri*), Florida duskywing (*Ephyriades brunnea floridensis*), Gulf Coast solitary bee (*Hesperapis oraria*), Key deer (*Odocoileus virginianus clavium*), Florida Keys tree snail (*Orthalicus reses nesodryas*), Key tree cactus (*Pilosocereus robinii*) Bartram's scrub-hairstreak (*Strymon acis bartrami*), Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*), and Key ringneck snake (*Diadophis punctatus acricus*) (Reece et al. 2013). Notably, the habitats of these species are largely outside the FLWC, either because they are naturally insular or because development has fragmented their coastal distribution. This example illustrates that the FLWC will not solve all of Florida's most critical conservation challenges.

Away from the immediate coastline, significant highwater conditions in the Water Conservation Areas (Central Everglades) over the years have resulted in loss of critical habitats from drowning of tree islands and devastation of fauna including fur-bearing animal populations from predation, disease, and starvation. Flooding in South Florida in 1982 for example resulted in high water conditions in Water Conservation Area 3, consolidating deer populations along limited high ground where they could be easily predated upon. The high-water conditions also cut deer off from food sources resulting in concerns of severe losses from starvation. As part of an effort to manage conditions, over 700 deer were euthanized that year (Johnson 1982). That said, in Florida there is concern about the fate of certain species in protected ecosystems in response to more flooding. Wading birds which typically benefit from shallow flood conditions have difficulty fledging chicks if ponding depth is too high during breeding season as otherwise concentrated prey populations in shallow pools are dispersed in deeper waters. Some of the challenges are the result of operational decisions to manage flood waters, a condition that is expected to become more frequent with climate change unless mitigating actions such as Everglades restoration projects are advanced and implemented.

In addition to measurable ecosystem impacts from flooding on natural lands, the *value* people derive from some kinds of natural lands may diminish as a result of increased flooding in the FLWC. Recreational use of natural lands in the WCA for hunting, fishing, camping and hiking are affected by closures during highwater conditions. Cultural practices of the tribal nations in some of these natural lands are also adversely impacted by high water conditions which would be worse in the future because of climate change. Without additional population pressure, or a change in the extent of the FLWC, it is expected that climate change has a potential to impact recreational use of the natural lands.

Natural lands provide some indirect benefits to the residents of Florida. Mangrove communities and coastal marshes, wetlands and forests in the FLWC could mitigate the impact of storm surge along the coastline, reduce erosion from waves, serve as windbreaks, and provide water quality benefits in addition to their function as habitat for fauna.

Mangroves and marshes are well adapted to absorb storm impacts, most notably storm surge, in coastal areas. Protecting existing mangroves and marshes as well as their restoration and/or propagation are a cost-effective nature-based solution for coastal communities looking to reduce their vulnerability to storm surge. In a recent study using an insurance industry catastrophe model, researchers assessed the flood reduction benefits of mangroves throughout Florida (Narayan et al. 2019). The findings showed that mangroves played a crucial role in mitigating storm surge damage during Hurricane Irma in 2017, reducing flood damages by 25.5% annually for property owners behind these ecosystems. The study emphasized the vital protective role of mangroves, revealing their significant economic value by averting $1.5 billion in surge-related flood damages to properties during Hurricane Irma, with every hectare providing an average of $7,500 in risk reduction benefits for coastal communities (Narayan et al. 2019).

Mangroves act as a barrier to flooding from storm surge for properties behind a mangrove forest. However, they can also be expected to increase storm surge seaward of the mangrove forest (Figure 53). For some coastal communities such as Marco Island and Chokoloskee that were developed outside of the natural mangrove barrier, flood levels can be higher than they would be if they were developed behind the mangrove forest (Narayan et al. 2019).

Wetlands International and the Nature Conservancy in their 2014 report, Mangroves for Coastal defense, concluded that mangroves provide flood risk benefits. Other studies have confirmed and quantified the benefits, the Adaptation of Coastal Urban and Natural Ecosystem (ACUNE) study by the University of Florida and Florida Gulf Coast University, for example, estimated damage avoidance to critical assets in Collier County at $13 million and $200 million respectively from Hurricanes Irma and Ian (Sheng In review). Their analyses completed using a cutting-edge model that resolves mangrove inland migration with rising sea level is one of several ongoing efforts to quantify the benefits to life and property of natural and nature-based solutions such as land conservation.

Additionally, approximately two-thirds of Florida’s floodplains, totaling about 10 million acres, lie within the Florida Wildlife Corridor (FLWC) (Archbold 2023). These floodplains serve as a buffer between our cities and the damaging effects of floods, reducing flooding downstream by storing and gradually releasing water over time. Wetlands and floodplains play a crucial role in mitigating the risk of flooding in developed areas, and the FLWC's conservation efforts contribute to maintaining these natural water management systems. This proactive approach helps minimize the impact of extreme rainfall events on adjacent developed lands, reducing the likelihood of flooding and minimizing damage to private property in nearby communities. Mapping areas flooded during Hurricane Ian reveals a significant overlap with the FLWC, emphasizing the need for effective conservation tools and the protection of low-lying areas to discourage future development in flood-prone zones (Galantowicz 2022).

