Final Project Memorandum
SECSC Project 006:
Assessing climate-sensitive ecosystems in the southeastern U.S.

1. ADMINISTRATIVE

Recipient: Jaime Collazo, US Geological Survey, North Carolina Fish and Wildlife Cooperative Research Unit, Department of Applied Ecology, North Carolina State University, Raleigh, North Carolina 27695.
Project title: Assessing climate-sensitive ecosystems in the southeastern U.S.
Agreement number: Research Work Order 200
Date of report: July 24, 2014
Period of time covered by report: September 1, 2012 – June 30, 2014
Actual total cost: $49,879.77

2. PUBLIC SUMMARY:

The southeastern U.S. contains a unique diversity of ecosystems that provide important benefits, including habitat for wildlife and plants, water quality and recreation opportunities. As climate changes, a better understanding of how our ecosystems will be affected is vital for identifying strategies to protect these ecosystems. We assessed climate change vulnerability for twelve ecosystems in the southeastern U.S. and Caribbean. We synthesized data and literature related to three components of vulnerability: climate sensitivity, climate change exposure, and adaptive capacity. We also summarized all information into a qualitative vulnerability rating for each ecosystem. Based on the available information, we identified critical management actions for reducing the vulnerability of each ecosystem. Next, for two of the twelve ecosystems, we used NatureServe's Habitat Climate Change Vulnerability Index (HCCVI) framework as an alternative approach for assessing vulnerability. Using the HCCVI, we developed a numeric vulnerability rating for the two ecosystems. Of the twelve ecosystems we assessed in the first approach, five were rated as having high vulnerability, six had moderate vulnerability, and one had low vulnerability. For the two ecosystems we assessed with both approaches, vulnerability ratings generally agreed. Important conservation strategies we identified to reduce vulnerability and improve adaptive capacity for the ecosystems included maintaining connectivity, restoring or maintaining disturbance processes, and minimizing the effects of urbanization. This synthesis of this information for key ecosystems across the entire Southeast and Caribbean will enable regional decision-makers to prioritize current efforts and plan future research and monitoring for conservation of these important ecosystems.

3. TECHNICAL SUMMARY:

The objective of this project was to identify strategies that will improve adaptive capacity for several important ecosystems in the southeastern US by assessing the current state of knowledge in climate change vulnerability. We selected a set of twelve important ecosystems for assessment after creating a list of candidate ecosystems and soliciting input from experts. For these ecosystems, we compiled data and literature related to three components of vulnerability: sensitivity, exposure, and adaptive capacity. We then summarized all information into a qualitative vulnerability rating for each ecosystem and identified critical management actions for reducing vulnerability by improving adaptive capacity. Next, for two of the twelve ecosystems, we used NatureServe's Habitat Climate Change Vulnerability Index (HCCVI) framework as an alternative approach for assessing vulnerability. This approach develops a series of numeric indices for components of vulnerability, and results in an overall numeric vulnerability rating.

This research accomplished our objective and resulted in a comprehensive look at the current state of knowledge on climate change vulnerability for these important ecosystems, along with strategies to improve adaptive capacity. Of the twelve ecosystems we assessed in the first approach, five were rated as having high vulnerability, six had moderate vulnerability, and one had low vulnerability. In general, ecosystems we assessed that were wide-ranging or matrix communities had lower vulnerabilities than those that were more range-restricted, or "insular". For the two ecosystems we assessed with both approaches, vulnerability ratings generally agreed. Possible conservation strategies to reduce vulnerability and improve adaptive capacity varied by ecosystem, but included many actions that are important even without climate change stressors. For example, maintaining connectivity, restoring or maintaining disturbance processes, and minimizing the effects of urbanization could be important strategies in the face of climate change. We concluded our work by identifying critical needs for informing future ecosystem vulnerability assessments in the Southeast and beyond. Among the major needs for many ecosystems were additional data on the response of hydrologic processes to climate change, and the impacts of climate change on biotic interactions. These results will be important for local and regional conservation, land management, and decision-making, and can inform future work on climate change vulnerability in the Southeast.

4. PURPOSE AND OBJECTIVES:

A regional assessment of vulnerability for important ecosystems across the Southeast is necessary in order to prioritize regional conservation actions and inform future monitoring efforts. Several national climate change conservation strategies have identified vulnerability assessments as a critical first step in determining which conservation actions are needed in critical habitats. For example, the National Fish, Wildlife and Plants Climate Adaptation Strategy lists vulnerability assessments as a key need for accomplishing the goal of conserving habitat in a changing climate. In addition, this work relates to several of the science themes identified by the Southeast Climate Science Center, including Themes 1 and 4: Climate and Other Appropriate Projections to Use for Resource Management; and Ecological Research and Modeling.

Therefore, our original objective was to identify strategies that will improve adaptive capacity for several important ecosystems in the southeastern US by assessing the current state of knowledge in climate change vulnerability. In particular, the research questions we proposed to address were: 1. What is the current status and distribution of these ecosystems? 2. To which effects of climate change is each ecosystem most sensitive? 3. How much exposure to these effects is each ecosystem likely to experience? 4. Which ecosystems will be more likely to be affected by future urban growth, and thus have lower adaptive capacity? Which are already well-represented in protected lands and thus have a higher potential for adaptation?

We met the objectives of the study and were able to address all of these research questions. There were no major differences between what we proposed and the resulting work. The biggest difference was that we assigned qualitative vulnerability ratings to all twelve ecosystems we assessed, and only used the HCCVI tool to assign a quantitative vulnerability score to two ecosystems. We had initially planned to use the HCCVI to assess all ecosystems. This change was made because of the time- and data-intensive nature of the HCCVI. We feel, though, that the qualitative vulnerability ratings we assigned are at least as valuable as the quantitative HCCVI scores because the literature reviews we did for the qualitative ratings incorporate a wider breadth of information than the HCCVI process does.

5. ORGANIZATION AND APPROACH:

We conducted this project in three steps. First, we assembled a list of candidate ecosystems in the Southeast for analysis based on metrics of potential sensitivity to climate change, supplemented with additional ecosystem suggestions from Southeast LCCs. That list is a product of expert knowledge that can be used by other, subsequent assessment efforts by the Southeast Climate Science Center and LCCs. Second, for a subset of the candidate ecosystems, we conducted an assessment of the current state of knowledge on climate change vulnerability for a subset of the candidate ecosystems. This assessment is "Phase I" of our analysis. For this analysis phase, we summarized available GIS data sets, along with literature and reports. Third, we selected two Phase I ecosystems for "Phase II", or in-depth analysis of climate change vulnerability. For Phase II analysis, we used NatureServe's new Habitat Climate Change Vulnerability Index tool (HCCVI; Comer et al. 2012), with inputs from niche models and vegetation dynamics simulation models, to more fully assess the potential impacts of climate change.

To develop our list of focal ecosystems, we used the databases and descriptions of ecological systems developed by NatureServe (Comer et al. 2003, NatureServe 2003). We selected 36 ecological systems in the Southeast that met one or more of the following criteria:

1. Likely to be subject to sea level rise or other hydrologic changes: Ecosystems in coastal or coastal plain regions, or wetland ecosystems
2. Likely to be influenced by temperature and/or precipitation and orographic effects: Ecosystems that occur at high elevation
3. Ecologically insular: geographically discrete, defined by boundaries with steep environmental gradients, strongly controlled by elevation or geologic factors, subject to stressful edaphic or disturbance regimes, or biogeographically endemic
4. Threatened: Classified as critically endangered, endangered, or vulnerable, based on IUCN Category, a metric for Ecological Systems that is currently in development by NatureServe.

