TACCIMO
Template for Assessing Climate Change Impacts and Management Options

TACCIMO Florida Reference Report

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Total Found: 240

Range: 1990 – 2021

Factor: Animal Communities (44)

Animal communities encompasses all faunal groups in a particular area and their relation to the surrounding environment. The effects of climate change on animal communities and populations will act through both direct effects on temperature requirements and indirect effects on habitat structure, resulting in shifting ranges and disrupted migrations. Specific effects will vary by taxa and species-specific life history traits. Management strategies to abate the effects of climate change focus on increasing landscape connectivity and maintaining high-quality habitats.

Category: Amphibians (8) Highlights

1. For all species except flatwoods salamander (Ambystoma cingulatum), Florida bog frog (Lithobates okaloosae), and Alabama waterdog (Necturus alabamensis) we identified at least two protected areas projected to contain climatically suitable habitat by 2050 under some scenario (median = 40, range = 2–660; Tables S2–S19). The sum of protected areas for each species with at least some protected habitat had a median value of 640,202 ha, with the smallest sum (3,281 ha) associated with projections for Webster's salamander (Plethodon websteri) and the largest (13,189,000 ha) with the tiger salamander. tigrinum. Of the 1,520 currently protected areas in our focal southeastern states, we have projected 866 (57%) (by at least one model) to maintain some climatically suitable habitat for priority amphibians. When we ranked protected areas based on the A2a weighted score of value as a long-term refugia (see "Data Analysis and Reporting" for details), the top 5% of the 866 units (Table 4) primarily included protected areas in the Appalachian and Cumberland Plateau regions of the southeast. We identified only one unit, Florida Caverns State Park, in the Coastal Plain region. The majority of the protected areas that we projected to be high-priority climatic refugia in 2050 were also identified as being of high climatic suitability to a large number of species currently (i.e., within the upper 25th percentile of sites as ranked by current climatic suitability; Table 4). Nevertheless, three units that ranked relatively low based on current estimates (lower 75th percentile), appear within the high-priority climatic refugia list for 2050. [Citation: Barrett et al 2014]

2. Climate change is driving shifts in the distribution of plants and animals, and prioritizing management actions for such shifts is a necessary but technically difficult challenge. We worked with state agencies in the southeastern United States to identify high-priority amphibian species, to model the vulnerabilities of those species to regional climate change, and to identify long-term climatic refugia within the context of existing conservation lands. Directly interfacing with state natural resource experts ensured that 1) species prioritization schemes extend beyond political boundaries and 2) our models resulted in conservation-relevant applications. We used a correlative model to project midcentury distributions of suitable climate for priority species and to evaluate each species' vulnerability to climate change. Using spatially explicit projected climate distributions, we ranked existing protected areas relative to their ability to provide climatic refugia for priority species in 2050. We identified 21 species as regional high-priority species. Fifteen of the 21 species are forecast to lose more than 85% of their climatically suitable habitat. Regions in the Appalachian Mountains, the Florida Panhandle, and the north-central region of Alabama are projected to lose the most climatic habitat for priority amphibian species. We identified many existing protected areas as midcentury climatic refugia in the Appalachians; however, our projections indicated refugia in the Southeast Coastal Plain to be exceedingly scarce. Although the topographic relief present in the Appalachians appears to provide future conservation opportunities via climatic refugia, the Coastal Plain affords fewer such opportunities and conservation of amphibians in that region is likely to be more

challenging. The approach outlined here could be applied across a broad range of taxa and regions. [Citation: Barrett et al 2014]

3. Hydroregimes of ephemeral wetlands affect reproductive success of many amphibian species and are sensitive to altered weather patterns associated with climate change. We used 17 years of weekly temperature, precipitation, and water depth measurements for eight small, ephemeral, ground water driven sinkhole wetlands in Florida sandhills to develop a hydroregime predictive model. To illustrate its utility for climate-change planning, we forecasted weekly wetland water-depths and hydroperiods (2012–2060) using our model and downscaled climate data from the CSIRO Mk3.5 Global Circulation Model under an A1B emissions scenario.We then examined how forecasted water depths and hydroperiods might alter reproductive success, and thereby populations, of five anuran species. Precipitation and water-depth from the prior week were significant predictors of water depth. Our model forecasted shallower depths and shortened hydroperiods for most wetlands when used with the CSIRO Mk3.5 A1B scenario. The forecasted hydroregimes would likely provide adequate reproductive opportunity for only one of the five species we examined. We demonstrate the utility of our model in examining how different climate change scenarios might affect hydroregimes and, indirectly, biological diversity. Climate change uncertainty highlights the importance of retaining multiple, hydrologically diverse wetlands on landscapes to maximize the potential for successful reproduction by species having differing hydroregime requirements. [Citation: Greenberg et al 2015]

4. Although the number of amphibian species did not differ [in a study in northwestern Florida on the effect of storm surge overwash on wetland amphibian communities] between wetlands with and without fish, the species composition of the amphibian community did differ among these wetlands with a specific suite of species tending to occur in wetlands without fish. [Citation: Gunzburger et al 2010]

5. Fourteen amphibian species were collected at both overwashed and non-overwashed wetlands [in a study in northwestern Florida on the effect of storm surge overwash on wetland amphibian communities] both before and after the storm surge (Table 2). Species not detected post-storm from overwashed wetlands but present in non-overwashed wetlands were Hyla squirella [squirrel tree frog], Pseudacris ornate [ornate chorus frog], Rana catesbeiana [American bullfrog], Rana clamitans [northern green frog], and Pseudobranchus striatus [northern dwarf siren] (Table 2). Two of these species, R. clamitans and R. catesbeiana, were also not detected at the overwashed wetlands prior to the storm. One species (Pseudacris nigrita [Southern Chorus Frog]) was found post-storm at overwashed wetlands and not at non-overwashed wetlands (Table 2). The five rarely detected species (detected at two or fewer wetlands) were only found prior to the storm (Table 2). [Citation: Gunzburger et al 2010]

6. Thus [in our case study on amphibian use of ephemeral ponds in the Ocala National Forest], Florida gopher frogs [Lithobates capito], pig frogs [Lithobates grylio], southern leopard frogs (Lithobates sphenocephalus) and bullfrogs (Lithobates catesbeianus)—all commonly captured at our study pond—would be unlikely to persist, as they have long larval development periods. Populations of summer breeders, such as oak toads [Anaxyrus quercicus], would also likely shrink or become locally extinct because summer hydroperiods under the MIROC3.2 A1B scenario [which uses a climate model and projects low population/high economic growth and high-energy use,] would be rare. The relative abundance of species would likely shift toward species such as the spadefoot toad (Scaphiopus holbrookii) that live longer and have fast-developing larvae. However, even persistence of the spadefoot toad is

uncertain because the interval between suitable hydroperiods could exceed their lifespan. [Citation: Greenberg et al 2013]

7. Due to several years of reduced rainfall (cumulative rainfall deficit of 94.0 cm from 1999–2001 at Wewahitchka [in the Apalachicola National Forest, Florida]), the moisture threshold for movement of most [Ambystoma cingulatum, Flatwoods salamanders] may not have been met in fall 2002 despite receiving slightly more rain in fall 2002 than fall 1999, the year when 21 immigrants were captured. Other than the proximate cues of rainfall and temperature (Palis 1997a), nothing is known regarding the environmental cues used by A. cingulatum to initiate migration to breeding sites. Further, several years of below-normal rainfall could have reduced feeding opportunities resulting in the lack of acquisition of energy reserves required for reproductive activity (Semlitsch et al. 1996). [Citation: Palis et al 2006]

8. During the 4-year study period [from 1999 to 2002, in the Apalachicola National Forest, Florida], the number of [Ambystoma cingulatum, Flatwoods salamanders] entering Pond 73-04 to breed dropped from 21 to one. The decline in the number of A. cingulatum migrating to pond 73-04 in 2000 and 2001 may have been due to insufficient rainfall. [Citation: Palis et al 2006]

Category: Birds (11) Highlights

1. The RCW [Red-cockaded Woodpecker (Dryobates borealis)] is a federally endangered species endemic to pine (Pinus spp.) forests in the southeastern United States. The species’ range spans from suitable forest in southeastern Virginia to the Florida peninsula to the south, and west into eastern Texas and Oklahoma…Spring temperatures have increased throughout the RCW range and have influenced breeding primarily through changes in nest initiation dates. Warmer spring temperatures advanced nesting, higher precipitation delayed nesting, and within a breeding season, earlier nests were more productive than later nests. No consistent effects of breeding season temperature or precipitation on reproduction remained after accounting for changing nesting dates. [Citation: DeMay et al 2019]

2. These results suggest that future studies and conservation measures on the Florida populations of Snowy Plover [Charadrius alexandrines] should focus on the average and variability of demographic rates and density dependence. In particular, the negative effects of SLR [sea level rise] may be mitigated by conservation measures that are designed to increase fecundity (e.g. nest success) and survival rates in these populations. [Citation: Aiello-Lammens et al 2011]

3. A direct path toward the [Atlantic] coast is key to whether a hurricane wrecks [endangered black-capped] petrels [Pterodroma hasitata] or not (Tables 1 & 2). We hypothesize that when west-approaching hurricanes recurve (turn north to northeast) north of Florida, the flight space and prevailing winds that exist between the storm’s perimeter and the coastline serve as a corridor through which birds are funneled to shallower, nearshore waters along the eastern seaboard (Fig. 3). Indeed, on average, hurricanes that did not produce specimens tended to recurve when almost 240 nautical miles east of the coast, while those producing carcasses pushed inland nearly 180 nautical miles before turning north (Tables 1 & 2). [Citation: Hass et al 2012]

4. Bachman's Sparrow (Aimophila aestivalis) [Map section page 176]: Both CCC and Hadley [general circulation models] project increases in range and abundance for this southern species. Expansion northward is associated with the future distribution of slash pine as well as increases in average annual

temperature. The only predicted decrease in abundance is associated with changes in summer drought in Florida. [Citation: Matthews et al 2004]

5. Coastal regions, which often have high bird diversity, will be affected by rising sea levels. Yet, because coastal wetlands are often bounded by agriculture and settlements, opportunities for range shifts are limited. These wetlands include Florida's Everglades and its globally important colonies of roseate spoonbills (Platalea ajaja), wood storks (Mycteria americana), and other waterbirds. [Citation: Şekercioğlu et al 2012]

6. While untangling the biogeoclimatology of SP [Snowy Plover (Charadrius a. nivosus)] in Florida, we found the almost paradoxical result that SP benefits from tropical cyclones through habitat creation and maintenance. [Citation: Convertino et al 2011]

7. The plots indicate that SP [Snowy Plover (Charadrius a. nivosus)] nesting sites [in Florida] are more common during the spring following a tropical cyclone affecting the region (red points). [Citation: Convertino et al 2011]

8. In addition, there may be positive effects of climate change on this species; Snowy Plovers [Charadrius alexandrines] seem to prefer nesting in locations that recently experienced a hurricane (likely because hurricanes can create favorable Snowy Plover breeding habitat; Convertino et al., 2011). However, a shift in the timing of hurricanes toward the breeding season can also result in reduced survival and fecundity and increased variance of these rates. [Citation: Aiello-Lammens et al 2011]

9. With 2 m SLR [sea level rise], the risk of extinction [of the Florida Snowy Plover (Charadrius alexandrines)] was 3.7% (0.037) more than the baseline risk of about 7%, risk of decline to 20 birds 7.6% (0.076) more, and EMA [expected minimum abundance] was 27.3 individuals less than without any SLR (Table 2), under the Medium values of all parameters. With 1 m SLR, the impacts were less: 1.9% increase in extinction risk, 6.3% increase in risk of decline, and 20.1 individuals decrease in EMA. [Citation: Aiello-Lammens et al 2011]

10. The simulation results show that SLR [sea level rise] will likely cause a decrease in the viability of the Florida Snowy Plover [Charadrius alexandrines] populations (Fig. 4). [Citation: Aiello-Lammens et al 2011]