Unfortunately, these natural communities may be lost or lose their ability to protect inland communities due to the effect of rising sea levels. Scientists are working to understand the mechanisms responsible for observed peat collapse in sawgrass marshes in the Everglades. These freshwater marsh communities with exposure to saltwater due to sea-level rise experience dieback and peat collapses (Figure 54). The collapsed portions of the marshes become open water ponds which could limit inland migration of mangroves as sea levels rise. For example, wetlands serve as important locations for diminishing storm winds, cleaning pollutants, and nursing fish populations by providing protective habitat. With sufficient flooding, including (but not limited to) eventual permanent inundation from sea-level rise, Florida’s coastal wetlands may cease to be wetlands. The result would be a degraded natural coastal defense system that once benefitted coastal and near-coastal human populations.

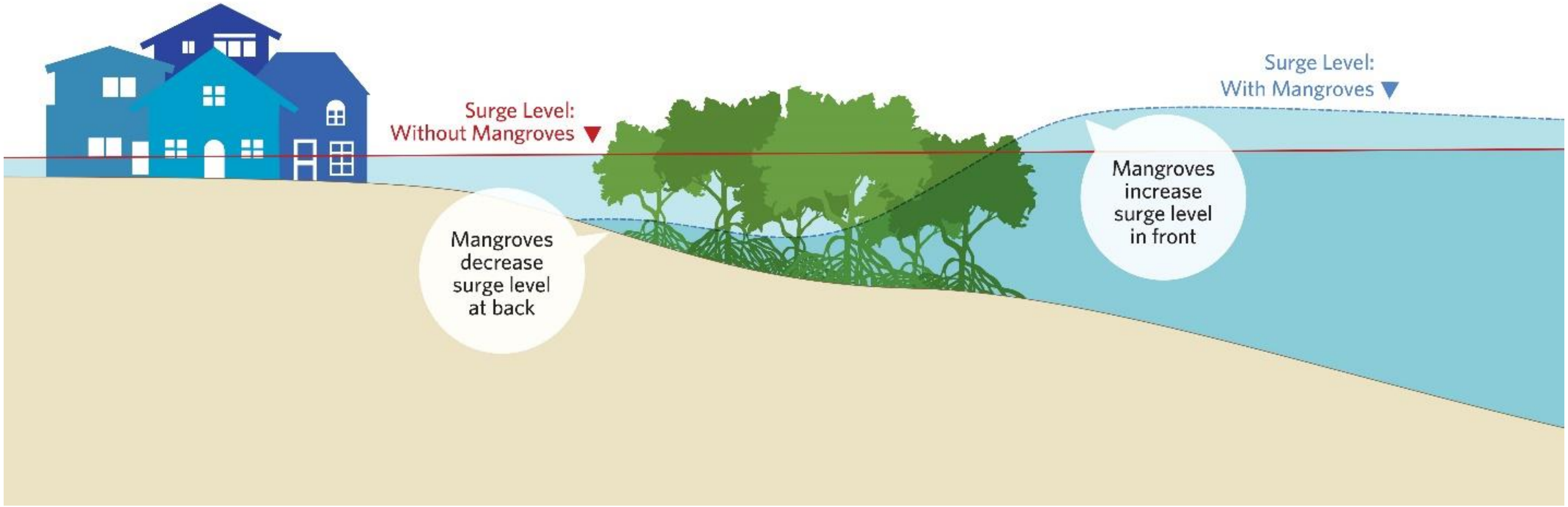
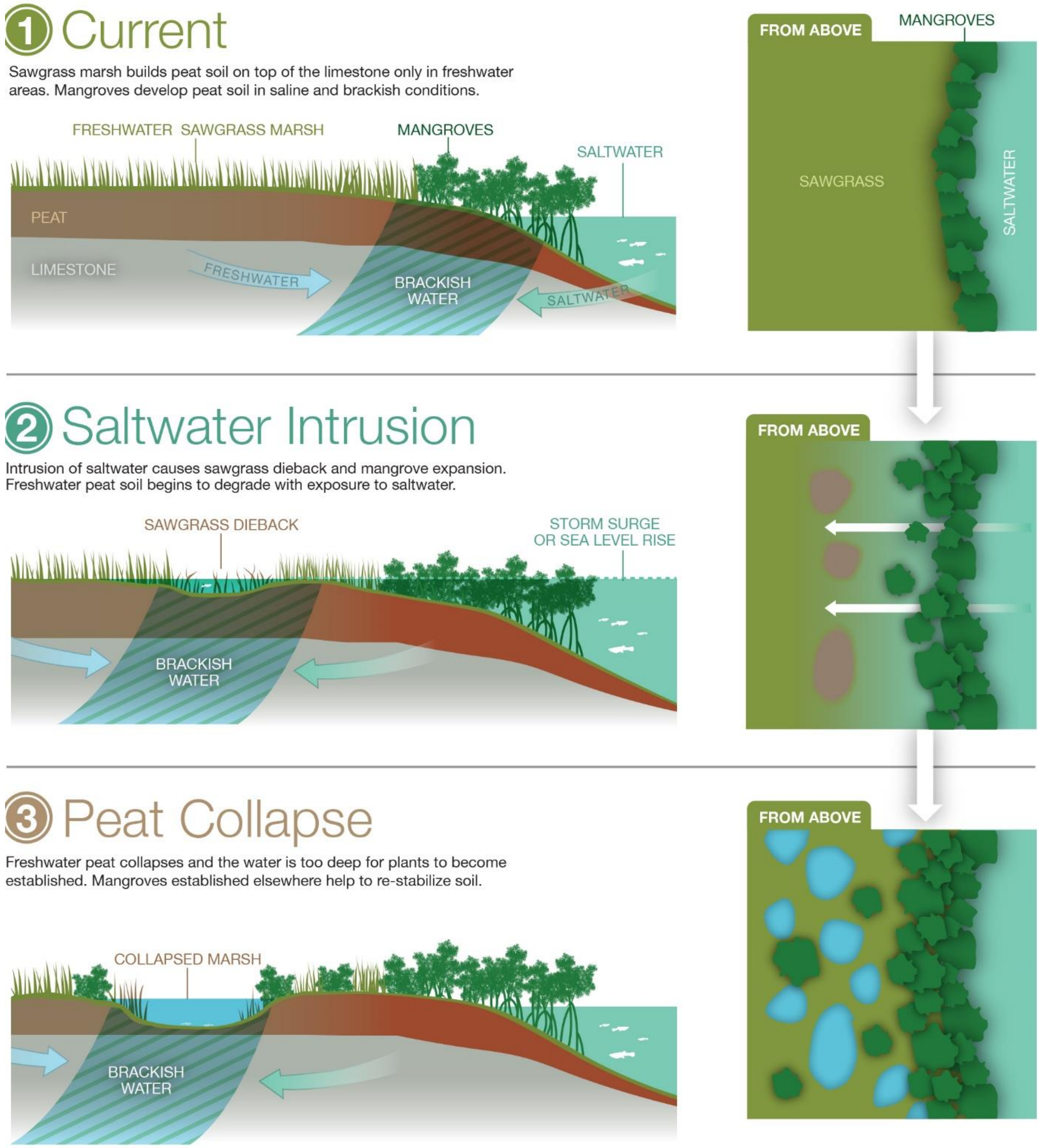