We used these criteria because these types of ecosystems may be especially vulnerable to climate change. They may have high sensitivity (e.g. high-elevation systems), high exposure (e.g. coastal systems), low adaptive capacity (e.g. insular systems), or a combination of these.

After this selection process, we solicited additional ecosystem suggestions from LCC staff and participants via email and conference call. The result was a list of 55 ecosystems (Table 1), including a mix of wetland and non-wetland systems, coastal, high and low elevation systems, and insular and non-insular systems.

From the list of 55 candidate ecosystems, we selected two with the majority of their extent in each of the six LCCs in the Southeast to be assessed in Phase I. This selection was made at random for every ecosystem except for those in the Caribbean LCC and the Gulf Coast Prairie LCC, which were selected based on the availability of data. The result was a list of twelve ecosystems (shown in bold in Table 1). Like the list of candidate ecosystems, the twelve ecosystems selected represent a range of wetland status, elevation, and insularity.

For each of these twelve Phase I ecosystems, we assessed the three components of climate vulnerability using information in published literature and reports, along with new GIS analysis. We assessed sensitivity based on the characteristics of each ecosystem. We assessed exposure based on the degree to which important climate and sea level variables will likely change in the future. For our assessment of sensitivity and exposure, we focused on climate factors that affect one or more of the following: the distribution of the ecosystem; important ecological processes, including fire and hydrology; the dominant plant species; and plant or animal species that are important for conservation. We considered all climate and climate-related factors, including temperature, precipitation, wind, storms, fire and hydrology. To assess adaptive capacity, we focused on the degree to which ecosystems can adjust to changing conditions. We focused on the degree to which each ecosystem had been affected by anthropogenic changes in the past, and projected future threats. We included past and future habitat fragmentation, habitat conversion, invasive plants, pests and pathogens, heterogeneity in elevation, and alterations to habitat from changes to hydrology or the fire regime.

Where available, we used GIS data to assess the three components of vulnerability in Phase I. We supplemented the GIS analysis with information from published literature to create a detailed report of climate change sensitivity, exposure, and adaptive capacity for each ecosystem. A detailed description of our GIS approach is below.

For Phase II of the assessment, we selected two ecosystems that were included in Phase I assessment. Those ecosystems were: Nashville Basin Limestone Glade and Woodland, and East Gulf Coastal Plain Near-Coast Pine Flatwoods. We chose these ecosystems because they represent two different types of ecosystems that share characteristics with many other systems in the Southeast: one system is an edaphically constrained, small-patch ecosystem that will not be affected by sea level rise by the end of the century (the Glade and Woodland system), and the other is a matrix ecosystem that is likely to be affected by sea level rise (the Near-Coast Pine Flatwoods system).

For Phase II analysis, we used NatureServe's Habitat Climate Change Vulnerability Index (HCCVI) framework (Comer et al. 2012). That framework distinguishes between factors that contribute to an ecosystem's climate change sensitivity, including the direct effects of climate, and those that influence its climate change resilience, which is comprised of the indirect effects of climate and an ecosystem's adaptive capacity (Figure 1). We followed the HCCVI methods suggested by Comer and colleagues in their pilot study, but modified them where appropriate for each ecosystem's geography and characteristics. Below, we describe our methods and data sources, highlighting the instances where our approach differed from the pilot study. Interested readers should refer to Comer et al. (2012) for more details on the HCCVI framework.

When applicable, we included sensitivity and resilience indices for mid-century and late century, as well as a minimum and maximum value for each time period. Doing so allowed us to incorporate changes in vulnerability over time, as well as differences among emissions scenarios and uncertainty in input data.

Table 1: All ecological systems that were candidates for analysis, based on selection criteria or suggested by LCC participants. Systems in bold were selected for Phase I assessment. The selection criteria are shown in the table, with the exception of IUCN status, which is currently provisional. An asterisk (*) indicates the two systems that were included in Phase II assessment.

Ecological System Name	Coastal status	Wetland	High elev	Insular	Suggestion from LCC
Atlantic Coastal Plain Clay-Based Carolina Bay Wetland	Coastal plain	Yes	No	Yes	No
Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland	Coastal plain	No	No	No	No
Atlantic Coastal Plain Peatland Pocosin and Canebrake	Coastal plain	Yes	No	Yes	No
Atlantic Coastal Plain Sandhill Seep	Coastal plain	Yes	No	Yes	No
Atlantic Coastal Plain Upland Longleaf Pine Woodland	Coastal plain	No	No	No	No
Caribbean Coastal Dry Evergreen Forest	Coastal	No	No	No	No
Caribbean Coastal Thornscrub	Coastal	No	No	No	No
Caribbean Floodplain Forest	Coastal	Yes	No	No	No
Caribbean Montane Wet Elfin Forest	No	No	Yes	Yes	No
Caribbean Riparian Forest and Shrubland	No	Yes	No	No	No
Central and Southern Appalachian Spruce-Fir Forest	No	No	Yes	No	No
Central Atlantic Coastal Plain Maritime Forest	Coastal	Yes	No	No	No
Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods	Coastal plain	Yes	No	No	No
Central Florida Wet Prairie and Herbaceous Seep	Coastal plain	Yes	No	Yes	No
Central Interior Highlands and Appalachian Sinkhole and Depression Pond	No	Yes	No	Yes	No
Central Interior Highlands Calcareous Glade and Barrens	No	No	No	Yes	Yes
Central Interior Highlands Dry Acidic Glade and Barrens	No	No	No	Yes	Yes
Cumberland Acidic Cliff and Rockhouse	No	No	Yes	Yes	No
Cumberland Seepage Forest	No	Yes	No	Yes	No
East Gulf Coastal Plain Depression Pondshore	Coastal plain	Yes	No	Yes	No
East Gulf Coastal Plain Interior Shortleaf Pine-Oak Forest	Coastal plain	No	No	No	No
East Gulf Coastal Plain Jackson Plain Prairie and Barrens	Coastal plain	No	No	Yes	Yes
*** East Gulf Coastal Plain Near-coast Pine Flatwoods**	Coastal plain	Yes	No	No	No
East Gulf Coastal Plain Southern Loess Bluff Forest	Coastal plain	No	No	No	No
East-Central Texas Plains Xeric Sandyland	No	No	No	No	Yes

Eastern Highland Rim Prairie and Barrens	No	Yes	No	No	No
Edwards Plateau Limestone Shrubland[a]	No	No	No	Yes	Yes
Edwards Plateau Cliff	No	Yes	No	Yes	Yes
Edwards Plateau Dry-Mesic Slope Forest and Woodland	No	Yes	No	No	Yes
Edwards Plateau Floodplain	No	Yes	No	No	Yes
Edwards Plateau Limestone Savanna and Woodland	No	No	Yes	No	Yes
Edwards Plateau Limestone Shrubland	No	No	No	No	Yes
Edwards Plateau Mesic Canyon	No	No	No	Yes	Yes
Edwards Plateau Riparian	No	Yes	No	No	Yes
Edwards Plateau Upland Depression	No	Yes	No	Yes	Yes
Manglar Costero del Caribe (Caribbean Coastal Mangrove)	Coastal	Yes	No	Yes	No
Manglar Estuarino del Caribe (Caribbean Estuarine Mangrove)	Coastal	Yes	No	Yes	No
*** Nashville Basin Limestone Glade and Woodland**	No	No	No	Yes	No
Ozark-Ouachita Mesic Hardwood Forest	No	No	No	Yes	No
South-Central Interior Mesophytic Forest	No	No	No	No	No
Southeastern Interior Longleaf Pine Woodland	No	No	No	No	No
Southern and Central Appalachian Cove Forest	No	No	Yes	No	No
Southern Appalachian Grass and Shrub Bald	No	No	Yes	Yes	No
Southern Appalachian Northern Hardwood Forest	No	No	Yes	No	No
Southern Coastal Plain Nonriverine Cypress Dome	Coastal plain	Yes	No	Yes	No
Southern Coastal Plain Seepage Swamp and Baygall	Coastal plain	Yes	No	Yes	No
Southern Piedmont Granite Flatrock and Outcrop	No	Yes	No	Yes	No
West Gulf Coastal Plain Catahoula Barrens	Coastal plain	No	No	No	Yes
West Gulf Coastal Plain Herbaceous Seep and Bog	Coastal plain	Yes	No	Yes	Yes
West Gulf Coastal Plain Mesic Hardwood Forest	Coastal plain	No	No	No	No
West Gulf Coastal Plain Nepheline Syenite Glade	Coastal plain	No	No	Yes	Yes
West Gulf Coastal Plain Seepage Swamp and Baygall	Coastal plain	Yes	No	No	Yes
West Gulf Coastal Plain Southern Calcareous Prairie	Coastal plain	Yes	No	Yes	No
West Gulf Coastal Plain Stream Terrace Sandyland Longleaf Pine Woodland	Coastal plain	No	No	No	Yes
West Gulf Coastal Plain Weches Glade	Coastal plain	No	No	Yes	Yes