11. The SLR [sea level rise] model (SLAMM)[Sea Level Affecting Marches Model] predicted future changes in the composition of land-cover types in the coastal habitats within the range of the Snowy Plover [Charadrius alexandrines], resulting in an overall decrease in 'dry' land-cover classes and an increase in the 'open ocean' class (Figure S1; for a subset of map layers, see Supporting Information Figure S2). [Citation: Aiello-Lammens et al 2011]

Category: Fish (7) Highlights

1. The top ten [invasive freshwater aquarium] species in the United States were expected to occur in Florida and Hawaii, based on current environmental conditions, while all the riskiest ones for 2050 were forecasted to have the highest probability of establishment in Florida (Table 2). For some of these species, propagule pressure was particularly high (e.g. the White Cloud Mountain minnow, Tanichthys albonubes), thus representing an important determinant of establishment risk, while for species imported at more moderate levels, traits such as size had a stronger influence on their likelihood of establishment (e.g. the

porthole shovelnose catfish, Hemisorubim platyrhynchos). Another example of traits importance is the Manuel's Piranha (Serrasalmus manueli), characterized by a relatively big size and whose high maximum temperature tolerance could make it more resistant to Florida summer peak temperatures, potentially allowing the species to establish despite the low number of propagules imported. [Citation: Venezia et al 2018]

2. Overall, the PET [propagule pressure proxies, environment and species traits] model estimated an increased risk of [freshwater fish] invasion from the aquarium pathway by the year 2050. In the United States, specifically, the states that were predicted to have the highest absolute establishment risk are Hawaii, Florida and Nevada under current climate conditions, while the riskiest ones under a climate change forecast for 2050 are Florida, Hawaii and Louisiana (Figure 2). The first two are indeed the states where the highest numbers of invasions in our dataset have occurred. However, the estimated risk increase in some regions, mainly Louisiana and Florida, was largely driven by more intense precipitations of the wettest month. [Citation: Venezia et al 2018]

3. On a regional basis, by 2100, the REF scenario [reference, or greenhouse gas concentrations of 1,759 ppm] projects that coldwater fisheries are limited almost exclusively to the mountainous areas of the West and have disappeared from Appalachia, while substantial portions of Texas, Oklahoma, Kansas, Arizona, and Florida are converted from warmwater to rough [or low recreational priority] species. While it is theoretically possible for guild shifts to “skip” a guild (e.g., shift from cold to rough), in all cases of our model output, shifts between habitat guilds passed from cold to warm and then to rough. The habitat shift from coldwater to warmwater fisheries is projected to be much less prevalent under the two GHG [greenhouse gas] mitigation scenarios. By 2100, coldwater fisheries are projected to remain in Appalachia under both mitigation scenarios, although reduced by roughly 50 % compared to current conditions. Coldwater fisheries are also projected to remain in the vast majority of the West with the exception of the desert Southwest. Lastly, we see almost no shifts from warm to rough fisheries in either mitigation scenario, except for small pockets in Texas under POL4.5 [which is a mitigation scenario using greenhouse gas concentrations of 500 ppm]. [Citation: Lane et al 2014]

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5. Stocks [of striped bass, Morone saxatilis] along the Gulf of Mexico and Florida east coast may be reduced or extirpated. Summer water temperatures there could be much in excess of those that the fish can tolerate, except where cool river waters are maintained by summer hypolimnetic discharges from

reservoirs or artesian water from large springs—which seem to be major factors in survival now (Wooley and Crateau 1983; Coutant 1985). [Citation: Coutant, 1990]

6. At present, coldwater fish in seasonally stratified lakes find habitat as far south as Nevada, Utah, Colorado, Kansas, Iowa, Ohio, and Pennsylvania (Figure 6). Climate warming will change that, except for a small fringe along the Canadian border and the west coast, where the good-growth period for coldwater fishes will shorten from about 150 d to 100 d (Figure 6). Coolwater fish currently find habitat in seasonally stratified lakes everywhere in the country (Figure 7). Climate warming will introduce summerkill of coolwater species in the southeastern states (Florida, Texas, Louisiana, Mississippi, Alabama, Georgia, North Carolina, and South Carolina). The good-growth period will be lengthened by up to 50 d in the northern and middle latitudes of the contiguous United States (Figure 7). [Citation: Stefan et al 2001]

7. For 172 locations with cool-water fish habitat remaining under a projected 2 × CO2 climate scenario, good-growth periods [GSL] range from 111 to 365 days with a mean value of 179 days (Fig. 5 middle and Table 3b). Good-growth periods are projected to increase by up to 127 days in the northern states and to decrease by up to 72 days in several southeastern states (e.g. Tennessee, Kentucky, and Florida, USA) for this medium-depth lake. Projected changes of GSL due to climate warming range from a 60% increase to a 35% decrease from the past values with an average 20% increase. [Citation: Fang et al 2004]

Category: General Impacts (6) Highlights

1. Coastal areas [of the Southern US] also have a mixture of vegetation types, such as fire-maintained wet pine savannas and flatwoods, seeps and pocosins, marshes, swamps, and bottomlands—that are home to diversity of species and are at risk from changing fire regimes and other indirect effects of climate change (chapter 3 [McNulty et al., 2013). One area of at-risk plant diversity is the Cape Fear Arch region of North and South Carolina: LeBlond (2001) lists 22 endemic and another 22 near-endemic plant species such as coastal goldenrod (Solidago villosicarpa) in coastal edge forests and roughleaf loosetrife (Lysimachia asperulifolia) in the ecotone between upland pine forest and pocosin (Sorrie and others 2006) in this region. Along the Eastern Atlantic and Florida coastlines that coincide with portions of the Atlantic Flyway, extensive development will likely eliminate important stopover habitat for spring and fall migrating birds as well as habitat for resident species. This coastline is also an important nesting area for sea turtles such as the leatherback [Dermochelys coriacea] and Kemp's Ridley (Lepidochelys kempii). This forecast will impact the habitat for 25 species of conservation concern including the red wolf [Canis lupus rufus], round-tailed muskrat [Neofiber alleni], and short-tailed snake (Lampropeltis extenuata). [Citation: Griep et al 2013]

2. In the context of environmental change (e.g., climate or land use), species with life history traits that make them more sensitive or less adaptable to change are more vulnerable to extinction. The ecological trait data considered in our study [of vulnerability assessments using the SIVVA (Sector Integrity Vulnerability Assessment) framework for 12 endangered subspecies and their closely related non-endangered subspecies in Florida] helps explain differences in extinction risk, where endangered subspecies showed larger home range sizes and greater dispersal limitation compared to non-endangered subspecies. [Citation: Benscoter et al 2013]

3. In addition to high vulnerability, endangered subspecies exhibited lower adaptive capacity and higher conservation value compared to non-endangered subspecies [in our study of vulnerability assessments

using the SIVVA (Sector Integrity Vulnerability Assessment) framework for 12 endangered subspecies and their closely related non-endangered subspecies in Florida]. Subspecies with significantly lower adaptive capacity were located in the Florida Keys (Odocoileus virginianus clavium [key deer], [Neotoma floridana smalli, Key Largo wood rat], Peromyscus gossypinus allapaticola [Florida salt marsh vole]), coastal areas ([Peromyscus polionotus phasma, Anastasia Island beach mouse], [Peromyscus polionotus niveiventris, Southeastern beach mouse]), and central Florida ([Ammodramus savannarum floridanus, Florida grasshopper sparrow]). These taxa not only have greater vulnerability (exposure+sensitivity), but also a compromised ability to adapt to environmental change (adaptive capacity). [Citation: Benscoter et al 2013]

4. The high threat of habitat inundation from sea level rise for endangered subspecies [shown in our study of vulnerability assessments using the SIVVA (Sector Integrity Vulnerability Assessment) framework for 12 endangered subspecies and their closely related non-endangered subspecies in Florida] is of primary concern because approximately 10% of Florida's land area lies less than 1 m above current sea level. The mean percentage of habitat loss under a 1 m sea level rise scenario was 52% for endangered subspecies, compared to 11% for non-endangered subspecies. Additionally, all but one endangered subspecies showed high vulnerability to habitat fragmentation ([Peromyscus polionotus niveiventris, Southeastern beach mouse] showed moderate vulnerability). Florida also has high rates of human population growth [Mackun & Wilson 2011] and land use conversion [Walker & Solecki 1997]. Sea level rise vulnerability coupled with landscape fragmentation may limit habitat availability and inhibit dispersal into new areas, and highlights the challenge of managing human land use activities in conjunction with biodiversity conservation [Brussaard et al.. 2010, Noss & Murphy 1995, Tscharntke et al. 2012]. [Citation: Benscoter et al 2013]

5. Endangered subspecies exhibited lower overall adaptive capacity as a group (higher SIVVA adaptive capacity scores) compared to non-endangered subspecies (x2 = 36.436, df =1, p,0.001; Figure 1) [in our study of vulnerability assessments using the SIVVA (Sector Integrity Vulnerability Assessment) framework for 12 endangered subspecies and their closely related non-endangered subspecies in Florida]. [Citation: Benscoter et al 2013]

6. Endangered subspecies as a group had higher SIVVA vulnerability than non-endangered subspecies (x2= 44.931, df =1, p,0.001; Figure 1), and pairwise differences within each taxon-pair indicated that all endangered subspecies had significantly higher vulnerability compared to their closely related nonendangered subspecies (p,0.05) [in our study of vulnerability assessments using the SIVVA (Sector Integrity Vulnerability Assessment) framework for 12 endangered subspecies and their closely related non-endangered subspecies in Florida]. [Citation: Benscoter et al 2013]

Category: Interactions With Other Factors (1) Highlight

1. The negative association between geographic distance to the coast and overall vulnerability has implications for conservation, because endangered taxa situated closer to the coast also showed greater habitat inundation under 1 m of sea level rise and greater vulnerability to habitat fragmentation [as shown in our study of vulnerability assessments using the SIVVA (Sector Integrity Vulnerability Assessment) framework for 12 endangered subspecies and their closely related non-endangered subspecies in Florida]. High population growth [Mackun & Wilson 2011] and coastal development in this region [Finkl & Charlier 2003] will affect conservation success for coastal and near-coastal taxa. Our

results are consistent with recent studies highlighting the vulnerability of Florida's coastal species to sea level rise [Maschinski et al. 2011, Saha et al. 2011, Schmidt et al. 2012]. Additionally, the negative correlation between dispersal distance and vulnerability to changes in precipitation may limit the ability of some taxa to track changing climate (e.g., P. c. coryi, O. v. clavium, R. s. plumbeus) if they need to disperse to find more suitable environments. [Citation: Benscoter et al 2013]

Category: Invertebrates (1) Highlight

1. Melanoplus sanguinipes, the lesser migratory grasshopper, is found over all of the United States (except for Florida and western California) and into southern Canada (Capinera and Sechrist 1982), and because it can be an outbreak species on agricultural crops, it has been monitored well in some areas. Olfert and Weiss (2006) used records from Saskatchewan from 1931 to the present to model its possible response to climate warming. The most favorable habitats for the grasshopper were mixed grassland and moist mixed grassland. Under conditions of a 2 °C temperature increase, the species became a possible outbreak pest in 17.3% of Canada. With a 4 °C increase, the species colonized new habitats such as the Boreal Plains and Boreal Shield, and Canada's susceptibility to outbreaks increased to 28.2%. With a 6 °C increase, the species would be able to live in most of Canada. In all scenarios, M. sanguinipes had the potential to become a major pest in cereal crops. [Citation: Brantley et al 2012]

Category: Mammals (6) Highlights

1. We predicted the future distribution of eastern woodrats [Neotoma floridana] under the best-case scenario (CSIROMK3.5 A1B) and the worst-case scenario (MIROC3.2 A1B) [climate change scenarios with A1B representing low population/high economic growth and high-energy use, and B2 representing moderate growth and low-energy use] for precipitation from 2000 and 2060 (McNulty et al. in press). Based on model projections for the best-case scenario, average annual precipitation across the current Texas range of the eastern woodrat would decrease from 107.0 to 101.4 cm/year, an annual reduction of 5.6 cm of precipitation per year. Only two counties (Kerr and Gillespie) would fall below the minimum precipitation of 72.0 cm/year for potential retention of eastern woodrats under the best-case scenario. Under the worst-case scenario, average precipitation across the current Texas range of the eastern woodrat would average 76.6 cm/year, a decrease of 30.4 cm (28%). By 2060, the range would retreat eastward approximately 160 km (Figure 11.1). [Citation: Greenberg et al 2013]