Figure 53. Mangroves and Surge. Mangrove forests protect coastal communities from storm surge and erosion from high-energy marine conditions; however, when development is permitted seaward of a mangrove forest, storm surge levels may become more elevated and lead to increased property damages. (Reprinted from The Nature Conservancy 2020.)



① Current

Sawgrass marsh builds peat soil on top of the limestone only in freshwater areas. Mangroves develop peat soil in saline and brackish conditions.

② Saltwater Intrusion

Intrusion of saltwater causes sawgrass dieback and mangrove expansion. Freshwater peat soil begins to degrade with exposure to saltwater.

③ Peat Collapse

Freshwater peat collapses and the water is too deep for plants to become established. Mangroves established elsewhere help to re-stabilize soil.

Figure 54. Understanding Saltwater Intrusion and Peat Collapse. (Davis and The Everglades Foundation 2018.)

If precipitation changes as described, it is critical to conserve as many acres of natural and working lands as possible, as they provide many of the regulating services that mitigate the effects of flooding. These services include absorbing and storing water, including providing clean water (water quality) to recharge (water supply) the Floridan Aquifer, sediment retention, and natural buffer systems that reduce storm impacts and redirect rain as runoff. Natural ecosystems are widely recognized for their ability to mitigate flooding impacts- an economic valuation study of Tampa Bay found that mangrove and inland ecosystems within 5 miles of the coast contributed more than $924 million in flood protection services (Todd et al. 2023). This value was obtained by calculating how much it would cost to build equivalent infrastructure to mitigate flood impacts. Based on this rationale, the value of FLWC in terms of flood control would be an astronomical economic value given its size and scope.

In **working lands and agricultural** settings, more flooding is detrimental because of the associated damages to crops and livestock which are particularly sensitive to the timing and depth of flooding. Agricultural lands, especially in South Florida or at low elevations are vulnerable to impacts of flooding and sea-level rise. In many cases, even where water fields are not inundated, high water table invading the root zone may be sufficient to impact production. Bayabil et al. (2022) find that the impact on soil storage of elevated groundwater levels due to sea-level rise and salinity risk from saltwater intrusion were potential risk factors for agriculture in South Florida. At higher elevations, impact of climate change due to drought and the associated fire risk previously described is more likely the main concern.

Flood risk in **urban settings** is well studied. Inundation or flood depth from the different flood drivers are determined using tools such as numerical models. Using information from structures and other assets exposed to the flooding, and relationships established between flood depth and damage for each type of structure, estimates of damage from floods of different severity can be established. Using these methods and considering future increases in rainfall intensity using change factors as well as different sea-level rise, it has been established that damage from flooding will increase over much of Florida.

Adding population growth to the picture means Florida’s flood risk will likely increase substantially. As such, to the extent that Florida’s booming population results in a geographically extensive set of new urban lands, Florida’s flood risk should grow proportionally. The effect of population is twofold. First, assuming an unchanged flood risk, the damage, a function of the exposure would increase because of the higher population. Second and more important though is that with population increase usually comes development. Despite regulatory requirements to limit the impacts of new development on the environment, replacement of natural lands with ability to store or recharge the aquifers with paved surfaces changes the runoff characteristics and increases flood risk. It is possible, with a well-designed stormwater system and elevated construction, to minimize the damage from flooding by limiting the exposure. There are concerns that improperly implemented some of these adaptations may increase flood risk for neighboring communities.

Increasing the area of land in conservation would have a generally beneficial effect on flood risk though there are specific conditions where the impact would be negative. When lands previously used for agriculture are taken out of production, agricultural practices that pump to depress the water table during wet periods are terminated. Recognizing these benefits, the state of Florida has funded programs to encourage use of non-active agricultural lands for storage and quality improvement purposes. Programs like SFWMD Dispersed Water Program (DWP) pay private landowners to store and manage water on their lands in a way that provides flood reduction, increased recharge and enhanced water quality benefits. Lomeu et al. (2022) and Bohlen et al. (2009) highlight the advantages and challenges of the Florida Ranchland Environmental Services Program (FRESP) in the Northern Everglades basin.