[a] Edwards Plateau Carbonate Glade and Barrens was originally selected, but this ecosystem is not included in the land cover map, and thus GIS analysis would not be possible for the ecosystem. The Edwards Plateau Limestone Shrubland was substituted because of its proximity and similarity to that system.

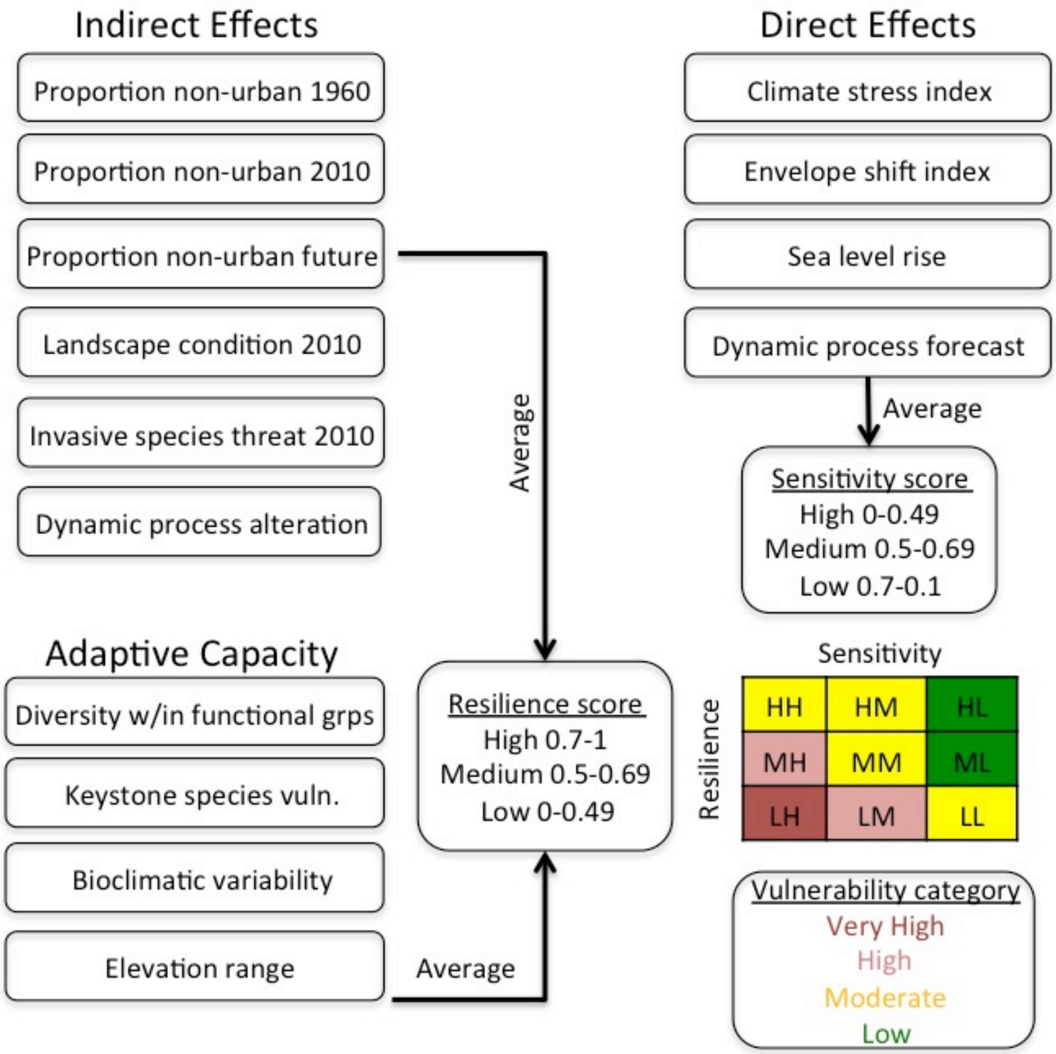

Figure 1: Flow chart for Habitat Climate Change Vulnerability Index (HCCVI) framework, modified from Comer et al. (2012) to reflect methods in the current study.

6. PROJECT RESULTS:

Phase I

As part of our assessment, we summarized temperature and precipitation variables for the Southeast and Caribbean. According to these summaries, there is much variation between emissions scenarios, and among climate models within the same scenario (Figures 2-7). Although individual GCMs vary in their quantitative projections, they overwhelmingly suggest the same qualitative change in the southeastern US and Caribbean: that temperatures will increase across the region under every emissions scenario for the middle and end of the century (Figures 2, 3, 5 and 6). There are a few exceptions for the southeastern U.S. for some seasons at mid-century under the B1 emissions scenario. In contrast, precipitation projections were highly uncertain both qualitatively and quantitatively. In the southeastern US and Puerto Rico, for every time period and emissions scenario, at least one GCM projected an increase in precipitation, while at least one other projected a decrease (Figures 4 and 7).

Of the twelve ecosystems we assessed, five were rated as having high vulnerability to climate change, six had moderate vulnerability, and one had low vulnerability (Table 2). The two Caribbean systems along with the East Gulf Coastal Plain Southern Loess Bluff Forest had the highest ratings for sensitivity to climate change. These three systems are all fairly range-restricted. The Caribbean Coastal Mangrove is especially sensitive to sea level rise and storm events. The other two, the Caribbean Montane Wet Elfin Forest and the East Gulf Coastal Plain Southern Loess Bluff Forest, are sensitive to changes in temperature because they provide refugia for disjunct species. Many of the other ecosystems we assessed are sensitive to changes in disturbances such as fire and hurricanes, or hydrology.

The two Caribbean ecosystems also had the highest ratings for climate change exposure (Table 1.5). The Caribbean Coastal Mangrove ecosystem is expected to have high exposure to sea level rise, while the Caribbean Montane Wet Elfin Forest is expected to experience increased temperatures, to which it is highly sensitive. Most other ecosystems had moderate ratings for climate change exposure. Many are expected to experience a change in fire regimes, hurricanes hydrology, and sea level rise. For many ecosystems, the future level of exposure to climate change is an area with a large amount of uncertainty. As a result, exposure to changes in drought, fires, and other precipitation-dependent factors are highly uncertain for all ecosystems we assessed.