2. The Cross Timbers form the western boundary of the range of at least eight species of southeastern small mammals that rely on forests, including the golden mouse (Ochrotomys nuttalli), woodland vole (Microtus pinetorum), southern flying squirrel (Glaucomys volans), eastern chipmunk (Tamias striatus), cotton mouse (Peromyscus gossypinus), eastern gray squirrel (Sciurus carolinensis), southern short-tailed shrew (Blarina carolinensis), and eastern woodrat (Neotoma floridana). Increases in temperatures, coupled with reductions in precipitation could result in reductions in forest cover and increases in shrublands in the western reaches of these species' ranges, resulting in reductions of forest-associated small mammals in Oklahoma and Texas. [Citation: Greenberg et al 2013]

3. Two broad strategies should be considered for the LKMR [the endangered Lower Keys marsh rabbit, Sylvilagus palustris hefneri, of the Florida Keys] and other coastal wildlife facing SLR. First, management actions should focus on decreasing coastal squeeze by facilitating inland habitat migration. In areas with significant human development, this will likely involve potentially costly, but highly effective choices, such

as purchasing private property and restoring degraded areas to promote ecosystem connectivity. Second, management actions should aim to improve the general health of coastal ecosystems by reducing other negative anthropogenic impacts. For the LKMR and other endemic species in the Florida Keys these actions may include invasive species control and increased prescribed fires. Some actions may be politically challenging, but strong human intervention is needed to ameliorate the ongoing and future impacts of rising seas. [Citation: Schmidt et al 2012]

4. Subspecies with the highest proportion of habitat inundation from sea level rise were located in the Florida Keys (Oryzomys palustris natator [silver rice rat], Odocoileus virginianus clavium [key deer], Sylvilagus palustris hefneri [lower keys marsh rabbit], Peromyscus gossypinus allapaticola [Florida salt marsh vole], [Neotoma floridana smalli, Key Largo wood rat]) or in coastal areas ([Peromyscus polionotus phasma, Anastasia Island beach mouse], [Peromyscus polionotus niveiventris, Southeastern beach mouse]) [in our study of vulnerability assessments using the SIVVA (Sector Integrity Vulnerability Assessment) framework for 12 endangered subspecies and their closely related non-endangered subspecies in Florida]. Subspecies in the Florida Keys facing habitat inundation are particularly vulnerable to dispersal limitations imposed by both the island archipelago and human development. [Citation: Benscoter et al 2013]

5. The LKMR [the endangered Lower Keys marsh rabbit, Sylvilagus palustris hefneri, of the Florida Keys] is in a precarious position given the planet's changing climate; their use of lowing-lying marshes on islands with human development make them highly susceptible to negative impacts from rising seas. Examining the loss of LKMR habitat over the last half century [from 1959-2006], it is clear that SLR [sea-level rise] was the largest driver of habitat loss. The direct loss of habitat from development appears marginal compared to 48% loss of LKMR habitat directly due to SLR. [Citation: Schmidt et al 2012]

6. Over the 47-year period from 1959 to 2006, 1266 ha of LKMR [the endangered Lower Keys marsh rabbit, Sylvilagus palustris hefneri, of the Florida Keys] habitat were lost, whereas 416 ha of LKMR habitat were created (Table 1). This amounted to a net loss of 64% of LKMR habitat. Considering all LKMR habitat in 1959 (1603 ha), the loss of habitat had three sources: 765 ha (48%) by SLR [sea-level rise], 123 ha (8%) by development, and 378 ha (24%) by other factors (Fig. 3a, b, c). [Citation: Schmidt et al 2012]

Category: Reptiles (4) Highlights

1. Thus, the loggerhead sea turtle [Caretta caretta] population [at Cape Romain, South Carolina] would be adversely affected if Raccoon Key and Cape, Lighthouse, and Bull islands are destroyed, reduced in size, or subject to tidal inundation. The impact of the loss of these particular islands on the loggerhead sea turtle population will be aggravated by the fact that they contain the largest undisturbed loggerhead nesting ground located outside of Florida in the United States (Cape Romain National Wildlife Refuge 1987). [Citation: Daniels et al 1993]

2. However, given that Florida could likely experience warming (IPCC, 2001) and is not buffered by oceanic features as in North Carolina (Boyles & Raman, 2003), there is a real possibility of further skewing or even complete feminization of the primary sex ratios [of loggerhead sea turtles (Caretta caretta)] in Florida, which holds the vast majority of nesting in the United States (Shoop & Kenney, 1992). [Citation: Hawkes et al 2007]

3. With the maximum 7.5 °C of predicted warming in AT [air temperature], more than 40% of clutches [of loggerhead sea turtles (Caretta caretta)] at our study site and 100% of clutches at Cape Canaveral, will incubate at temperatures above the lethal limit, suggesting that nest incubation would no longer be viable at some Florida beaches during the current seasonal window of nesting. [Citation: Hawkes et al 2007]

4. With the predicted rise in future AT [air temperature], nests will begin to incubate at sand temperatures above the pivotal temperature (29.2 °C; Mrosovsky, 1988) for loggerheads [Caretta caretta], producing more female offspring. Simple heuristic simulation of likely hatchling sex ratios under these conditions (Fig. 5a and b) show that over 80% female hatchling production is predicted to occur in this part of North Carolina with 2 °C increase in AT. Further south, at Cape Canaveral, Florida, total feminization would occur with 2 °C of warming in AT and after 3 °C clutches would begin to incubate at temperatures above the lethal limit (35 °C; Ackerman, 1997). However, such clutch death is not likely to begin until 5 °C of warming in AT has occurred in North Carolina. [Citation: Hawkes et al 2007]

Factor: Climate Trends (5)

Climate is generally defined as the average weather, but more specifically refers to the statistical description of qualities of the climatic system over a period of time. Qualities include long-term temperature and precipitation patterns. Effects of a changing climate lead to global effects such as sea level rise and the changing of global scale circulation. In addition to acting on current stressors, the changing climate will itself act as a unique factor challenging historical planning and management assumptions.

Category: General Impacts (3) Highlights

1. Using an extensive dataset (1897–2017) in the Coastal Plain of the southeastern United States, we examined changes in annual dry season length, total precipitation, and (since 1945) the seasonal distribution of thunder-days as a correlate of lightning activity. We focused on nine states in the southeastern United States known to have lightning-ignited fire seasons: North and South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, and eastern Texas. We found that across the entire region, the dry season has lengthened by as much as 156 days (130% over 120 years), both starting earlier and ending later with less total precipitation. Longer dry seasons likely have greater overlap with seasonal periods of thunderstorm (lightning) activity, which has remained essentially unchanged over the last 70 years. The southeastern United States, especially Florida and the Gulf Coastal Plain, experiences some of the highest lightning flash densities in the world (≥12 flashes/square km/year; Noss, 2018). If we extrapolate our data using slopes derived from the past 120 years, trends suggest that by 2050, the dry season could be up to 42 days longer than it is now, and exponentially drier. [Citation: Fill et al 2019]

2. Key features of note [for Cornerstone B in the Southern US, the Cornerstone Futures being a portfolio of scenarios using climate models and projections of anthropogenic futures, with Cornerstone B projecting low population growth and high energy-use/economic-growth,] are the improved flow of moisture from the Gulf of Mexico northward across the Appalachians and dry conditions across Florida during winter. The area of moist conditions shifts northward during spring as dry conditions expand across the Coastal Plain. Summer brings dry conditions to much of the South, with the exception of the Coastal Plain where precipitation from afternoon thunderstorms balances the dry conditions. During fall, dry conditions return to the Coastal Plain. [Citation: Stanturf et al 2013]

3. For current conditions under Cornerstone A [the Cornerstone Futures being a portfolio of scenarios using climate models and projections of anthropogenic futures, with Cornerstone A projecting low population growth and high energy-use/economic-growth], winter is the primary rainy season [in the Southern US], although the areal extent of this wet area is restricted to the Appalachians as reflected by the PDI [potential drought index] (fig. 17.8). During the summer, Cornerstone A is dominated by pronounced drying and fails to capture the summer rains in Florida and along the Coastal Plain. Over the course of 50 years, this drying is further reinforced and virtually eliminates all areas of negative PDI values (fig. 17.9). [Citation: Stanturf et al 2013]

Category: Interactions With Other Factors (2) Highlights

1. Although similar concerns for the well-being of the gopher tortoise under changing climatic conditions have not been expressed, we suggest that it may be at least as poorly equipped to deal with changes in rainfall as the desert tortoise. West-central Florida already may have generally reduced summer rainfall as a consequence of land use changes (Marshall et al. 2004), and rainfall in the region is predicted to decline substantially over the next 50 years, especially during the potentially crucial winter–spring cooler dry season (The Nature Conservancy 2009). The lack of what appear to be desert adaptations (but see Bradshaw 1997; Morafka and Berry 2002) in the gopher tortoise naturally leads to the assumption that water imitation has not been a particular problem, which, in turn, leads to complacency about the possibility of future water limitation. The virtually complete lack of data on water balance under natural drought conditions is problematic, however. [Citation: McCoy et al 2011]

2. Comparison of the resource accumulation patterns exhibited by related species inhabiting disparate hydrological conditions can provide insight into how they are affected by and respond to different environments. We compared the seasonal body condition of the desert tortoise (Gopherus agassizii) in the Mojave Desert with that of the gopher tortoise (Gopherus polyphemus) in central Florida. We assessed body condition indirectly, with indices derived from the relationship between body mass and size. In turtles, variation in body mass largely reflects tissue hydration, water stored in the bladder, and food stored in the gut. Mean body condition was lower and seasonal fluctuations were of lesser amplitude in the gopher tortoise than in the desert tortoise. Over the short term, body condition of the desert tortoise is correlated strongly with rainfall, but body condition of the gopher tortoise is not. These differences between the two species are consistent with what is known about their physiology and behavior under current climatic conditions. Changing rainfall patterns may severely affect the desert tortoise. The physiological reaction of the gopher tortoise to drought conditions also may put it at substantial potential risk from climate change. [Citation: McCoy et al 2011]

Factor: Coastal Ecosystems (76)

Coastal ecosystems encompasses estuaries, coastal forests, and wetlands, as well as natural beach communities. Sea level rise will drive change in the future, both through direct inundation and increasing salinity in estuaries and aquifers. Coastal wetlands and forests will also change with increasing temperatures and changing precipitation regimes, and mangrove communities may expand. Management options focus on regional planning for inland migration of coastal systems as well as wetland restoration efforts.