II.C. Adaptive Capacities: How the FLWC May Affect Florida’s Climate Resilience

As presented in Section I.C., Conceptual Framework, an important piece of the climate resilience equation is *adaptive capacity*. This concept describes potential and observed responses to the effects of exposures to the stresses. To repeat the example from that section, consider a sweet corn farmer exposed to hotter and drier growing conditions. How the farmer responds to the predictably lower corn yields if no response is enacted reflects his or her adaptive capacity. Adaptive options for the farmer include, among others, shifting planting dates next season to avoid exposing the crop to the stress, thereby reducing the diminished yield, or switching from one sweet corn varietal to another, selecting for seeds to plant with a lower sensitivity to increasing heat and dryness.

Interestingly, for a report on how the FLWC may affect climate resilience, the FLWC is itself a reflection of the state’s adaptive capacity. This law represents perhaps the world’s most ambitious land conservation program in terms of acreage and expense. The effort is all the more remarkable in that it applies to a place that is simultaneously experiencing exceptionally high demand for land for urban and suburban uses. (By contrast, attempting to conserve even large swaths of land that have little alternative commercial present value is less challenging in political and financial terms.) The FLWC is a powerful testament to the state’s adaptive capacity as applied to managing the biodiversity-population growth dynamic.

Since the law was not intended to enhance climate resilience, any climate benefits from the FLWC will be incidental. That said, those climate benefits will likely not be trivial. Having a successful FLWC means achieving climate resilience should be significantly easier and quicker for Florida than if the FLWC fails to conserve more land. More specifically, as outlined in this section, there are three domains where climate resilience efforts appear to be gaining momentum in Florida as elsewhere in the U.S.: urban planning, private climate finance, and climate smart agriculture programs. Just as the FLWC is not conceived as a tool to improve climate resilience, so too are these three domains conceived of independent from the FLWC. Yet in both cases, there is potential benefit from one to the other.

First, however, a brief word about *constraints* on adaptive capacity is in order. If the ideas laid out in this report were easy to implement, they likely would have already been implemented. These actions require motivation, knowledge, money, and as is often the case with any ambitious effort, trade-offs with other desirable activities. The array of FLWC stakeholders being so vast and varied means that finding these qualities present in large degrees is a challenge to say the least. Moreover, initiatives such as the FLWC need to engage with individual parcel owners at the same time as they need to prioritize conservation locations and approaches from a broader perspective. The interests of individual landowners may not align with the interests of the region. Balancing these often-differing sets of interests is an abiding challenge. This hurdle is amplified by the fact that the state has since 2011 weakened local land-use planning by lowering standards for comprehensive plan amendments and by imposing local land use pre-emptive policies.

II.C.1. Urban Planning

Florida is experiencing unprecedented population growth, predicting an annual influx of almost 310,000 people from 2021 to 2026, equivalent to adding a city the size of Orlando each year (Perry, Rogers and Wilder 2022). This surge is accompanied by challenges like skyrocketing housing costs, a collapsing insurance market, and demographic shifts away from coastal areas (First Street Foundation 2023). The state grapples with accommodating this rapid growth in a resilient manner and defining the relationship between resilient cities and the environment.

In 2021 alone, 674,740 people moved to Florida (U.S. Census Bureau 2021b), and the trend continues, with Polk, Lee, and Hillsborough counties seeing a combined population growth of about 90,000 residents (Tampa Bay Development Council 2023). Intrastate shifts include Miami-Dade County experiencing significant population loss, primarily to Broward and Palm Beach counties (Fitzpatrick, Beheraj and Funcheon 2023). The cost of living, impacted by rising home prices and rent, contributes to relocation decisions (Simonton 2023). Florida's complex demographic and cost of living trends fuel expansive development, particularly in the central part of the state (Singerman 2023), posing a threat to critical linkages within the Florida Wildlife Corridor (FLWC). The state's future growth scenarios, as explored in the Florida 2070 project, emphasize the need for balancing conservation and development across the state through the protection of agricultural and natural lands within the FLWC and the discouragement of sprawling low-density development by incentivizing the creation of new walkable neighborhoods and communities (1000 Friends of Florida 2016).

Responsible urban planning and design is crucial for the long-term resilience of the FLWC. Smart growth strategies like promoting walkable, mixed-use development and discouraging sprawling single-use development, help slow the geographic expansion of our cities without restricting the number of new residents. This approach reduces demand for sprawling development, encourages reinvestment in urban areas, minimizes habitat fragmentation, and ensures the FLWC's ecological integrity. The following planning strategies are utilized to increase land use efficiency while protecting the FLWC simultaneously.

Smart Growth is a policy framework that enhances the efficiency of city services, infrastructure delivery, and community livability. It promotes walkable, mixed-use development, quality parks, greenspace, and investments in public transportation. Prioritizing infill development, supporting diverse housing types, and investing in public transit contribute to efficient land use, reduced infrastructure costs, and improved quality of life (Emerine et al. 2014).

Sprawl Repair transforms underperforming single-use developments into complete communities, fostering economic, social, and environmental benefits (Tachieva 2010). Retrofitting underutilized areas minimizes the need for new land, attracts investment, creates jobs, and boosts economic activity. Sprawl repair is a catalyst for economic development, transforming outdated areas into thriving hubs and reducing demand for greenfield development.