Four ecosystems were rated as having low adaptive capacity, which adds to their climate change vulnerability (Table 2). Two of them, the Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods, and the Edwards Plateau Limestone Shrubland are susceptible to changes in the structure and species composition of the habitat due to fire suppression. The other two low-rating systems, the Nashville Basin Limestone Glade and Woodland and the Caribbean Montane Wet Elfin Forest ecosystems, are range-restricted. These ecosystems and their species will have low capacity to migrate in response to changes in climate. Most other ecosystems were rated as having a moderate level of adaptive capacity. These ecosystems had one or more factors that decrease adaptive capacity, such as small patch sizes, threats from development, invasive species or diseases, fire suppression, and hydrology. However, these threats were usually balanced with factors that increase adaptive capacity, such as a high level of protection for conservation.

Overall, five ecosystems in our assessment were rated as having high vulnerability to climate change. Two of them, the Caribbean Coastal Mangrove and Caribbean Montane Wet Elfin Forest ecosystems both had high levels of sensitivity and exposure, with low or moderate adaptive capacities. In both of these ecosystems, management options include maintaining and restoring connectivity with adjacent ecosystems. The Nashville Basin Limestone Glade and Woodland ecosystem, and the Edwards Plateau Limestone Shrubland both had moderate ratings for sensitivity and exposure, but low adaptive capacities. For both systems, decreasing non-climate stressors were important management strategies to increase adaptive capacity. For the Nashville Basin Limestone Glade and Woodland ecosystem, conserving remaining examples of the system was also important. In the Edwards Plateau Limestone Shrubland ecosystem, restoring connectivity was a strategy that was identified. One ecosystem, the East

Gulf Coastal Plain Near-coast Pine Flatwoods, had high sensitivity to climate change, along with moderate expected exposure and adaptive capacity. Management strategies to improve adaptive capacity in that ecosystem could include conducting prescribed burns to maintain adaptive capacity and prevent large wildfires.

The only ecosystem that we rated as having low vulnerability to climate change was the Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods ecosystem. Our analysis and literature synthesis suggested that the ecosystem processes and major species are minimally sensitive to changes in climate. While it may be exposed to changes in fires, hurricanes, and sea level rise, our assessment also suggested that these changes may be minimal. However, there is a great deal of uncertainty associated with those changes. Finally, the adaptive capacity of this ecosystem is moderate, but the minimum impact from climate change keeps the system’s overall vulnerability low.

Table 2: Vulnerability rating for the 12 Phase I ecosystems. These ratings are qualitative based on synthesis of literature and new analysis. See text for details on the factors that contribute to vulnerability of each system.

Vulnerability rating	**Ecosystem**
High	Caribbean Coastal Mangrove (Manglar Costero del Caribe)
High	Caribbean Montane Wet Elfin Forest
High	East Gulf Coastal Plain Southern Loess Bluff Forest
High	Edwards Plateau Limestone Shrubland
High	Nashville Basin Limestone Glade and Woodland
Medium	Central Florida Wet Prairie and Herbaceous Seep
Medium	East Gulf Coastal Plain Near-Coast Pine Flatwoods
Medium	Edwards Plateau Mesic Canyon
Medium	South-Central Interior Mesophytic Forest
Medium	Southern Coastal Plain Nonriverine Cypress Dome
Medium	Southern Coastal Plain Seepage Swamp and Baygall
Low	Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods

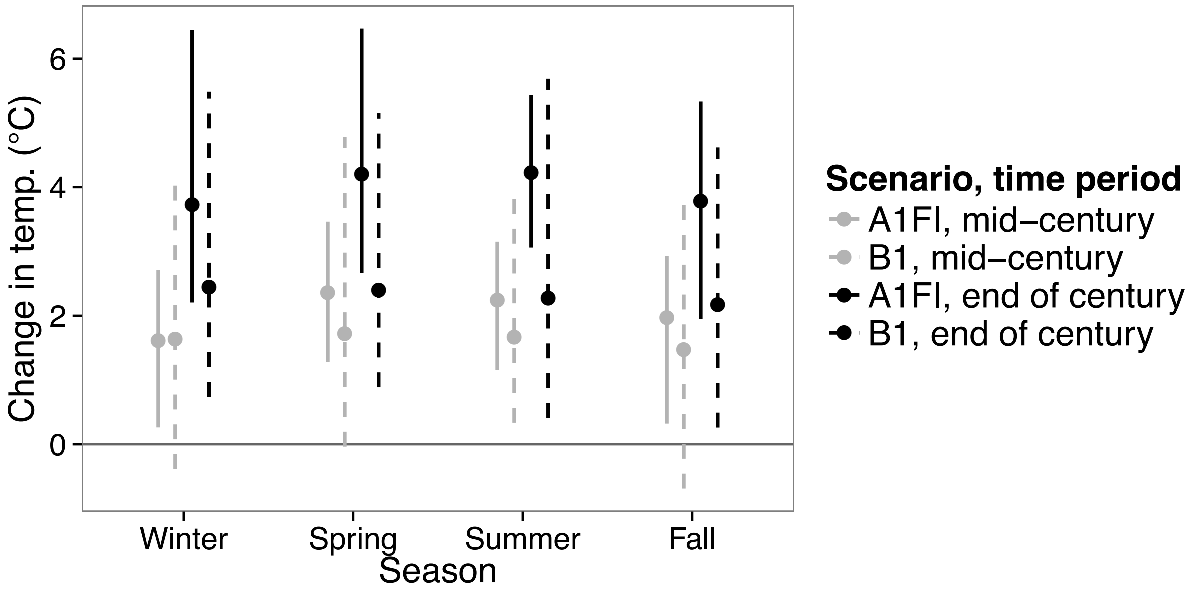

Figure 2: Projected change in seasonal maximum temperature (°C) across the southeastern US for the middle (2040-2060) and the end of the 21st century (2080-2100) compared with the recent time period (1981-2000) for two emissions scenarios. Solid dot and error bars represent the mean and range of projections across climate models under each scenario.

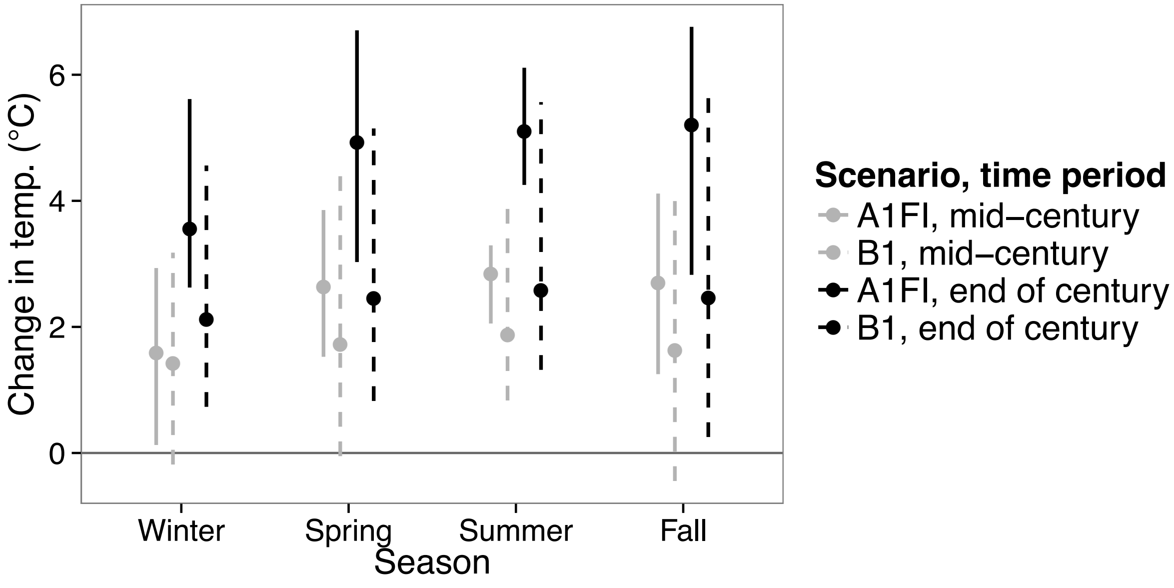

Figure 3: Projected change in seasonal minimum temperature (°C) across the southeastern US for the middle (2040-2060) and the end of the 21st century (2080-2100) compared with the recent time period (1981-2000) for two emissions scenarios. Solid dot and error bars represent the mean and range of projections across climate models under each scenario.