Category: Coastal Forests (21) Highlights

1. Due to its low elevation and a higher-than-global-average local rate of sea-level rise, the region (Florida's Big Bend) is losing coastal forest to encroaching marsh at an unprecedented rate…We replicated and updated (previous) studies with Landsat satellite imagery covering the entire Big Bend region from 2003 to 2016 and corroborated results with in situ landscape photography and high-resolution aerial imagery. Our analysis of satellite and aerial images from 2003 to 2016 indicates a rate of approximately 10 km2 year− 1 [of forest loss] representing an increase of over 800%. Areas previously found to be unaffected by the decline are now in rapid retreat…We expect similar change to occur throughout Florida's more populated coastal regions where shoreline protections and beach nourishment projects may be delaying the impacts of rising seas (Estevesf and Finkl 1998; Raabe and Stumpf 2016). [Citation: Mccarthy et al 2021]

2. Between 1992 and 2014, tidal flooding of forest islands [on the Big Bend coast of Florida, U.S.A.] increased by 22%–117%, corresponding with declines in tree species richness, regeneration, and survival of the dominant tree species, Sabal palmetto (cabbage palm) and Juniperus virginiana (southern red cedar). Rates of S. palmetto and J. virginiana mortality increased nonlinearly over time on the six most frequently flooded islands, while salt marsh herbs and shrubs replaced forest understory vegetation along a tidal flooding gradient. [Citation: Langston et al 2017]

3. Not only is sea level rise driving long-term deterioration of coastal freshwater forest, but it is also driving community reassembly in relict [non-regenerating] islands. Loss of forest species [coastal forests are usually dominated by Sabal palmetto (cabbage palm) and Juniperus virginiana (southern red cedar),] creates available space in the landscape, providing opportunities for other communities (e.g., shrubby high marsh and herbaceous low marsh) to colonize islands that historically supported freshwater forest. We observed [on the Big Bend coast of Florida, U.S.A.,] complete turnover in species composition on relict forest islands in response to changing environmental conditions over the course of 20 years (Figure 7). As trees died with increased tidal flooding, they were replaced by salt marsh shrubs, which in turn were replaced by herbaceous salt marsh vegetation at higher tidal flooding frequencies. [Citation: Langston et al 2017]

4. At two of our three study sites [of the coastal Everglades, Florida], we measured significant increases in mangrove area and concomitant decreases in marsh area [from 1928-2004]. This is what we would predict given increases in sea level in South Florida. As sea level increases at upstream locations, salinity also increases. Mangroves are salinity tolerant, whereas the freshwater marsh plants are not. [Citation: Smith III et al 2013]

5. There was no relationship between number of fires and ecotone movement [from 1928-2004] at the 2nd Onion Bay study site [of the coastal Everglades, Florida] ($t = 1.532, P < 0.158$). A highly significant relationship was found at SH5 ($t = 4.312, P < 0.005$). Areas with the most fires had shifted the greatest distance along the SH5 mangrove–marsh ecotone (Figure 8). [Citation: Smith III et al 2013]

6. There was no relationship between rates of mangrove area change [from 1928-2004] and sea level at Key West ($t = 0.428, P < 0.67$) [of the coastal Everglades, Florida]. Similarly, there was no significant relation between mangrove change and water level at P35 ($t = 1.881, P < 0.102$). [Citation: Smith III et al 2013]
7. With expected increases in the rate of sea-level rise coupled with increasing drought frequencies due to global climate change, accelerated rates of coastal forests disappearance [in Waccasassa Bay, Florida] are likely and may already be evident. [Citation: Desantis et al 2007]

8. Coastal forests in Waccasassa Bay [Florida] declined during 2000–2005 at rates greater than expected from rates during the previous 8 years likely due to the synergistic effects of a drought event and sea-level rise. [Citation: Desantis et al 2007]

9. Although [in Waccasassa Bay, Florida] [Sabal palmetto, cabbage palmetto] and [Juniperus virginiana, southern red cedar] do suffer salt damage, they may actually benefit from the presence of moderately saline source water if competition with less salt-tolerant species is, therefore, reduced, as suggested for the interactions between mangroves and fast-growing glycophilic plants (Sternberg & Swart, 1987). Above the salinity threshold at which regeneration of J. virginiana ceases, S. palmetto maintains monodominant stands that eventually die off as the salinity continues to increase. J. roemerianus is usually not present within the tree islands, but it surrounds most of them. Increased tidal inundation due to rising sea levels will continue to threaten these tree communities, as reported for tropical hardwood hammocks and pine forest in the Florida Keys (Ish-Shalom et al., 1992; Ross et al., 1994). [Citation: Desantis et al 2007]

10. The chronic effects of sea-level rise on coastal forests in Waccasassa Bay [Florida] were exacerbated by the 1998–2002 La Nina-associated drought. In particular, [Sabal palmetto, cabbage palmetto] suffered greater mortality rates during 2000–2005 than 1995–2000 (paired Student's t-test: $P<0.01$, $n=13$; Fig. 6). Mortality rates of S. palmetto in plots with >=8 weeks of flooding during 2000–2005 were at least two to 15 times the 1995–2000 mortality rates (Fig. 6). [Juniperus virginiana, southern red cedar] also suffered significantly greater (paired Student's t-test: $P<0.05$, $n=6$) mortality during 2000–2005 than during 1995–2000 in all forest plots with >=1 week of flooding (Fig. 6), with mortality rates approximately 0.3–19 times greater than the earlier estimates from 1995 to 2000. [Citation: Citation: Desantis et al 2007]

11. The 2005 census [of tree species in Waccasassa Bay, Florida] documents the disappearance of [Sabal palmetto, cabbage palmetto] >2 m tall from the most frequently flooded plot (D2) and disappearance of [Juniperus virginiana, southern red cedar] from the three plots with the most frequent tidal flooding where it was present in 2000. In other words S. palmetto remained in plots with <=26 weeks of tidal flooding, whereas J. virginiana was only present in plots experiencing <=13 weeks of tidal flooding (Table 1). [Citation: Desantis et al 2007]

12. Coastal forest stands [between 1955-2005 in Waccasassa Bay, Florida] declined in species richness with decreasing elevation ($r2=0.43$, $P<0.05$) and increasing tidal flooding frequency ($r2=0.68$, $P<0.001$; Table 1). [Citation: Desantis et al 2007]

13. Our results [of the effect of sea level rise on the reduction of pine (Pinus spp.) forests] indicate that pine mortality on Sugarloaf Key [Florida] proceeded from the margins of the original forest [pre-1935] toward its center (Fig. 3), and from lower to higher elevations (Fig. 4). They further indicate that these pine forests subsequently succeeded to more halophilic vegetation types, and that the sequence advanced furthest in the areas first affected (Fig. 6). These results together signify a progressive salinization in much of the island's upland habitat during a period when sea level was rising at a fairly constant rate of ≈2.4 cm/decade (Fig. 2). [Citation: Ross et al 1994]

14. The pulses of mortality that occurred at our study site [in Waccasassa Bay on the west coast of Florida] in association with drought and storm caused permanent changes in forest structure primarily because sea-level rise had al-ready reduced or eliminated regeneration in these stands. [Citation: Williams et al 2003]

15. Among the more salt-tolerant tree species of the forest fringe [in Waccasassa Bay on the west coast of Florida], drought-associated mortality occurred only in late stages of decline, where regeneration had ceased decades earlier. [Citation: Williams et al 2003]

16. Both storm and drought were associated with pulses of mortality in coastal stands at our study site [in Waccasassa Bay on the west coast of Florida]. Both selectively removed Juniperus [southern red cedar, Juniperus virginiana var. silicicola] from stands, leaving Sabal [cabbage palm, Sabal palmetto] more dominant. The overall importance of these events in causing forest loss, however, lies in their spatial relationship to effects of sea-level rise. [Citation: Williams et al 2003]

17. Sabal trees [cabbage palm, Sabal palmetto] died over the course of this study [in Waccasassa Bay on the west coast of Florida] at a fairly constant rate (Figure 3), and yearly mortality rates appeared homogeneous (X2 = 5.7, df = 6, n.s.). In contrast, mortality rates of Juniperus [southern red cedar, Juniperus virginiana var. silicicola] were not homogeneous (X2 = 57.9, df = 6, p<0.01). Mortality rates were significantly elevated for two years after the 1993 storm (Figure 3b). Average mortality during the drought (1998-2000) appeared slightly elevated, but was not significantly different from mortality during "normal" years. The insignificance of the increase in overall Juniperus mortality during the drought can be attributed to the fact that Juniperus mortality was not elevated in plots classified as "healthy" or "intermediate" during the drought. It was only elevated in stands in the last stages of decline (Table 1). [Citation: Williams et al 2003]

18. Our previously published studies of coastal forest change in a marshy, tectonically stable region on the west coast of Florida indicated that sea-level rise affected the coastal hard-wood forest initially by eliminating the regeneration of tree species. Relict, non-regenerating stands of more sensitive species were found within healthy regenerating stands of tree species with more tolerant seedlings. [Citation: Williams et al 2003]

19. In terms of the suitability of abiotic conditions in newly-available habitat, we make the assumption that the abiotic conditions that determine the relative abundance of mangrove forests in Florida will be similar in other parts of the southeastern U.S. For most of the region, this assumption is probably appropriate; however, in areas with very low precipitation (e.g., arid parts of southwest Texas) or continuous freshwater flow (e.g., parts of Louisiana), the abundance of mangrove forests relative to unvegetated tidal flats and/or salt marshes will likely be different (Dunton et al. 2001; Montagna et al. 2007). [Citation: Osland et al 2012]

20. Our analyses indicate that salt marshes in the states of Louisiana, Texas, and parts of Florida are especially sensitive to winter climate change due to their proximity to the winter climate threshold that differentiates between mangrove forest and salt marsh dominance. [Citation: Osland et al 2012]

21. Our results indicate that, within the [southeast U.S.] region, salt marshes in Louisiana, Texas, and Florida are most vulnerable to winter climate change-induced mangrove forest range expansion; for example, with a 2 to 4 degree C increase in MAMT [mean annual minimum temperature], 6820 (95% of LA state total), 1970 (100% of TX state total), and 830 (60% of FL state total) km2 of salt marsh could become vulnerable to mangrove forest replacement (Figs. 4 and 5a). Along the Atlantic coast, all of the salt marshes in Georgia (1480 km2; 100% of state total) and many of the salt marshes in South Carolina (890

km2; 63% of state total) could become vulnerable to mangrove forest replacement with a 4 to 6 degree C increase in MAMT relative to the modern climate (Figs. 4 and 5a). [Citation: Osland et al 2012]

Category: Coastal Wetlands (13) Highlights

1. The results also indicate that on average mangrove forests can keep pace with current SLR [sea-level rise] but would have difficulty at higher SLR scenarios projected for 2070. We are aware that a deeper unpacking of storm surges and other forms of extreme climatic events is needed. Yet, there was significant evidence of mangrove migration into the freshwater wetlands upstream. The movement of the mangrove community into the freshwater marsh habitat, facilitated by increased freshwater inflows, tidal surge salt wedge incursion and propagule recruitment (Cahoon et al., 2006; Doyle et al., 2010; Smoak et al., 2013; Raabe and Stumpf, 2016) is a Directed adaptation that shows a great deal of promise. Increased freshwater flows could stave off projected saltwater intrusion and facilitate mangrove inland migration under less salty water conditions (Raabe et al., 2012). Thus, maintaining lower salinities could make the mangrove community more resilient. [Citation: Sklar et al 2021]

2. Drought can have significant effects on CFWs [coastal freshwater wetlands] by reducing freshwater supply and increasing saltwater intrusion (S2 47). Often in conjunction with saline intrusion, drought has resulted in observable negative effects on CFWs, particularly for vegetation structure and productivity (S2 47; 104). Drought and salinity resulted in tree mortality, reduced recruitment, increased leaf litter biomass, and decreased annual net primary productivity in forested wetlands of Louisiana and Florida (S2 47; 104). Drought also resulted in delayed and shortened growth periods for coastal marsh species, suggesting that growth inhibition and dieback could occur over extended periods (S2 61). [Citation: Grieger et al 2020]

3. [O]ur macroclimatic models [for temperature and precipitation regimes] show that transformative changes in tidal saline wetland plant community structure are probable across large portions of the [United States' Northern Gulf of Mexico]...this century. The greatest projected changes in vegetation composition are in Texas, Louisiana, and parts of northern Florida, near the marsh-to-mangrove transition zone (Fig. 5b-d, left). Large portions of these coastal reaches are likely to transition from marsh-to-mangrove dominance by 2100 (Osland et al., 2013). [Citation: Gabler et al 2017]

4. Our analyses [in the United States' Gulf of Mexico] identify strong relationships between plant productivity and SOM [soil organic matter]. SOM was lowest in coastal wetlands that lacked vascular plants and in coastal wetlands that were dominated by succulent salt marsh plants. In contrast, SOM was highest in wetlands dominated by productive graminoid salt marsh and mangrove plants...These results suggest that in wetter portions of the northern Gulf of Mexico (e.g., Louisiana and Florida), the belowground implications of mangrove expansion into the existing graminoid-dominated salt marshes may not be as high as in drier estuaries (e.g., south Texas) where mangrove expansion may occur at the expense of salt marshes dominated by succulent plants (Yando et al., 2016, 2018). [Citation: Osland et al 2018]