The FLWC serves as a model for **park and green space planning** across the state. Prioritizing local conservation, restoration, and recreational goals, while connecting state conservation networks, is considered best practice. Landscape-scale analysis can inform the creation of local wildlife corridors based on FLWC methodology, allowing communities that may not be adjacent to the FLWC to participate in local conservation efforts (Daskin 2023).

Clustered development is a regulatory tool that encourages concentrated building and infrastructure, leaving portions of a property or municipality that may support sensitive habitats protected from development. This approach supports conservation while providing incentives for developers. Best practices, like Traditional Neighborhood Development (TND) principles, promote well-designed communities, adding value and demand for access to conserved lands.

Critical Linkages represent the best remaining opportunities to functionally connect major existing public and private conservation lands within the FLWC (Figure 5). They are vital for wildlife movements and are threatened by development pressure. The Florida Ecological Greenways Network and the FLWC aim to conserve these connections (Center for Landscape Conservation Planning Staff 2021). The loss of critical linkages jeopardizes wildlife movement and other core goals of the FLWC and highlights the race against sprawl playing out across the state to complete the FLWC.

Land use policies are also implemented to respond to ongoing changes in development:

- **Zoning Reform** - Land use zoning in the United States emerged in the early 1900's as a response to rapid urbanization, industrialization, and shifting demographics. Zoning reform is crucial for creating walkable neighborhoods, reducing dependency on cars, and preserving sensitive landscapes. Reforms involve removing barriers to new housing in urban areas such as exclusionary land use regulations that enforce exorbitant minimum parking requirements and suburban lot standards in urban areas
- **Transfer of Development Rights** - Transfer of Development Rights (TDR) programs are market-based tools where development rights are voluntarily transferred from "sending" areas to "receiving" areas. TDRs support conservation by allowing property owners of environmentally sensitive lands the ability to sell or transfer development rights to areas more suited to development. These programs can be effective at a variety of scales from individual neighborhoods to entire regions. A statewide TDR program could be one tool to help address the complex challenges posed by shifting populations and rising seas. Effective TDR programs require transparent and reliable markets to host the exchange of development rights, adaptability, and carefully determined sending and receiving areas.
- **Traditional Neighborhood Development** - Traditional Neighborhood Development (TND) ordinances are used to encourage the development of new walkable neighborhoods instead of auto-oriented tract housing. TNDs create human habitats optimized for health, happiness, and economic prosperity. TND principles include providing a mix of housing types, connected streets, trails, and green spaces. Well-designed neighborhoods increase property values for the communities they are in, improving access to a variety of amenities and improving quality of life for all residents.