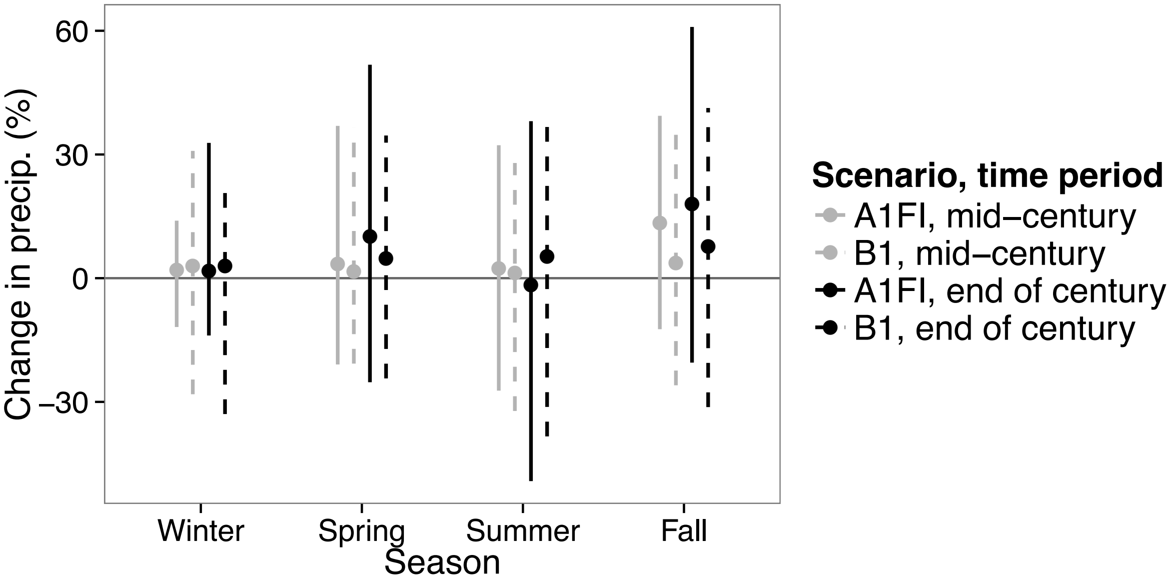

Figure 4: Percent projected change in seasonal average precipitation across the southeastern US for the middle (2040-2060) and the end of the 21st century (2080-2100) compared with the recent time period (1981-2000) for two emissions scenarios. Solid dot and error bars represent the mean and range of projections across climate models under each scenario.

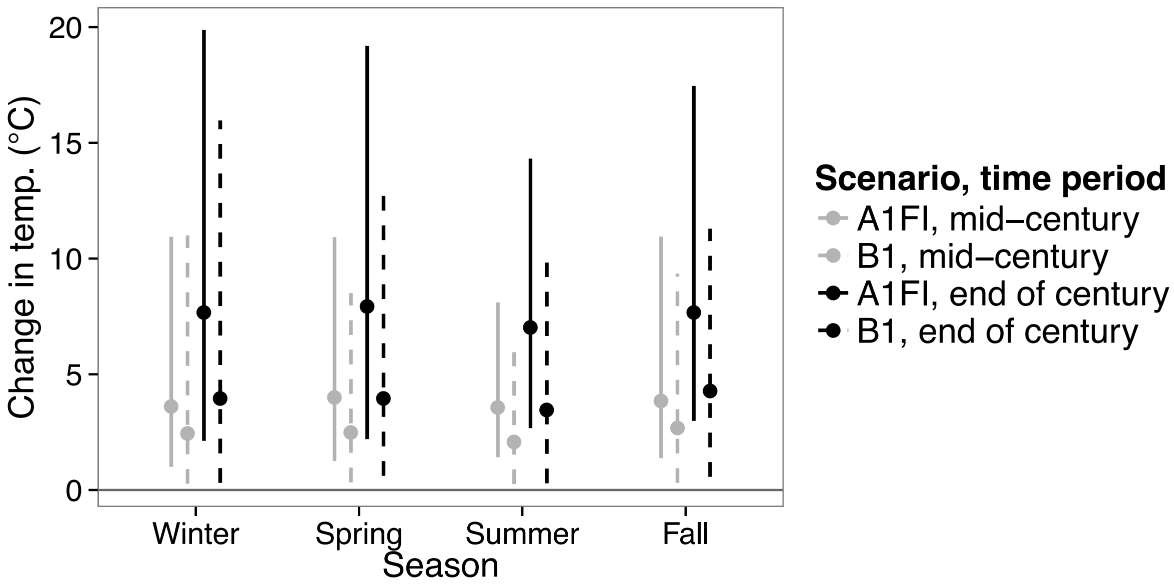

Figure 5: Projected change in seasonal maximum temperature (°C) for all climate stations in Puerto Rico climate stations for the middle (2040-2060) and the end of the 21st century (2080-2100) compared with the recent time period (1981-2000) for two emissions scenarios. Solid dot and error bars represent the mean and range of projections across climate models under each scenario.

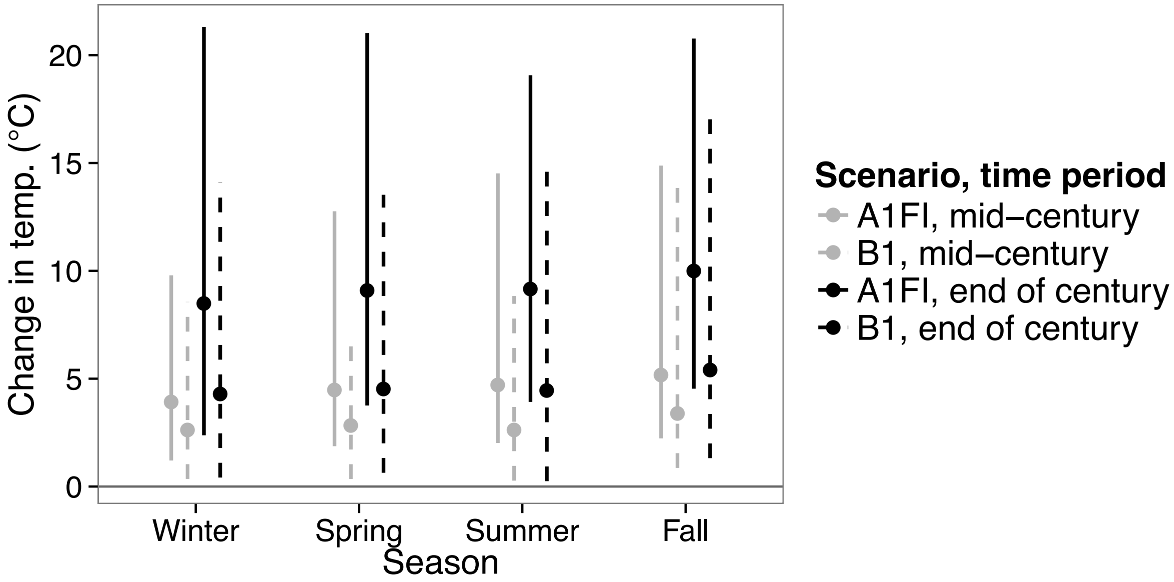

Figure 6: Projected change in seasonal minimum temperature (°C) for all climate stations in Puerto Rico climate stations for the middle (2040-2060) and the end of the 21st century (2080-2100) compared with the recent time period (1981-2000) for two emissions scenarios. Solid dot and error bars represent the mean and range of projections across climate models under each scenario.