5. [The research sites are in the U.S. and include Alligator River National Wildlife Refuge in North Carolina (site AR), a loblolly pine plantation in North Carolina (site LP), a wetland in Florida (site FL-WET), an upland in Florida (site FL-UP), and a wetland in South Carolina (site SC)(Fig. 1)]…At the 15-day…scale, the future

water table would decline at all sites under the RCPs 4.5 [representative concentration pathways] scenario and especially the RCPs 8.5 scenario [Table5,] (Fig. 6). [Citation: Zhu et al 2017]

6. [The research sites are in the U.S. and include Alligator River National Wildlife Refuge in North Carolina (site AR), a loblolly pine plantation in North Carolina (site LP), a wetland in Florida (site FL-WET), an upland in Florida (site FL-UP), and a wetland in South Carolina (site SC).](Fig. 1)…[Our] modeling analysis suggests that future climate change may considerably affect water table level. The annual average water table exhibits a decreasing trend in all five wetlands predicted by 20 GCMs [general circulation models] under both the RCPs [Representative Concentration Pathways] 8.5 and RCPs 4.5 scenarios [Table 4,] (Fig. 5). [Citation: Zhu et al 2017]

7. We quantified and compared the area available for landward migration of tidal saline wetlands and the area where urban development is expected to prevent migration for 39 estuaries along the wetland-rich USA Gulf of Mexico coast. We did so under three sea level rise scenarios (0.5, 1.0, and 1.5 m by 2100)...Within the region, the potential for wetland migration [was] highest within certain estuaries in Louisiana and southern Florida (e.g. Atchafalaya/Vermilion Bays, Mermentau River, Barataria Bay, and the North and South Ten Thousand Islands estuaries)…These are estuaries where ecological impacts and transformations due to sea level rise are expected to be very large. The Charlotte Harbor, Tampa Bay, and Crystal-Pithlachascotee estuaries (Florida) have the highest amounts of urban land expected to constrain wetland migration. Urban barriers to migration are also high in the Galveston Bay (Texas) and Atchafalaya/Vermilion Bays (Louisiana) estuaries. [Galveston Bay, Atchafalaya/Vermilion Bays, Louisiana and, the West Mississippi Sound, Louisiana/Mississippi] are estuaries that have both a large amount of land available for wetland migration and a large amount of land where urban barriers are expected to prevent migration. [Charlotte Harbor, Tampa Bay and Crystal-Pithlachascotee, Florida are all] highly urbanized (Terando et al., 2014), and have very little land available for landward migration. [U]nder higher rates of sea level rise where existing wetlands are not able to keep pace with sea level rise via vertical adjustments, the potential for coastal wetland loss (i.e. coastal squeeze) in these estuaries is very high. [Citation: Borchert et al 2018]

8. Coastal red mangrove communities might shift further to the north on the Florida and Texas Gulf Coast. Along the Louisiana coast, reduced frost frequency would allow expansion of black mangrove forests. [Citation: Twilley et al 2001]

9. Wetlands at St. Marks National Wildlife Refuge [in northwest Florida] flooded by storm surge overwash from Hurricane Dennis showed substantial changes in water chemistry from the pre-storm condition. Overwashed wetlands experienced a dramatic initial increase in chloride concentrations which decreased markedly over time after the storm, but none of the wetlands returned to their pre-storm chloride levels during the study period [in a study of the effect of storm surge overwash on wetland amphibian communities], even the three sampled 33 months post-storm in April 2008 (Fig. 2). [Citation: Gunzburger et al 2010]

10. Specific conductance was low and fairly constant across wetlands prior to the storm surge (generally<100 µS/cm) [in a study in northwestern Florida on the effect of storm surge overwash on wetland amphibian communities], but increased post-storm at the overwashed wetlands and remained much higher for the following 12 months (Fig. 4). Specific conductance values in overwashed wetlands immediately post-storm ranged from 932 to 15,900 µS/cm with a mean value of 7,613 µS/cm, well above the range

considered to be brackish (1,600–4,800 µS/cm). Specific conductance was significantly higher in overwashed than in non-overwashed wetlands post-storm (ANOVA, F = 21.9, P\0.001, df = 1) [Citation: Gunzburger et al 2010]

11. Ponds receiving overwash directly from the hurricane storm surge showed an increase in major-ion concentrations [in a study in northwestern Florida on the effect of storm surge overwash on wetland amphibian communities] of two to three orders of magnitude, including calcium, magnesium, sodium, potassium, chloride, and sulfate (e. g. Biggins Pond, Fig. 3a). Otter Lake (Fig. 3b) showed a much smaller increase in major ions, and the increase was not observed until almost a year following the hurricane. Many ponds showed no increase in major ions after the storm (Fig. 3c). [Citation: Gunzburger et al 2010]

12. Hurricane winds may also alter vegetation structure within freshwater wetlands which influences species composition and abundance of fishes and invertebrates (Roman et al. 1994). In some cases species in the same habitat may be affected differently by hurricanes, with population size of some species declining after a storm and others remaining the same or increasing (Loope et al. 1994; Schriever et al. 2009; Vilella and Fogarty 2005). Many ecosystems adjacent to coastal areas prone to hurricanes appear resilient to the effects of wind, rain, and flooding (Roman et al. 1994). [Citation: Gunzburger et al 2010]

13. Tropical species are living at the edge of their upper physiological limits of salinity (Walker 1985; Walker et al. 1988) and temperature (Zieman 1975; Koch et al. 2007), so further increases in salinity as a result of climate change and freshwater extraction may have significant consequences for tropical seagrasses particularly in estuaries with restricted circulation and high rates of evaporation such as Shark Bay, Baffin Bay and Florida Bay in the USA (Koch et al. 2007). [Citation: Erwin,2009]

Category: General Impacts (10) Highlights

1. After 2060, all 18 modeled climate realizations [general circulation models for the Coupled Model Intercompaison Project Phase 5 (CMIP5)] project consistently suitable conditions for mangroves. This expansion of mangroves across the current ecotone [in northeast Florida, USA] will likely be accompanied by a northward migration of the range limit of mangroves. [Citation: Cavanaugh et al 2019]

2. If these projected trends [of daily minimum temperature from 1850 to 2100 simulated by 18 general circulation models for the Coupled Model Intercomparison Project Phase 5 (CMIP5)] are realized, we expect mangroves within the current ecotone [in northeast Florida, USA] to be largely freed from freeze damage, enabling them to more permanently displace salt marsh vegetation…The multimodel mean projection suggests that mangrove suitability will increase through the end of the century as the probability of freeze event strong enough to induce widespread mangrove mortality steadily declines. [Citation: Cavanaugh et al 2019]

3. Urban development and the effects of sea level rise threaten wildlife habitat and plant species in the Atlantic and Gulf Coastal Plain and Peninsular Florida. The projected inundation and loss of mangrove and coastal live oak [Quercus virginiana] forests would reduce nesting habitat for several birds, snakes, and reptiles. Forecasted development along the coastline portion of the Atlantic Flyway will likely eliminate important stopover habitat, as well as nesting areas for several imperiled sea turtles. Inland, the diversity of flora in fire-maintained Coastal Plain ecosystems is threatened by urban development and changing fire regimes. [Citation: Griep et al 2013]

4. These looming difficulties [for management of pine-rockland communities in the Florida Keys] can be made more tractable if strategic planning and adaptive management can effectively encompass, in a hierarchical manner, both the broad NWR [national wildlife refuge] system and individual, isolated refuges. Indeed, FWS's [US Fish and Wildlife Service] mandate to manage for biological integrity, diversity, and ecosystem health (FWS 2000) requires them to implement collaborative landscape-level planning as local habitat succession makes moving targets of coastal plant and animal assemblages. With its long history of actively managing a network of wintering, breeding, and staging sites for migratory birds, FWS is well positioned to carry out such system-wide management (Scott et al. 2008). [Citation: Ross et al 2009]

5. Management [in the Florida Keys] should also include the translocation to core areas of rare pine-rockland species surviving in marginal conditions elsewhere on the same or adjacent islands. This form of assisted migration (McLachlan et al. 2007) is an "inter-situ" conservation strategy, according to the terminology of Burney and Pigott Burney (2007). [Citation: Ross et al 2009]

6. Core-area management [in the Florida Keys] should include mitigation of hydrologic barriers that could compromise its effectiveness. Such activities might include (a) culverting of roads that impound tidal waters, causing salts to concentrate following flooding events, or (b) blocking or filling of canals and ditches that transport saltwater into freshwater ecosystems. In exceptional cases, establishment of physical defenses, such as levees, could provide some short-term (eg years to several decades) protection from storm surges. [Citation: Ross et al 2009]

7. Current pine-rockland sites [in the Florida Keys] with the best prospects for persistence can be identified on the basis of surface topography, hydrogeology, forest and landscape structure, and adjacent land use. The SeaChange model (Figure 3) was a simple initial attempt to identify such core sites. More sophisticated models should be developed to identify core areas of at least 25 ha on individual lower Keys islands. [Citation: Ross et al 2009]

8. The physical effects of sea-level rise on terrestrial environments of the Florida Keys are likely to include changes in the position of the water table, the salinity at its surface, and the salinity of the soil solution. Our vegetation analyses [of 16 plant communities on Sugarloaf and Big Pine Keys, Florida] (Fig. 5) indicate that these three factors are very closely correlated with plant community composition and structure, and that they vary together over the landscape as a whole. Their spatial covariation is indicative of strong functional interdependence. [Citation: Ross et al 1994]

9. With the arrival of an active hurricane period due to decadal-scale variability (Goldenberg et al. 2001), the interaction between sea-level rise and storm surge will soon reach a tipping point with respect to the maintenance of local freshwater ecosystems [in the Florida Keys]. Possible acceleration in sealevel rise (Church and White 2006) and increase in hurricane intensity (Webster et al. 2005) due to global warming could bring this tipping point closer. [Citation: Ross et al 2009]

10. Our data showed that the area of pine [Pinus spp.] forest on Sugarloaf Key [Florida] declined from an initial 88 ha (furthest extent of pine remains) before 1935, to 30 ha by 1991 (Figure 2). The transformation of pine forest to more salt-tolerant vegetation types proceeded continuously, though at variable rates, and from low to high elevation. Live pine trees surviving in peripheral areas experienced diminished plant moisture potential and showed isotopic signs of physiological stress. The upslope recession in the pine

forest border was generally consistent with a progressive salinization and rise in the groundwater associated with sea-level rise. [Citation: Ross et al 2009]

Category: Interactions With Other Factors (4) Highlights

1. In all coastal counties and Gulf-wide, sea-level rise of any rate or cause, relative or eustatic, is expected to cause widespread loss or retreat of coastal forests as dictated by the local environmental setting. The SLOPE model results show that predicted habitat loss (retreat) over the next century without climate change effects will exceed a million hectares varying by location, but substantially greater in the western Gulf where geologic subsidence is rapid. Mangrove forests that dominate tropical shores of south Florida are expected to migrate (expand) upslope with increasing sea level and shift the proportion of forested habitat in coastal areas. Temperature variations toward increasing mean surface temperatures and less frequent freeze episodes may similarly alter the mix of temperate and tropical species diversity and increase the spread and abundance of mangrove species northerly. [Citation: Doyle et al 2010]

2. In the [United States'] northern Gulf of Mexico, the salt marsh–mangrove ecotone is an area where range limits and ecotone dynamics can [both] be studied as recent decreases in winter temperature extremes have allowed for mangrove expansion at the expense of salt marsh…[In our study of two locations, one in Louisiana and the other in Florida]…there was a positive relationship between mangrove tree height and rooting extent. We found that the horizontal expansion of mangrove roots into salt marsh extended up to eight meters beyond the aboveground boundary. [Citation: Yando et al 2018]