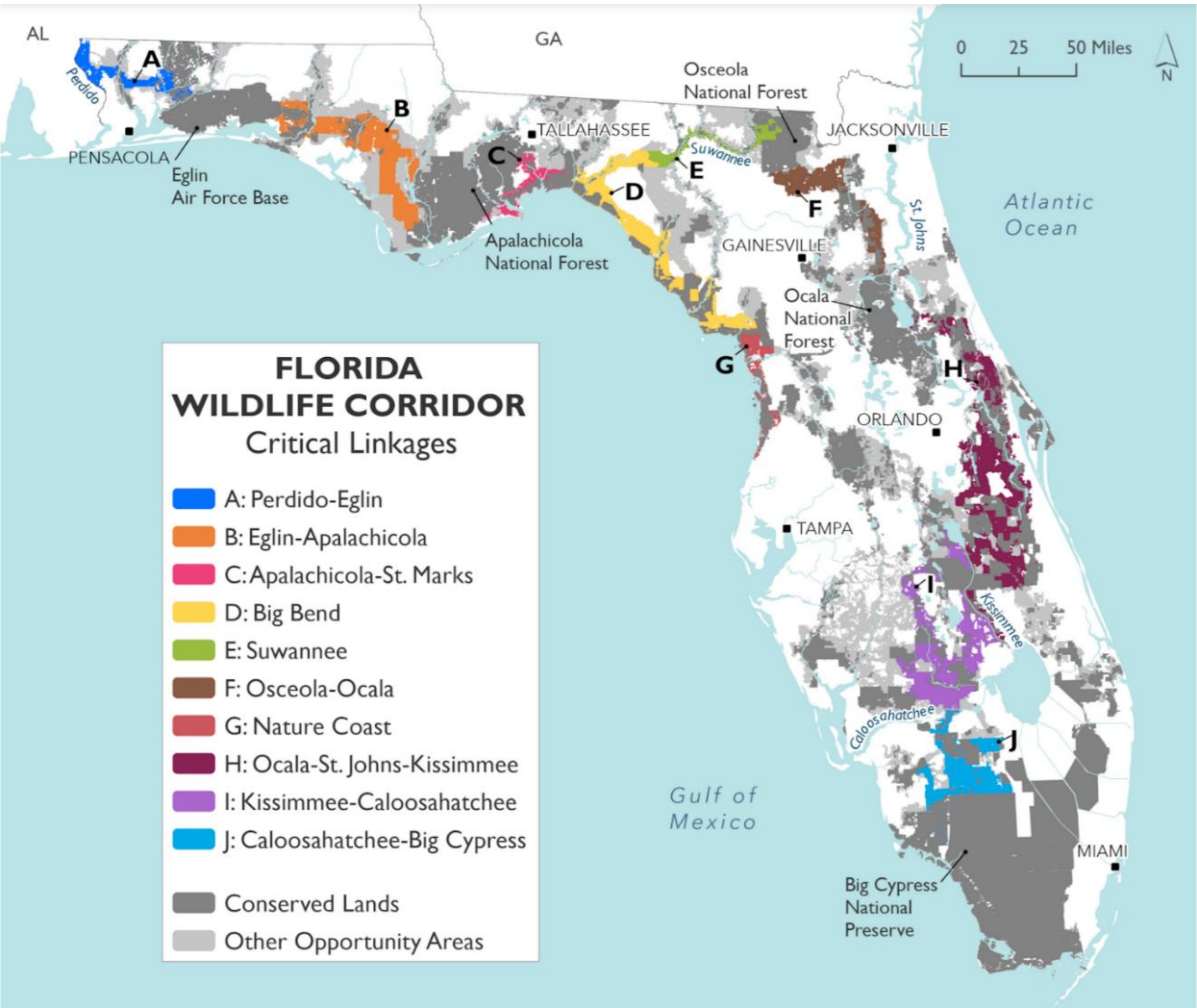


Figure 55. Identified Critical Linkages of the Florida Ecological Greenway Network. (Map by: Meeks, A., Archbold Biological Station; Reprinted from WUSF NPR; Spear 2021.)

II.C.2. Private Climate Finance

The field of climate resilience has evolved over time from identifying problems to envisioning policy responses to developing engineering solutions. The question of financing the solutions has generally been implicitly taken as the domain of Federal and state governments through new taxes, tax incentives, or subsidies. For example, the FLWC is articulated as a state law to be funded by state programs, including but not necessarily limited to the Florida Forever Program in the Department of Environmental Protection, and the Rural and Family Lands Protection Program in the Department of Agriculture and Consumer Services only recently has the domain of private finance and private market solutions emerged as an additional mechanism for advancing climate resilience. As such, there is not much detail to offer here on private means for advancing the sensitivity-reducing and adaptive capacity-enhancing goals discussed in the preceding sections, though there is great potential for public-private partnerships.

Two such avenues deserve mention here. One is a nascent industry; the other is more theoretical. First, several self-styled “climate banks” or “green banks” have been launched in Florida in recent years. As the names suggest, these institutions specialize in helping families and businesses secure the necessary capital for reducing their environmental impacts. Of note is the apparent emphasis on serving low- to moderate-income households by creating products tailored for, for example, renters or landlords.

Second, and more theoretical than with the case of climate banking, carbon markets continue to be discussed worldwide as a means for internalizing the costs of climate change linked with fossil fuel combustion. Similar markets have been created with great success for other pollutants, such as the precursors of acid rain, nitrogen oxides (NO_x) and sulfur dioxide (SO_2). The general idea is the government sets a cap and/or a price on pollution, and companies are endowed with a certain allotment of pollution rights and the right to buy and sell those rights. Slowly over time the government lowers the allowable aggregate emissions levels. Companies that know how to reduce their emissions inexpensively below their allotments find themselves with a surplus, which can be sold for profit. Companies that cannot or choose not to reduce emissions can purchase the rights to emit needed. The environment benefits and so too do the companies. This model of regulatory carbon markets has spawned a few voluntary such efforts that have not been studied in detail.

The newer idea of carbon markets has not enjoyed the success of the older pollution markets. One reason is the Federal government has not mandated or incentivized the carbon markets to be launched and cultivated. Another reason is the pervasiveness of carbon in the economy. Unlike acid rain, carbon emissions are embodied in virtually every transaction and activity engaged in by households and businesses every day. Accounting standards are only now emerging to support this industry.

A carbon credit represents a quantity of carbon dioxide or equivalent greenhouse gases that has been reduced, avoided, or removed by a mitigation activity. Carbon credits are issued to project developers after they have met stringent rules set out by governments or an independent certification body and after being verified by a third-party auditor. Carbon market standards are developed through an open process of public consultation, transparency, and independent third-party assessment. To launch, credible carbon markets are increasingly accepted as needing to satisfy a few criteria that to date have proven elusive (Canham 2021):

1. Additionality: A carbon credit is “additional” if it represents emission reductions that are above and beyond what would have been achieved under a “business as usual” scenario; i.e., it would not have occurred in the absence of the carbon market project.
2. Permanence: Emissions that are removed or reduced need to be ‘permanently’ removed or reduced in order to have an impact for the climate. Permanence could mean in perpetuity, or for a finite, specified period of time such as minimally 100 years.

3. Avoiding ‘leakage’: When a project stops carbon-emitting activities—such as deforestation—in one area, but the carbon-emitting activities may shift to another area. This ‘leakage’ of carbon emissions means there is no net carbon benefit to the atmosphere of the costs incurred.
4. Safeguards: to protect biodiversity and ensure that communities and Indigenous peoples are able to fully and freely participate in and benefit from the project.

Carbon markets have been operating for a few years with varying degrees of success in Europe and in a couple of regions in the U.S. and Canada. The concept has been promoted in the U.S. Congress for at least a decade. It does not appear to have nearly the popular support required to become law anytime soon. In theory, voluntary carbon markets represent a viable if largely untested and un-scaled alternative or supplement to state-run versions.

If carbon markets were to be implemented in Florida or the US, landowners in the FLWC would be in a strong position to capitalize on some new benefits. Specifically, landowners would have an incentive to participate in FLWC conservation in the form of direct payments received in proportion to the amount of carbon their lands sequester or store. As for easement payments, this would help keep natural or working lands from being developed. Both natural and agricultural lands can store and sequester carbon sufficient for a viable carbon market. However, careful accounting for stocks and sequestration rates is required to ensure payments are credible and the above additionality requirement is met. In sum, carbon markets can in theory serve as an added incentive for landowners to conserve their land over and above what benefits are offered by the state.