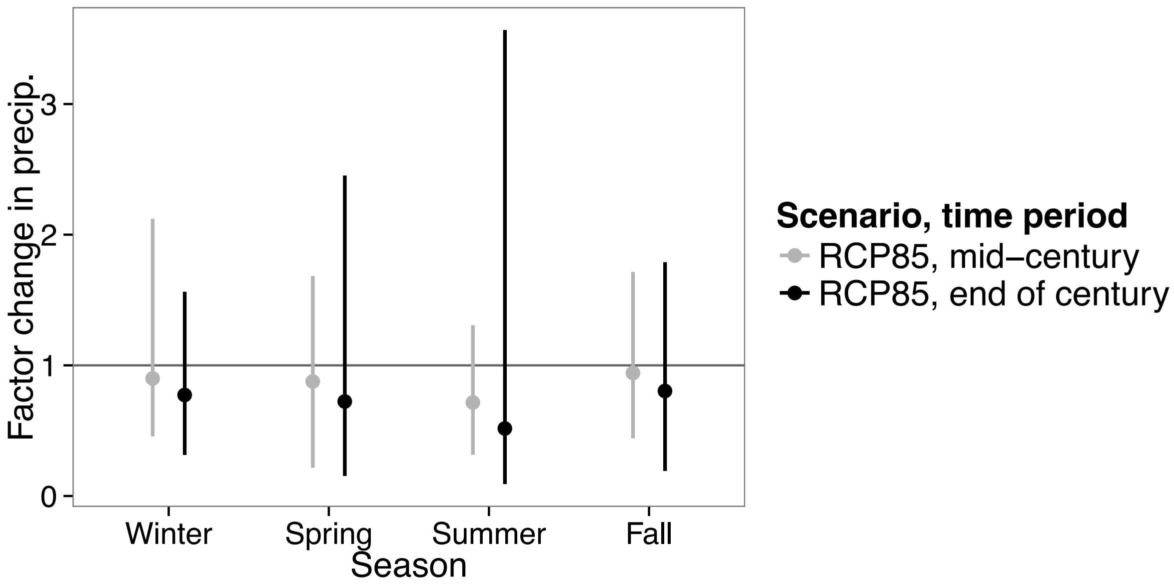

Figure 7: The projected factor change in seasonal average precipitation across the southeastern US for the middle (2040-2060) and the end of the 21st century (2080-2100) compared with the recent time period (1981-2000) for two emissions scenarios. Solid dot and error bars represent the mean and range of projections across climate models under each scenario. Values below 1 represent a decrease in precipitation, while values above 1 represent an increase.

Phase II

The HCCVI framework was used to calculate vulnerability scores for the East Gulf Coastal Plan Near-coast Pine Flatwoods ecosystem and the Nashville Basin Limestone Glade and Woodland ecosystem. Results show that for each ecosystem, scores varied by time period and with assumptions of minimum and maximum future impacts (Table 3, Figure 8). Details about the results for each ecosystem can be found in the subsequent sections of this report.

In general, for both mid- and late-century time periods, the Nashville Basin Limestone Glade and Woodland ecosystem had slightly higher vulnerability than the Near-coast Pine Flatwoods ecosystem (Table 3, Figure 8). Their sensitivity scores were more different from one another than their resilience scores, which were most similar at mid-century. Likewise, the systems had similarities and differences for individual metrics calculated in the HCCVI. The systems had similar values for the climate stress index, indicating small to moderate changes in climate for the current ecosystem ranges over the 21st century. The dynamic process forecast values for both systems indicate high future ecological departure due to altered fire regimes. Past urbanization was relatively low for both ecosystems, but present and future urbanization is projected to be higher for the Limestone Glade and Woodland ecosystem than for the Near-coast Pine Flatwoods ecosystem. However, current landscape condition is better for the Near-coast Pine Flatwoods ecosystem than for the Limestone Glade and Woodland ecosystem. Both ecosystems have relatively low elevation and bioclimatic variability and high diversity within important functional groups.

Both systems scored lowest in metrics related to adaptive capacity, compared with direct effects and indirect effects. Low scores were influenced by the narrow range of bioclimatic and elevation bands in which each system is distributed. In addition, the Nashville Basin Limestone Glade and Woodland ecosystem had relatively low scores for metrics related to the direct effects of climate change, indicating high sensitivity, especially for the end of the century. The dynamic process forecast for that ecosystem indicates that the vegetation dynamics of that system could be altered substantially throughout the century. For the East Gulf Coastal Plain Near-coast Pine Flatwoods ecosystem, the dynamic process forecast also indicated a high level of alteration. However, for that ecosystem, the envelope shift index for that ecosystem shows the largest decline by the end of the century.

Table 3: Phase II vulnerability assessment results from the Habitat Climate Change Vulnerability Index (HCCVI) framework. See Figure 1 for details on the calculations.

				Direct effects			
System	Time period, min/max	Climate stress index	Envelope shift index	Dynamic process forecast	Sea level rise	Sensitivity score	
East Gulf Coastal Plain Near-coast Pine Flatwoods	Mid-century min	0.85	0.81	0.31	0.99	0.74	Low
	Mid-century max	0.75	0.63	0.31	0.92	0.65	Medium
	Late-century min	0.75	0.54	0.31	0.99	0.65	Medium
	Late-century max	0.55	0.25	0.29	0.92	0.50	Medium
Nashville Basin Limestone Glade & Woodland	Mid-century min	0.88	NA	0.22	NA	0.55	Medium
	Mid-century max	0.78	NA	0.22	NA	0.50	High
	Late-century min	0.77	NA	0.21	NA	0.49	High
	Late-century max	0.51	NA	0.21	NA	0.36	High

					Indirect effects			
System	Time period, min/max	Prop. non-urban 1960	Prop. non-urban 2010	Prop. non-urban projected	Landscape condition 2010	Invasive species threat 2010	Dynamic process alteration	Avg.
East Gulf Coastal Plain Near-coast Pine Flatwoods	Mid-century min	0.98	0.84	0.84	0.59	0.80	0.68	0.79
	Mid-century max	0.98	0.84	0.82	0.59	0.70	0.68	0.77
	Late-century min	0.98	0.84	0.84	0.59	0.80	0.68	0.79
	Late-century max	0.98	0.84	0.81	0.59	0.70	0.68	0.77
Nashville Basin Limestone Glade & Woodland	Mid-century min	0.96	0.69	0.64	0.70	0.70	0.49	0.70
	Mid-century max	0.96	0.68	0.63	0.70	0.50	0.49	0.66
	Late-century min	0.96	0.69	0.64	0.70	0.70	0.49	0.70
	Late-century max	0.96	0.68	0.63	0.70	0.50	0.49	0.66

Table 3, continued: Phase II vulnerability assessment results from the Habitat Climate Change Vulnerability Index (HCCVI) framework. See Figure 1 for details on the calculations.