3. Long-term maintenance of pine [Pinus spp.] forests [on the Florida Keys] depends on periodic fire, which, provided by needle fall from a full pine canopy. Where core sites currently lack such a canopy, it may be necessary to use prescribed fire to prepare the site, followed by augmentation of natural regeneration with seeded or planted pines. Once pines are established, management should focus on maintaining a high-diversity community that can serve as a seed source for adjacent areas following storm-surge events. [Citation: Ross et al 2009]

4. Sea-level rise has certainly reduced fire frequency over millennia by fragmenting a continuous landmass and inhibiting fire spread from island to island [in the Florida Keys]. Moreover, within islands, the landscape has evolved into a patchwork of flammable uplands embedded within a relatively fire-resistant swamp matrix. Even within the upland patches, minor depressions intersect the shallow water table, raising fuel moisture, reducing fire intensity, and promoting hardwood shrub invasion. [Citation: Ross et al 2009]

Category: Sea Level Rise (28) Highlights

1. Coastal hammocks and buttonwood forests are compositionally different from inland hammocks in the ENP [Everglades National Park], with unique combinations of common and rare species. Importantly, whereas all hammocks in the estuarine/coastal zone rely upon localized freshwater for much of the year, periods of drought force the plants to either use saline water or tolerate some measure of drought. We predict a decline in the extent of coastal hardwood hammocks and buttonwood forests with the initial rise in sea level before the onset of sustained erosional inundation. The change in the extent of hardwood and buttonwood forests will be brought about by decline in freshwater recharge volume in conjunction with an increase in porewater salinity, which will push the hardwood species to the edge of their drought

(freshwater shortage and physiological) tolerance. Along with the coastal hammocks and buttonwood forests, scores of critically imperiled and or endemic species will be jeopardized, and possibly be extirpated from the United States. Reductions in freshwater inflows into the estuarine portion of the Everglades will accelerate the loss of salinity-intolerant coastal plant communities. Restoring freshwater inflow might be the only mechanism to mitigate, in the short term, the effects of rising sea levels in the Everglades. [Citation: Saha et al 2011]

2. Land submergence is most extensive within the mid-Atlantic [U.S.] sea-level rise hotspot that stretches from North Carolina to Massachusetts, where relative sea level is rising three times faster than eustatic [global] rates (Sallenger et al. 2012). For example, 400 [square] km of uplands in the Chesapeake Bay region have converted to tidal marsh since the mid-1800s (Schieder et al. 2018), and large tracts of hardwood and cedar [Cedrus] forest death have been observed in Delaware Bay (Smith 2013). However, ghost forests are not confined to the sea level rise hotspot; they have also been documented throughout the Florida Gulf Coast (Raabe et al. 2016; Langston et al. 2017), the St. Lawrence estuary in Canada (Robichaud and Begin 1997), and tidal freshwater forests in South Carolina, Georgia and Louisiana (Conner et al. 2007; Craft 2012). There has been 148 [square] km of forest conversion over 120 years along the Florida Gulf Coast (Raabe et al. 2016), and near complete loss of pine [Pinus] forests in the Lower Florida Keys (Ross et al. 1994). [Citation: Kirwan et al 2019]

3. The Florida Peninsula, especially around Palm Beach and Miami, is threatened by projected 10 to 25 percent urban growth and also by sea level rise (chapter 13 [Lockaby et al., 2013]). This area is ecologically diverse and unique; Monroe and Miami-Dade counties include part of the Everglades and are a mix of pine forests, hammocks, beach dune and strand, prairies, cypress swamps, mangroves, and freshwater and saltwater marshes. These counties contain seven plant species listed as threatened or endangered (U.S. Department of the Interior 2011); while most of them may be further threatened by urban growth and sea level rise, marine species such as Johnson’s seagrass (Halophila johnsonii) could expand their range (Virnstein and Hall 2009). The habitat of several aquatic and marsh species in the Everglades may be vulnerable to sea level rise. This includes the common yellowthroat (Geothlypis trichas), greater siren (Siren lacertina), northern harrier (Circus cyaneus), squirrel treefrog (Hyla squirella), and American mink (Mustela vison). The Florida Peninsula also includes the inland Lake Wales Ridge. Although this area is projected to have a moderate (3 to 10 percent) increase in urban area and forest loss, its diverse fire-maintained ecosystems may be more threatened by changing fire regimes that could accompany climate change. [Citation: Griep et al 2013]

4. Projections of sea level changes can help managers identify portions of the coastline that could be monitored more closely. For example, figure 13.18 shows that the entire Louisiana coastline is in the high risk category with coastal area below 1.5 m, but the Gulf coast portion of southern Florida is ranked in the moderate risk category even though its coastal area is also below 1.5 m, suggesting that its response to a rising sea may be slower than if predicted from elevation alone (Thieler and Hammar-Klose 2000). Figure 13.19 shows that portions of the North Carolina coastline and the Atlantic coast of Florida are in the high risk category, but because those coastal areas are between 1.5 and 3.5 m, a sea-level rise of 1 m may not affect those higher elevation areas. [Citation: Lockaby et al 2013]

5. Sea-level may rise from 0.4 to 2.0 m by the end of the 21st century (table 13.5) (McMullen and Jabbour 2009, Rahmsorf 2007, Solomon and others 2009). Along the Atlantic Coast in the study region [the southern US] there is approximately 7,297 square miles (~4.6 million acres) of coastal land below an

elevation of 1.5 meters (North Carolina and Florida have the most coastal area below 1.5 m), with an additional 5,573 square miles (~3.5 million acres) of coastal land between 1.5 and 3.5 m. Along the Gulf Coast there is approximately 13,605 square miles (~8.7 million acres) of land below an elevation of 1.5 m (Louisiana and Texas have the most coastal area below 1.5 m), with an additional 6,430 square miles (~4.1 million acres) of coastal land between 1.5 and 3.5 m (fig. 13.16). If sea level rose 1.5 m we estimate that 2,633 square miles (~1.6 million acres) of forests could be affected along the Atlantic Coast, and 3,352 square miles (~2.1 million acres) of forests could be impacted along the Gulf Coast. When physical processes are considered by the coastal vulnerability index, along the Atlantic Coast North Carolina and Virginia have the most coastline in the very high-risk class, and along the Gulf Coast, Louisiana and Texas have the most coastline in the very high-risk class (fig. 13.17). [Citation: Lockaby et al., 2013]

6. Estimating extreme high AMWLs [annual maximum water levels] for any return period (e.g., 25, 50, 100, 200, 500 years) for future years are very important to coastal flood mitigation planning and coastal development. The extreme AMWLs by accounting for SLR [sea level rise] projections based on Eqs. (17) and (18) are more reliable to provide information to support coastal planning and flood hazard mitigations [for Florida and similar locations]. [Citation: Xu & Huang, 2013]

7. The Atlantic Coastal Ridge is the preferred location for well fields because additional treatment is often required for poorer quality groundwater withdrawn farther inland. Construction of the Palm Aire well field, located west of the Pompano Beach [Florida] well field, was an effective mechanism for reducing groundwater withdrawals near the coast; shifting withdrawals inland raised the water table near the coast and reduced the threat of salt water intrusion. [Citation: Langevin & Zygnerski, 2012]

8. It is reasonable to assume that increased rates of sea-level rise much larger than those considered here [0.8 to 2.0 meters by 2100, Pfeffer et al. 2008] would have serious impacts on the fresh coastal groundwater supplies of southeastern Florida. For these larger rates of sea-level rise, it is unclear if adaptation measures and changes to the infrastructure could meet potable water demands while simultaneously providing flood protection. [Citation: Langevin & Zygnerski, 2012]

9. There are three findings that we find quite striking: First, the high similarity in the variations of monthly sea level data over large distances and different geographical locations [in the Gulf Stream (GS)] indicates a common large-scale forcing. Local land subsidence, local wind pattern and local ocean dynamics (e.g., shallow estuarine dynamics in the CB [blue circles] versus Atlantic coastal currents), may play a lesser role in variations over time scale longer than few months. Second, the very high correlation found (R=-0.85) between long-term variations in sea level records and changes in the GS strength imply potential predictive skill for projection of future SLR [sea level rise]. Finally, the SLR acceleration in the mid-Atlantic region [Boon, 2012; Ezer and Corlett, 2012a,b; Sallenger et al., 2012] appears to be associated with a significant weakening of the GS over the past decade or so. This trend shown here for the GS gradient and the Florida Current transport, may be supported by recent observations of the AMOC (Atlantic Meridional Overturning Circulation) [McCarthy et al., 2012]. [Citation: Ezer et al., 2013]

10. Sea-level rose in Cedar Key, approximately 30 km northwest of Waccasassa Bay [Florida], at an average rate of 2.4 mm yr-1 from 1939 to 2005 (NOAA: Center for Operational Oceanographic Products and Services, 2006; Fig. 2). During our study period, MHHW [mean higher high water] actually declined by approximately 3 mm yr-1 from 1992 to 2000 and then increased at a rate of about 17 mm yr-1 from 2000 to 2005 (Fig. 2). [Citation: Desantis et al., 2007]

11. Whereas the presence of a freshwater lens may temporarily buffer soil and groundwater from sea-level-derived salinity changes, an increase in the frequency and extent of tidal intrusion into interior areas during storms or spring tides may accelerate the salinization process [in the Florida Keys]. [Citation: Ross et al., 1994]

12. In a scenario of rising sea level [for the Florida Keys], an increase in the level of the water table would reduce freshwater recharge capacity, leading to an overall increase in groundwater salinity. In turn, higher and more saline groundwater would contribute to an increase in soil salinity through capillary wetting from beneath. The magnitude of the effect would depend on surface elevation and whether the capillary fringe rose far enough through the limestone bedrock to intersect the bottom of the soil profile. [Citation: Ross et al., 1994]

13. The composed 100 and 200 years extreme high water elevations in the year of 2100 by accounting SLR [sea level rise] projections are higher than those without accounting for SLR impacts. At Pensacola [Florida Gulf coast] station, the 100 years extreme high water level estimated by AMWLs [annual maximum water levels] with SLR effect in 2100 is 0.19 m higher than the one estimated by that without considering SLR effect. At Fernandina [Florida Atlantic coast] Station, the difference of estimation by accounting SLR effect is 0.17 m higher, with the AMWL at 3.46 m in 2100. Therefore, for coastal flood hazard planning and coastal engineering design, the impact of sea level rise on the extreme water levels should be included. [Citation: Xu & Huang, 2013]

14. For instance, the potential influence by SLR [sea level rise] on the hurricane storm surge hazards in Sarasota County of Florida are studied by Frazier et al. (2010). The analysis shows that SLR significantly affects storm surge impacts of future land-falling hurricanes in Sarasota County. The study also demonstrates that even if hurricanes neither become more frequent nor more intense, SLR will still increase the impacts of storm surge. If hurricanes do become more frequent or more intense, there will be more potential risks associated with storm surge damage. [Citation: Xu & Huang, 2013]

15. Results of a numerical modeling analysis suggest that groundwater withdrawals [from a shallow coastal aquifer system in the Pompano Beach well-field and southeastern Florida area] were the dominant cause of a multi-decade salt water intrusion event, and that historical sea-level rise (about 25 cm for the simulation period) contributed to the extent of the intrusion by about 1 km. [Citation: Langevin & Zygnerski, 2012]

16. More recent projections by the IPCC (Meehl et al. 2007) seem to project sea level rising at a slower rate, but the revised estimates do not include some feedback mechanisms that are anticipated to occur, such as rapid ice sheet melting. Recent studies (Pfeffer et al. 2008) have shown that sea level may rise by 0.8 to 2.0 m by 2100. [Citation: Langevin & Zygnerski, 2012]

17. As shown by Werner and Simmons (2009), [coastal aquifer] systems that are head controlled are more susceptible to salt water intrusion caused by sea-level rise than those that are flux controlled. For confined aquifers that are flux controlled, sea-level rise may not have any effect on salt water intrusion (Chang et al. 2011). [Citation: Langevin & Zygnerski, 2012]