II.C.3. Climate Smart Agriculture Programs

Florida has been a global agricultural powerhouse for decades. The industry currently uses nearly two-thirds of the state’s land area as agricultural land, which includes crop and ranchland. This counts for 44,703 farms divided over 9.7 million acres (FDACS 2024). In 2018, the total sales revenue over all the sectors, crop, livestock, forestry, and fishery products, was $10.2 billion (UF IFAS 2020). The state is the leading producer in value of production of several different crops like cucumbers, grapefruit, squash, mangoes, passion fruits, sugarcane, squash, radishes, tomatoes, guavas, watermelon, and kumquats. Tomatoes, melons, and sweet corn have a combined annual production value of over $1 billion (USDA 2024). Approximately 400,000 acres of farmland are designated for commercial citrus groves, producing close to 77 million boxes of citrus fruit in 2019 (UF IFAS 2020). Florida also ranks as number 13 nationwide in terms of number of cattle brought to market each year (Florida Beef Council 2024). More than 5 million acres of land was used for beef and dairy cattle production in 2018 (UF IFAS 2020). Besides crops and animals, Florida is the second-largest horticultural crop producer in the U.S. (UF IFAS 2020).

Given the size and success of Florida agriculture, it makes sense that the state’s public and private agricultural interests would already been engaged in producing response options for farmers to the challenge (or opportunity) that climate change presents their operations. For example, the USDA offers financial and technical assistance in implementing climate-smart management solutions for people in the agricultural sector (USDA 2022). USDA's conservation programs were provided with an additional $19.5 billion from 2023 to 2027 by the Inflation Reduction Act to strengthen efforts to mitigate climate change (USDA 2022). The main goal is to support farmers and ranchers who implement conservation practices that reduce greenhouse gas emissions and increase carbon sequestration in soils and trees. At the University of Florida’s Institute of Food and Agricultural Systems, innovations in carbon sequestration techniques include programs such as the AgroClimate Crop Season Planning Tool (Staub et al. 2022).

These efforts include a variety of formal and informal “ag extension” (or similar) education and training programs. Such efforts instruct professionals how cover crops, low-till or no till nutrient management, wetland restoration and reforestation, and even Artificial Intelligence (AI; e.g., Eli-Chukwu 2019), which could not only enhance agricultural profitability but also aid carbon sequestration.

III. Conclusions and Future Directions

For Florida to continue to thrive economically and advance towards a more sustainable future, protecting biodiversity, maintaining ecological connectivity, and mitigating and adapting to climate change are all necessary. Moreover, all of these measures are interrelated. Our study has shown that parts of the Florida Wildlife Corridor (FLWC) are vulnerable to the impacts of climate change, especially in coastal and other low-lying areas (including some far from the coast) subject to inundation from sea-level rise, storm surge, and extreme rainfall events during hurricanes and other storms. Increasing temperatures, wind speeds during storms, and fire risks also threaten to change the composition and structure of natural communities both inside and outside the FLWC. Extreme temperatures, in particular, pose an immediate health risk to people and will likely threaten some nonhuman species.

Completion of the FLWC by protecting its opportunity areas has the potential to substantially reduce the impacts of climate change on humans and on nature by mitigating the effects of climate stressors on natural systems and by maximizing the ability for natural and semi-natural landscapes to provide climate-related benefits, such as storm protection and flood storage. Efforts to mitigate climate change by drastically reducing greenhouse gas emissions will make climate adaptation easier to achieve.

III.A. Productive Areas for Additional Exploration

Considerable uncertainty remains about how to implement and manage the FLWC going into the future. These are largely questions that must be addressed by new policy experimentation grounded in new research and community engagement efforts. Many of these recommendations derive from prior work by the University of Florida Center for Landscape Conservation Planning, and the Florida Conservation Group. Critical themes for new research include:

- Priority areas for facilitating functional shifts of coastal ecosystems in response to sea level rise as well as opportunities to resist sea level rise through coastal wetland restoration and management.
- Focal species habitat changes and connectivity needs in relation to climate change and potential habitat loss from development.
- Predictive mapping of potential climate refugia locations – for people as well as animals – to ensure any such areas are functionally included and strategically prioritized within the FLWC. For example, what are people likely to do as sea-level rise, intense rainfall events, and other changes in hydrological regimes continue to increase flooding in Florida. Will they move from low-lying coastal areas towards the ridges? Will they leave Florida entirely? Or will they elect to stay and endure the slow rollout of negative impacts to their homes, businesses, and communities? These questions constitute an increasingly active and pressing area of research, business, and policy interests (Harris 2023; Keates 2023; Bittle 2024).
- Identification of regional strategies for land-use planning that break down county and other local government barriers, such as implementing regional Transfer of Development Rights (TDRs).
- Determining best methods/practice/program options for addressing related underserved landowner/community needs.
- Exploration of how best to leverage existing three sets of professional networks that provide a natural foundation for amplifying the climate resilience benefits of the FLWC: urban planning; private climate finance; and climate smart agriculture programs. Interestingly, all three of these domains are increasingly active in not only the public sector but also the private sector.

- Valuation of ecosystem services like water storage and storm protection, and strategies to promote payment for ecosystem services.