		Adaptive Capacity							
System	Time period, min/max	Diversity within functional groups	Keystone species vuln.	Bioclimatic variability	Elevation range	Avg.	Resilience score		Vulnerability category
East Gulf Coastal Plain Near-coast Pine Flatwoods	Mid-century min	0.90	0.69	0.32	0.07	0.50	0.64	Medium	Low
	Mid-century max	0.80	0.50	0.32	0.07	0.42	0.60	Medium	Moderate
	Late-century min	0.90	0.40	0.32	0.07	0.42	0.61	Medium	Moderate
	Late-century max	0.80	0.30	0.32	0.07	0.37	0.57	Medium	Moderate
Nashville Basin Limestone Glade & Woodland	Mid-century min	0.90	0.69	0.08	0.11	0.45	0.57	Medium	Moderate
	Mid-century max	0.80	0.50	0.08	0.11	0.37	0.52	Medium	High
	Late-century min	0.90	0.40	0.08	0.11	0.37	0.53	Medium	High
	Late-century max	0.80	0.30	0.08	0.11	0.32	0.49	Low	Very High

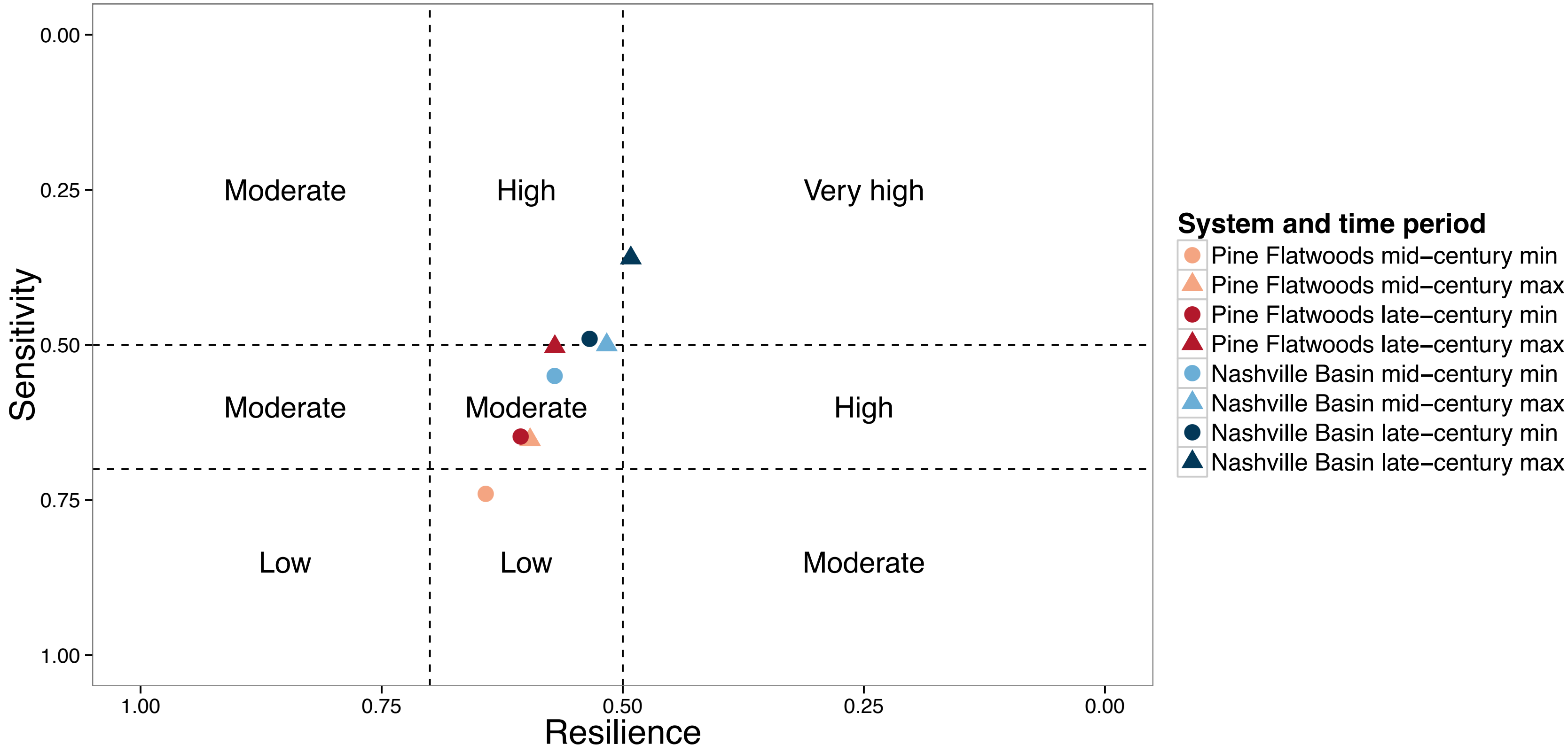

Figure 8: Results from HCCVI analysis for the East Gulf Coastal Plain Near-coast Pine Flatwoods and Nashville Basin Limestone Glade and Woodland ecosystems. Labels on the figure indicate the climate change vulnerability rating, according to Comer et al. (2012). Metrics for direct climate effects make up the sensitivity score. Metrics for indirect effects and adaptive capacity combine to make up the resilience score. Resilience values closer to 0 indicate lower resilience to climate change, and sensitivity values closer to 0 indicate higher sensitivity to climate change.

7. ANALYSIS AND FINDINGS:

We produced a report based on our findings. The report contains vulnerability assessments for all ecosystems, as well as an overview of the major framework, methods, and results of our work. The report is currently in review. The citation for the draft report is:

Costanza, J.K., Beck, S., Pyne, M., Terando, A., Rubino, M., White, R., Collazo, J. Assessing Climate-sensitive Ecosystems in the Southeastern U.S. *In review.*

The major, synthetic findings of our research include strategies to increase adaptive capacity and areas of uncertainty in vulnerability assessments that could be addressed by future research.

Strategies to increase adaptive capacity

For each ecosystem, our vulnerability assessment identified actions that could be taken to increase adaptive capacity. Many of these conservation strategies apply outside the framework of climate change as well. For example, in many ecosystems, maintaining or restoring connectivity within the ecosystem or with adjacent ecosystems could be an important strategy to ensure that important species would be able to shift their ranges to accommodate climate change. Minimizing non-climate stressors was also identified as a potential strategy in several ecosystems. Such actions that minimize non-climate stressors could include restoring disturbance regimes such as wildfire and grazing, slowing or stopping the spread of invasive species, and minimizing development. This list of strategies suggests that even when the specific effects of climate change on ecosystems are uncertain or difficult to quantify, management that maintains or restores important ecological processes or species could be important in the future. It also agrees with the types of strategies identified for reducing vulnerability in other studies (e.g. Glick et al. 2011).

Sources of uncertainty and needs for future research

While compiling these vulnerability assessments, we identified several sources of uncertainty or other areas that warrant further research. Research needs for specific ecosystems are detailed in each system's assessment. We focus here on needs and uncertainty that apply to many ecosystems.

The metrics and data related to the exposure portion of vulnerability contained a high degree of uncertainty in our assessment. For example, currently available climate data for Puerto Rico suggest potentially large future changes in temperature and precipitation with high uncertainty (Figures 1.8, 1.9, 1.10), which contributed to high exposure ratings for the Caribbean ecosystems we assessed. Because the climate of the Caribbean is difficult to simulate with GCMs, further work on climate projections in the region is needed (Hayhoe 2013, Ryu and Hayhoe 2013). Even for ecosystems in the southeastern US, differences in climate projections, especially for precipitation, make it difficult to make even qualitative assessments of the direction of change in some processes such as drought and fire regimes. In addition, for many ecosystems, there is a critical need for further research on how climate change will affect hydrology (Seager et al. 2009). While in some isolated cases such as the East Gulf Coastal Plain Near-coast Pine Flatwoods, there was existing information on the effects of climate on hydrology (Lu et al. 2009), for most ecosystems such information was lacking.