18. Three separate sea level rise increase simulations were conducted by increasing sea level to 0.6, 0.9, and 1.22 m. Results of the simulation clearly show significant increase in groundwater levels and relative chloride concentrations with increase in sea level [in South Florida] (Figures 16a and 16b). In well F-319 an increase of sea level from 0.34 to 0.6, 0.9, and 1.22 m results in an average of 4, 9, and 15% increase in groundwater elevation respectively. Similarly, in well G-3229 the average relative chloride concentrations would increase by 103, 310, and 639% respectively. The increase in groundwater elevations and salinity concentrations varies from location of the wells and its proximity to the coast. [Citation: Guha & Panday, 2012]

19. Increases in rainfall associated with global climate change may slow coastal forest retreat in the face of sea-level rise, while the increased incidence of droughts or consumptive water use by humans may accelerate it. [Citation: Williams et al., 1999]

20. Coastal forest retreat on this relatively undeveloped carbonate coastline [in Waccasassa Bay State Preserve on the west coast of Florida], therefore, appears fully consistent with impacts of continuing sea-level rise, whereby salt exposure associated with tidal flooding eliminates tree regeneration well before mature trees die. [Citation: Williams et al., 1999]

21. Of the species studied [on the west coast of Florida], Sabal and Juniperus were best able to maintain green leaves under conditions of continuous salt exposure, whereas Quercus could survive extremely high salt exposure by dying back and resprouting following salt removal. [Citation: Williams et al., 1999]

22. Salinization of groundwater appeared to occur during early to middle stages of stand decline: shallow groundwater beneath [plot] H1, where ample regeneration of Sabal, Juniperus, and Quercus occurred, was brackish at certain times of year (up to ~15 g sea salt/L several times during 1994–1995). Groundwater salinity under plots H2 and H3, where no regeneration of Quercus occurred and that of Sabal and Juniperus was marginal, was substantially higher than under H1 when it was measured in 1997. This pattern suggests that the salinization of groundwater could be a cause of regeneration failure. However, its role in forest decline on carbonate coasts [such as on the west coast of Florida] is unclear. [Citation: Williams et al., 1999]

23. Whereas failure of tree regeneration in the Mississippi Delta has been linked to rising water levels and increased flooding stress (Baumann 1987, DeLaune et al. 1987, Conner and Day 1988), and failure of Sabal regeneration on sandy coasts has been attributed to erosion (Brown 1973), failure of tree regeneration in this system [on the west coast of Florida] was associated with exposure to tidal water and increasing salinity of the groundwater. [Citation: Williams et al., 1999]

24. A change in understory composition accompanied forest decline at the seaward margin of coastal forest [on the west coast of Florida]. Whereas the tree species in frequently flooded plots were a subset of those occurring in adjacent coastal forest, the understory experienced complete species turnover (Appendix). [Citation: Williams et al., 1999]

25. Mean relative sea level at Cedar Key, Florida, rose an average of 1.5 mm/yr between 1939 and 1994, a rate consistent with most estimates of global sea-level rise (Warrick and Oerlemans 1990, Davis and Mitrovica 1996). MHHW [mean higher high water for the year] rose at a higher rate (~2.8 mm/yr, Fig. 3,

Stumpf and Haines 1998). Sea level and MHHW during 1991 and 1992 were the highest on record. [Citation: Williams et al., 1999]

26. For the four tree species that occurred in island plots [on the west coast of Florida] (Sabal, Juniperus, Quercus, and Celtis), mature individuals existed in more frequently flooded sites [indicative of future sea level rise] than did their seedlings, suggesting that regeneration failed before mature individuals were eliminated (Table 2). [Citation: Williams et al., 1999]

27. Regardless of the mechanism by which rising seas eliminate coastal forest, tree regeneration may be much more sensitive to rising seas than mature-tree survival. Increases in hydroperiod in the Mississippi Delta have eliminated tree regeneration in forest stands (DeLaune et al. 1987, Conner and Day 1988, Conner and Brody 1989). Failure of tree regeneration has also been linked to saltwater intrusion (e.g., Penfound and Hathaway 1938). [Citation: Williams et al., 1999]

28. First, a number of the basins that exhibit current problems are located along the Gulf Coast where they will be significantly impacted by sea level rise during the next century as well as the decrease in freshwater inflow predicted by the Hadley Center model. If the model projections are correct, these basins and estuaries in Louisiana, Mississippi, Alabama, and Florida should see significant increases in salinity levels associated with saltwater intrusion as well as a degraded quality of the inflows that do occur. Based on these observations it is quite possible that many of these areas could exhibit brackish and eutrophic conditions throughout much of the year. These conditions may negatively impact the aquaculture and tourism industries.

Factor: Extreme Weather (15)

Extreme weather refers to weather events that historically occur less than 5% of the time. Extreme weather events can produce forest disturbances, such a wind or flooding from Hurricanes or damage from ice storms. With climate change, local, regional, and global changes in temperature and precipitation can influence the occurrence, timing, frequency, duration, extent, and intensity of extreme weather events. Large scale disturbances may provide an opportunity to implement adaptive management strategies to deal with a changing climate.

Category: Interactions With Other Factors (2) Highlights

1. Trends in the frequency of flooding above the four NWS [National Weather Service] flood thresholds computed using Poisson regression reveal a stark contrast between increases in flood risk around the upper Midwest/Great Lakes region and decreases on the Gulf Coastal Plain, the southeastern United States, and California (Figure 2). Broadly speaking, these patterns are similar to the changes in liquid water equivalent measured by NASA's GRACE mission (GRACEannual, used here as a proxy for overall basin wetness); two-thirds of GHminor and GRACEannual trends exhibit the same sign (Figure S9). This cooccurrence of positive/negative trends in flooding and basin water storage suggests that progressive changes in basin wetness arising from combined climatic and anthropogenic influences precondition the local flood potential [see Reager et al., 2014]. Localized increases in flooding in the Gulf of Mexico, near New Orleans, and selected locations in Florida are also visibly in agreement with GRACE. Flood trends in the western half of the conterminous USA, Alaska, and Puerto Rico show mixed patterns of increases and decreases, while California stands out with almost uniform decreases in flood frequency (Figure 2). [Citation: Slater & Villarini, 2016]

2. Even previously fireprone ecosystems may experience damaging fire frequencies and/or intensities through the interaction of ECEs [Extreme Climate Event] and established invaders. The cogongrass (Imperata cylindrica) invasion in Florida pine ecosystems has increased fire intensity, causing greater native species mortality and facilitating further invasion (Lippincott 2000). Although such interactions have rarely been studied, these examples highlight how positive feedbacks could allow invasive species to “transform” some ecosystems to new, possibly persistent states. [Citation: Diez et al., 2012]

Category: Precipitation Extremes (3) Highlights

1. [Meteorological and hydrological droughts were analyzed for 5797 North American watersheds over the 1980–2009 historical period, as well as for the near- (2036–2065) and far-future (2070–2099) periods.] Both climate models [50-member CanESM2 and 40-member CESM1] predict a worsening of summer meteorological droughts [based on precipitation deficit alone] over most of Canada (West and Central Canada), Midwest and over the coast in Southeast U.S. along the Gulf of Mexico. There are large differences over the High Plains and the East Canada. CESM1 consistently predicts direr future meteorological droughts, with the exception of Southern Texas and the Northeast. The worst changes in the 100-year meteorological drought frequency are observed in Florida, with up to a ten-fold increase for CanESM2 (the current 100-year meteorological drought becoming a 10-year drought in the distant future) and a 20-fold increase for CESM1. [Citation: Zhao et al., 2020]

2. The number of extreme rainfall events is increasing. For example, the number of days with 3 or more inches of precipitation has been historically high over the past 25 years, with the 1990s, 2000s, and 2010s ranking as the decades with the 1st, 3rd, and 2nd highest number of events, respectively (Figure 19.3). More than 70% of precipitation recording locations show upward trends since 1950, although there are downward trends at many stations along and southeast of the Appalachian Mountains and in Florida (Figure 19.3). [Citation: Carter et al., 2018]

3. IPCC (2007) projected climate change for the Everglades [region in Florida] predicts there will be an increased occurrence of drought due to changes in precipitation patterns in the southeastern U.S. [Citation: Malone et al., 2013]

Category: Temperature Extremes (3) Highlights

1. Over the 20th century the number of 95°F days has declined overall; however, an upward trend has been seen since the 1970s. Model simulations indicate further increases throughout the region, with the largest increases of more than 35 days occurring in south central Florida, where the climate of 2055 is simulated to feature 40-50 days over 95°F during the year. The smallest increases of 4-10 days per year occur in the highest elevation areas along the spine of the Appalachians, where the historical period averages less than 10 days exceeding 95°F in a given year. The NARCCAP model changes in the number of 95°F days across the Southeast are statistically significant… All grid points satisfy category 3, with the models indicating that the change in the number days below 32°F across the Southeast is statistically significant. The models also agree on the sign of change, i.e. they are in agreement that the number of days with a minimum temperature of less than 32°F will decrease throughout the region under this scenario… The NARCCAP models indicate that the changes in the number of consecutive days over 95°F across the Southeast are statistically significant. The models also agree on the sign of change, with all grid points

satisfying category 3, i.e. the models are in agreement that the number of consecutive days above 95°F will increase throughout the region under this scenario. [Citation: Kunkel et al., 2013]

2. It appears that the probability of a severe freeze in Florida depends upon the state of the Pacific/North American (PNA) pattern. Mean and mean minimum winter temperatures are significantly lower when the PNA index is positive. Furthermore, a strong persistent PNA pattern (monthly PNA index > 2) substantially increases the probability that Florida will experience a widespread severe tree-damaging freeze... When the PNA index is positive, cold fronts are likely to be coming in from the north, shifting temperature distribution downward; conversely, when the index is negative, the likelihood of cold outbreaks is reduced... El Nino-Southern Oscillation (ENSO) events appear to increase the likelihood of a persistent positive PNA pattern, although we have seen above that the relationship between ENSO and Florida temperatures is weak and some of the extreme values of the PNA index occurred during non-ENSO winters. [Citation: Downton & Miller, 1993]

3. The comparison of the Mean Residual Life (MRL) plots, derived from the Generalized Pareto Distribution (GPD), of the observed data and the ensembles showed that the extremely low temperatures were more likely to occur during the EL Nino-Southern Oscillation (ENOS) neutral or La Niña winters, not during the El Niño winters. The model results divided by the North Atlantic Oscillation phases were also investigated, and the MRL plots of the positive and neutral phases showed the similar characteristics to the observations. These similarities suggest that the Florida State University/Center for Ocean-Atmospheric Prediction Studies Regional Spectral Model can capture tendencies of the freezes in winters, if provided with accurate sea surface temperature information. [Citation: Goto-Maeda et al., 2008]

Category: Tropical Cyclones (7) Highlights

1. Knowledge of the potential effects of hurricanes and cyclones on subtropical forest structure and ecosystems services in North America, the Caribbean region, Australia and Southeast Asia is growing because of the predicted increase in hurricane intensity and occurrence. The study's results [looking at hurricane damage in the highly forested Lower Suwannee River watershed in west Florida and the more urbanized Pensacola Bay located in northwestern Florida] can serve to map and identify particularly vulnerable zones, as well to assess how direct drivers (e.g. hurricanes and cyclones) can affect aboveground carbon storage, and consequently carbon sequestration in the long-term, and timber volume; thus alter management practices in areas with a high probability of ecosystem services loss. Land managers should include the potential occurrence of direct and indirect drivers, such as hurricanes, in their management plans and be aware of the consequences in terms of effects on ecosystem services especially when planning for conservation strategies and payment for ecosystem service programs. [Citation: Delphin et al., 2013]

2. For example [in the highly forested Lower Suwannee River watershed in west Florida and the more urbanized Pensacola Bay located in northwestern Florida], our aboveground carbon storage and timber volumes results for both watersheds were different in terms of hurricane impacts (Table 3). Although the Pensacola Bay watershed has a higher wind risk rating, the Lower Suwannee shows greater potential for damage from hurricanes (Figs. 3 and 4). The Lower Suwannee watershed is highly and contiguously forested compared to the more urbanized, fragmented Pensacola Bay watershed. Hence, since only "natural" forests and their biomass were considered in this analysis, and not urban forests, we found greater potential impacts on the Lower Suwannee watershed. [Citation: Delphin et al., 2013]