This last point deserves particular mention. Education and outreach about the value of natural and rural lands for sustaining vital economies and healthy communities and regarding the need for sound science and ecological design in large scale planning can help advance public support for the FLWC and compatible land use decisions. Ecosystem services, also called nature's contributions to people (Diaz et al. 2018), are almost certainly enhanced by the FLWC, yet at this time these contributions have not been comprehensively quantified. An ecosystem services valuation study focused on the FLWC would correct this deficiency. At the least, a benefit-transfer study should be conducted, which would summarize ecosystem services values from prior studies derived in other contexts and aggregate previous valuation studies into a single value range for the FLWC. A more comprehensive and accurate approach would be to commission a thorough study of the FLWC's ecosystem services values. Ecosystem services valuations of the FLWC should be repeated on a regular basis because of the rapidly changing population, land cover, and climate of Florida. These changes can be expected to affect the magnitude and even the rank-ordering of the various services over time.

Thus increasing the technical effectiveness and public salience of any new specific FLWC policies and programs would benefit from an ecosystem services valuation study specifically focused on only the FLWC. Two approaches are available for such an advance. The most comprehensive and accurate approach is to commission a thorough study of the region's ecosystem services values. A less time- and resource-intensive approach (but also of necessity less complete and precise) is to conduct a benefit-transfer study, which averages ecosystem services values from prior studies derived in other contexts (e.g., elsewhere in the state -- for example North Florida conservation forestry [Kreye et al. 2014]). It aggregates previous ecosystem service valuation studies into a single value range that (with some precautions and careful interpretation) can be applied, as a placeholder, to the same ecosystem services in our study location.

Finally, these studies should be commissioned on a regular basis. By definition, ecosystem services valuations are a function of the biophysical and socio-economic conditions of the moment. For a coupled human-environment system such as the FLWC that is evolving so rapidly in climate and population terms, the magnitude of services should be expected to vary significantly over time, with potentially important implications for policy and private landowner decisions. This hypothesis can be tested by regularly conducting ecosystem services valuations.

III.B. Actions We Can Take Now

The most important action that can be taken within the immediate future is to bring the opportunity areas within the FLWC into conservation ownership or perpetual conservation easements. Funding to date is approaching $1 billion since the law was signed in 2021. These funds support land acquisition efforts to expand the current 10 million acres of protected land. To conserve the remaining approximately 8 million acres will require vastly increased funding. Some means to accomplish this conservation include:

- **Conservation Funding -** Fully Fund Florida Forever and Rural and Family Lands Protection Program (at least $250 million/year for each).
- **Florida Land Protection** - Maximize Federal NRCS, U.S. Department of Defense Readiness and Environmental Protection and Integration Program (REPI), and USFWS land protection spending in Florida.
- **Ecosystem Payments** - Make increased use of payments for ecosystem services: water storage, storm protection, focal species habitat, etc.

- **Flexible Conservation Incentives** - Implement limited conservation programs such as term easements or habitat management plans that provide landowners incentives short of in perpetuity options, permitting the landowners to advance towards full conservation partially or incrementally.
- **Natural Capital Focus** - Emphasize the value of natural capital and the “green infrastructure” approach to land-use planning.
- **Density Alignment** - Assure that any new developments have minimum densities that align with FLWC goals.
- **Smart Redevelopment** - Consider incentivizing well-located and well-designed redevelopment that accommodates as many new residents as possible in existing developed areas to avoid new conversion of habitats to development, which would have direct and indirect impacts on the FLWC.
- **Interface Management Incentives** - Consider land use planning options including incentives that better plan and manage urban-wildland interface to address safe continued use of prescribed fire, reduce wildfire probabilities and impacts, and reduce other impacts associated with intense development adjacent to rural lands.
- **Floodplain Development Control** - Limit additional development in floodplains. This goal is challenged by the fact that the extent and locations of the state’s floodplains are changing, due to climate change. But at a minimum, new developments in floodplains should be discouraged because they raise our exposures to potential flood damages and loss of life. Insurance premia should reflect this risk better than is the case at present. As insurance rates rise to better reflect actuarial conditions, homeowners currently living in the floodplain, especially low- to moderate-income households, will need assistance with the higher expenses or else they will be forced to move to a lower-risk zone.
- **Agricultural Conservation Options** - Agriculture has an important role to play in climate adaptation and completion of the FLWC. Conservation easements, because they are voluntary and incentives-based, have great appeal across the political spectrum. For example, some of our most critical opportunity areas within the FLWC are ranches that are under intense pressure by developers interested in building new developments in rural areas. Besides funding from Florida Forever and the Rural and Family Lands Protection Program, multiple options exist for ranchers and farmers to take advantage of state and federal programs for conservation of agricultural lands. The ecological benefits of such conservation include protection of coastal wetlands and waterbodies, enhancement of dispersal opportunities for species escaping inundated habitats, water storage and filtration, food/fiber security, and improved management of nutrients and greenhouse gases.
- **Staffing Support** - Expanded and sustained staffing support for the FLWC to maintain awareness by elected officials and the general public.

In summary, Florida's future ecological and economic prosperity depends in no small part on the success of our parallel efforts to conserve land, protect against climate change, while also promoting economic development. The Florida Wildlife Corridor is perhaps the leading example of an initiative that can advance towards all of these goals. But success is not guaranteed, as something of this scale has not been attempted before. Therefore, we need to continue to monitor and examine our progress and be prepared to shift course if needed to capitalize on emerging opportunities and to avoid unexpected pitfalls. By embracing the recommended actions in this report —ranging from securing critical conservation lands to engaging in innovative policy reforms and community collaborations — we can forge a path toward a more sustainable and resilient Florida.

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