Another major area for additional research is on the future of biotic interactions including trophic relationships and dispersal under climate change. These are often difficult to predict (Blois et al. 2013), and as a result, there is little data on species interactions that can inform ecosystem vulnerability assessment. In limited places within our Phase I analysis, we were able to incorporate species interactions. For example, in the Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods and East Gulf Coastal Plain Near-coast Pine Flatwoods systems, we considered the effects of cogongrass, an invasive species that can increase fire intensity and lead to increased pine mortality following wildfires. Within the current HCCVI framework, the dynamic process forecast, invasive species threat, and keystone species vulnerability metrics are all places where information on species interactions could be incorporated. Again, with few exceptions, we did not incorporate information on species interactions in our HCCVI assessment.

8. CONCLUSIONS AND RECOMMENDATIONS:

The Southeast contains a variety of diverse, important ecosystems, from montane woodlands to grasslands to coastal systems. Likewise, the types and magnitudes of likely climate change effects on these ecosystems vary greatly. Five of the ecosystems we assessed were rated as having high vulnerability compared to others in the region. The characteristics of these ecosystems vary, but all are somewhat range-restricted and occur in ecologically or geographically unique habitats. All but one, the East Gulf Coastal Plain Southern Loess Bluff Forest, were labeled as “insular” in our initial ecosystem selection process. The insular nature of those ecosystems will make adaptation to even moderate climate change difficult. For those ecosystems, potential conservation strategies could include reducing the effects of non-climate stressors, maintaining remaining examples, and ensuring connectivity with similar ecosystems.

The other ecosystems we assessed will also be important to consider for management. The ecosystems that were given a vulnerability rating of “moderate” have moderate to high values in at least one of the three components of vulnerability. Therefore, management to reduce exposure or increase adaptive capacity will be essential. The one ecosystem that was given a rating of “low” vulnerability, the Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods, had a fairly low sensitivity to climate change based on current knowledge, but had reduced adaptive capacity. Monitoring and maintenance of natural processes in that ecosystem could be important strategies for that ecosystem.

The methods we used in this study demonstrate two approaches for assessing ecosystem climate change vulnerability. One major difference between the two approaches is the numeric score for vulnerability calculated with HCCVI, versus the qualitative rating based on our own judgment, informed by literature and analysis in Phase I. There are definite advantages to calculating numeric scores. While in Phase I, we assigned only one category of vulnerability per ecosystem, in the HCCVI method, we calculated a range of numeric vulnerability scores to capture uncertainty in data, and scores varied by time period. These numeric values for each component of vulnerability facilitate comparison among a large pool of ecosystems via graphical representations and other visualizations (e.g. Figure 1.11). This approach would work well for situations in which many ecosystems need to be assessed in a short period of time. On the other hand, data and literature synthesis we did for Phase I can provide a more nuanced assessment of vulnerability that we were not able to capture with the HCCVI alone. This approach, ideally combined with the HCCVI approach, is ideal when there are few ecosystems to assess, when a detailed written report is desired, or when there is ample time to synthesize a wide body of existing literature. To maximize the value of future vulnerability assessments in the Southeast and beyond, we recommend that a comprehensive assessment include both approaches.

9. MANAGEMENT APPLICATIONS AND PRODUCTS:

By assessing vulnerability and pointing to key actions that could increase adaptive capacity, this study provides important information for conservation of these important ecosystems. The literature syntheses and GIS analysis for individual ecosystems will inform management actions of conservation practitioners working locally to manage these ecosystems. Specifically, the assessment includes management actions or further research that could help increase adaptive capacity and decrease climate vulnerability for each ecosystem. The overall results regarding which ecosystems may be more vulnerable to climate change will benefit regional decision-makers who need to prioritize actions among many ecosystems across the Southeast.

We worked directly with several individuals, who are also coauthors of the report:
Scott Beck, NC State University
Milo Pyne, NatureServe
Matthew Rubino, NC State University
Adam Terando, USGS Southeast Climate Science Center
Rickie White, NatureServe

We solicited feedback on our work from LCCs and others along the way. Several managers, researchers, and decision makers from LCCs, public agencies, universities, and NGOs provided feedback on ecosystem selection and reviewed vulnerability assessments. Following is a list of those individuals and their affiliations:
Jennifer Cartwright, USGS – ecosystem selection
Lee Elliott, Missouri Resource Assessment Partnership/University of Missouri – assessment review
Jane Fitzgerald, American Bird Conservancy – ecosystem selection
Bill Gould, Caribbean LCC – ecosystem selection, contributed data
Doug Marcy, NOAA – contributed data
Alexa McKerrow, USGS – full report review
Rua Mordecai, South Atlantic LCC – ecosystem selection, assessment review
Bruce Moring, USGS – ecosystem selection
Brent Murry, Caribbean LCC – assessment review
Judy Teague, NatureServe – assessment review
John Tirpak, Gulf Coastal Plains and Ozarks LCC – assessment review, full report review
Jeff Walck, Middle Tennessee State University – assessment review
Bill Wolfe, USGS – ecosystem selection

10. OUTREACH:

We completed a report that will be published via USGS or the NC Agricultural Research Service. The report is currently in review. The citation is:

Costanza, J.K., Beck, S., Pyne, M., Terando, A., Rubino, M., White, R., Collazo, J. Assessing Climate-sensitive Ecosystems in the Southeastern U.S. *In review.*

We also plan to work with researchers in the USGS Tennessee Water Science Center to produce at least peer-reviewed publication from our work.

REFERENCES:

Blois, J. L., P. L. Zarnetske, M. C. Fitzpatrick, and S. Finnegan. 2013. Climate change and the past, present, and future of biotic interactions. Science (New York, N.Y.) 341:499–504.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schultz, K. Snow, and J. Teague. 2003. Ecological systems of the United States: a working classification of U.S. terrestrial systems. Arlington, VA, USA. 82 pages.

Comer, P. J., B. Young, K. Schulz, G. Kittel, B. Unnasch, D. Braun, G. Hammerson, L. Smart, H. Hamilton, S. Auer, R. Smyth, and J. Hak. 2012. Climate Change Vulnerability and Adaptation Strategies for Natural Communities: Piloting Methods in the Mojave and Sonoran Deserts. Report to the U.S. Fish and Wildlife Service. Arlington, VA, USA. 73 pages.

Glick, P., B. A. Stein, and N. A. Edelson. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Washington, DC, USA. 168 pages.

Hayhoe, K. 2013. Quantifying Key Drivers of Climate Variability and Change for Puerto Rico and the Caribbean. Final Report to the Southeast Climate Science Center. Raleigh, NC, USA. 241 pages.

Lu, J., G. Sun, S. G. McNulty, and N. B. Comerford. 2009. Sensitivity of pine flatwoods hydrology to climate change and forest management in Florida, USA. Wetlands 29:826–836.

NatureServe. 2003. Ecological Systems of Latin America and the Caribbean Database, version 1.01. NatureServe, Arlington, VA, USA.

Ryu, J.-H., and K. Hayhoe. 2013. Understanding the sources of Caribbean precipitation biases in CMIP3 and CMIP5 simulations. Climate Dynamics 42:3233–3252.

Seager, R., A. Tzanova, and J. Nakamura. 2009. Drought in the southeastern United States: causes, variability over the last millennium, and the potential for future hydroclimate change. Journal of Climate 22:5021–5045.