3. Hurricanes can decrease aboveground carbon storage in the study area's forests [in the highly forested Lower Suwannee River watershed in west Florida and the more urbanized Pensacola Bay located in northwestern Florida]. However, not all carbon will be lost, with variable dynamics in the short term as well as in the mid and long term. In the short term, carbon pool changes occur as aboveground carbon in live materials shifts to dead and downed carbon dead and additional carbon can also be stored in the salvaged timber and associated wood products (McNulty, 2002; Timilsina et al., 2013). According to McNulty (2002), only 15% of the total carbon can be salvaged after a major hurricane and the rest is decomposed and returned to the atmosphere over the long-term. If these lands are allowed to recover to a forested state, net carbon accumulation will occur over a period of decades (Powell et al., 2008). However, if hurricane frequency increased, forests structure and function would not have sufficient time to recover and specific ecosystem services (i.e. carbon and timber) would be reduced (McNulty, 2002), but other tradeoffs (i.e. invasives, wildlife habitat) might increase. [Citation: Delphin et al., 2013]

4. For the Pensacola Bay watershed [in northwest Florida], the aboveground carbon storage in 2003 was 1,392,000 Mg, and this estimate is the maximum carbon storage that could potentially be lost in a worst case scenario. High average values were located in the western part of the watershed. About 0.3% of the existing forest area in the watershed is under high risk of damage due to hurricanes; but the rest, 99.7% are under low risk of damage (Fig. 4; Table 3). The aboveground carbon in the high risk zone was 0.5% of the total aboveground carbon stored (1,392,000 Mg) in the watershed. [Citation: Delphin et al., 2013]

5. In 2003 the aboveground forest carbon storage was 10,194,000 Mg for the Lower Suwannee River watershed [in west Florida]. Considering the worst case scenario where hurricanes potentially impact all the forest areas in the watershed, the approximate amount of potential loss of carbon aboveground can be the entire standing stock. Highest average potential losses were located in the northeastern part of the watershed in Suwannee County (Table 2). The area corresponding to the high risk was 13% and the low risk area was 87% of the watershed (Table 3 and Fig. 3). The aboveground carbon in the high forest damage risk zone included 31% of the total estimated for the watershed. The high damage zone (1) and the moderate or low damage zone (2), had 3,117,000 Mg C and the second zone had 7,077,000 Mg C, respectively. [Citation: Delphin et al., 2013]

6. We used USDA Forest Service Forest Inventory and Analysis (FIA) program cycle 8 (2002-2007) data to analyze forest aboveground carbon storage and timber volume and obtain relevant forest structure characteristics that determine a forest's vulnerability to hurricane damage. In the high [hurricane] damage zone [in the highly forested Lower Suwannee River watershed in west Florida and the more urbanized Pensacola Bay located in northwestern Florida], the most affected type of tree species were softwoods with: smaller diameters, greater heights, and lower basal areas. However, in zone 2, the most affected were hardwoods with larger diameters, greater heights, and lower basal areas (Table 2). [Citation: Delphin et al., 2013]

7. Tree species with a greater proportion of total carbon biomass above ground and in leaf tissue are more susceptible to uprooting (King, 1986). The two ends of the species susceptibility to hurricane damage are loblolly pine (Pinus taeda) and Baldcypress (Taxodium distichum). Mature pines have closed, compact crown far from the ground, on stems with little taper. The pines often grow on sandy soils with poorly anchored root systems. Old growth baldcypress have a highly tapered trunk, is extremely well rooted, and has an open canopy. When both these southern Florida forest types were exposed to Hurricane Andrew

in 1992, the pines experienced 25–40% damage while the bald cypress was less than 10% (Davis et al., 1996). [Citation: McNulty, 2022]

Factor: Fire (10)

Fire, in the form of both wildfire and prescribed fire, acts as a major disturbance force in forested systems. Climate change will likely increase the severity and frequency of wildfire events at multiple scales. Wildfire has potential to interact negatively with other stressor, including forest pests, accelerating climate change ecosystem effects. However, the application of fire as a management tool has tremendous opportunity to reduce the risk of wildfire, control post-disturbance regeneration, and provide needed habitat types.

Category: Fuel Treatments (4) Highlights

1. Although Florida may experience the largest increase in precipitation, it was also projected [by the Dynamic Land Ecosystem Model, which linked carbon pools and fuel types to predict the spatial and temporal pattern of fuel loads,] to experience warmer climate which will enhance the decomposition of ecosystem fuel load. Therefore, the highest increase of fuel load will be found in South Carolina, which was projected to have the second largest increase in precipitation, and the most significant decrease in daily maximum temperature (−1 ◦C) (Fig. 3). [Citation: Zhang et al, 2010]

2. The fuel load of Southern Texas and Florida, however, was projected to increase significantly [by the Dynamic Land Ecosystem Model which linked carbon pools to fuel types to predict the spatial and temporal pattern of fuel loads,] possibly due to the effect of increased nitrogen deposition in 2050. In general, the spatial pattern of fuel load change is quite similar to the climate changes, indicating the dominant effect of climate on the dynamic of fuel load in SUS [Southern US] during the study period (2002–2050; Fig. 2C and F). [Citation: Zhang et al, 2010]

3. Previous research indicated that the productivity and biomass of southern forest are sensitive to the variation of annual precipitation (McNulty et al., 1996). We therefore expect that the ecosystems which will experience increased precipitation will have higher fuel production. The increased moisture, however, may also alter the fuel bed condition and reduce the fire risk. The arid ecosystems in the west part of the study region [including 13 southern states: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia] were projected to experience higher temperature and lower precipitation in 2050, which will exacerbate the severity of the drought stress and inhibit fuel production. [Citation: Zhang et al, 2010]

4. A state-level analysis [in the study region including 13 southern states: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia,] shows that the minimum daily temperature will increase significantly in all southern states (Fig. 3). Higher night-time temperature will accelerate the decomposition of detritus pools and enhance plant respiration rate, thus resulting in reduced fuel load in 2050. [Citation: Zhang et al, 2010]

Category: Wildfire Trends (6) Highlights

1. The end of the fire season tended to shift to an earlier date in several states [from a data set of long-term biomass consumed derived from geostationary satellite data across the Contiguous United States (CONUS) from 1995 to 2011]. A significant trend occurred for Alabama, California, Colorado, Florida,

Georgia, Kansas, Kentucky, Louisiana, Maine, Maryland, Mississippi, Missouri, North Carolina, North Dakota, Nebraska, South Carolina, Tennessee, Texas, Virginia, and West Virginia. The rate of shift was 1.5–5 d/yr, which is similar to the start of the fire season shifts. The fire season duration only showed significant trends in eight states. They were Alabama, Arizona, California, Colorado, Louisiana, Maryland, Minnesota, and Tennessee. Among these, the fire season duration reduced in Arizona (4.0 d/yr, P value = 0.039), California (2.5 d/yr, P value = 0.066), and Colorado (3.6 d/yr, P value = 0.04), with the biomass consumed being largest in California and fifth largest in Arizona. [Citation: Zhang et al., 2010]

2. [For the Southern US,] In 50 years, all Cornerstone Futures [which are a portfolio of scenarios using climate models and characterized by various projections for future population, income, and energy,] depict drier conditions (fig. 17.3). Cornerstone A [which is characterized by low population growth and high energy-use/economic-growth,] depicts the most severe conditions with an eastward expansion of the western dry area and the development of a similar area in southern Georgia and Florida; only the Appalachians maintain a negative PDI [potential drought index]. The other Cornerstone Futures are very consistent in their depiction of drier conditions, though the magnitude of the drying is far less than in Cornerstone A. The central part of the region shifts from negative PDI values to a more balanced condition and the band of near zero PDI in the Coastal Plain becomes better defined. All three of the primary fire areas depicted in figure 17.1 experience an increase in wildfire potential, with Cornerstone A showing the most dramatic increase and B [low population growth and high energy-use/economic growth, but with a different climate model than Cornerstone A], C [moderate population/income growth and energy use,] and D [moderate population/income growth and energy use, but a different climate model that Cornerstone C,] showing more modest increases. [Citation: Stanturf & Goodrick, 2013]

3. Data from this single forest unit [Osceola National Forest in Florida] appear to be solely responsible for the linkage identified in the regional models between lightning flashes and wildfires. Reinforcing this inference is the fact that the model for the Coastal Plain East region (which includes Osceola National Forest) is the only one where lightning-flash density is associated with wildfire incidence. We conclude that ignition source plays a minor role in explaining the temporal and spatial pattern of wildfire occurrence in the southeastern United States. In forests where fuels are abundant and lightning incidence is not limiting, climatic drought emerges as the principal influence on wildfire. Others have reached similar conclusions elsewhere (Minnich, 1983; Minnich and Chou, 1997; Vazquez and Moreno, 1998). [Citation: Mitchener & Parker, 2005]

4. [In a study examining climate, lightning and wildfire interactions across the southeastern US,] Lightning-flash incidence was generally high throughout the Coastal Plain (especially Florida) and low in the Appalachian Highlands (Table 1). The vast majority of all flashes were of negative polarity; however, there is a distinct geography of positive flash occurrence in the southeastern United States. The greatest positive lightning-flash densities occurred in forest units of the western Gulf Coastal Plain and Ozark/Ouachita highland, whereas the lowest positive flash densities were found in the Appalachian Highlands of Virginia. [Citation: Mitchener & Parker, 2005]

5. Although peat fire risk [in the Florida Everglades] was closely correlated with water levels, a scatterplot of water level vs. risk value (unranked) shows the effect of the secondary variables [burn history, duration of dry out, vegetation, soil type, soil total phosphorus, and soil bulk density] on the relationship. In this regard, the status of these other factors substantially lowered or enhanced risk at many locations, particularly where water levels were between -2 and -3 ft (Fig. 2). [Citation: Smith et al., 2003]

6. Generally, when it has rained, more strikes are required to ignite fires. This is especially true for July; when July is wet, it takes more lightning strikes to ignite fires, and when July is dry, fewer strikes are needed to ignite fires. July rainfall is particularly important because it corresponds to the peak in lightning incidence. This trend is clearly visible in the monthly strike to ignition ratio data. The fewest strikes are required to ignite fires in July just after the annual dry period, and the maximum number of strikes is required to ignite fires in October after the summer wet season (Mailander 1990). [Citation: Duncan et al., 2010]

Factor: Forest Health (12)

Forest Health is often threatened by the presence of harmful forest pests, including insects and pathogens. Forest pests include native and exotic and invasive and non-invasive species. Forest stresses caused by the effects of climate change provide competitive advantages for some forest pests to expand their ranges. Some native species, such as bark beetles, can become very destructive when forests are stressed by extreme weather and climatic changes. Increases in forest pests may require a re-evaluation of current management practices with a focus on reducing forest stress from drought. Pest focus, but not only pests.

Category: Exotic Insect Pests (1) Highlight

1. The pattern of potential suitable habitat for the gypsy moth [Lymantrai dispar] in January would be similar for all three storylines [which are based on three to four climate models and projections for population and economic trends] in the 2020 projections. Much of the South is potentially suitable, with the exception of a few counties in southern Florida, western Oklahoma, and Texas. The suitable habitat in July could become bigger under the B1 storyline [which projects low population growth, high economic growth, and a shift to the service/information economy] compared to A1B [which projects low population growth, high economic growth, and high energy use] and A2 [which projects continuous population growth and high economic growth]. Reduction in July suitable habitat is likely by 2060 under the A1B storyline. The A2 storyline predicts a slight northward shift in 2060 (Figure 6.7). [Citation: Olatinwo et al., 2014]

Category: General Impacts (4) Highlights

1. The experimental [longleaf] pines [Pinus palustris] in our study [in Gainesville, Florida, U.S.] diverged over time for traits associated with resource capture and use. Individuals exposed only to invasion, or only to drought, were taller and had larger height to diameter ratios, on average, than individuals experiencing no stress or both stressors. [Citation: Alba et al., 2019]

2. [In our study in Gainesville, Florida, U.S., of native longleaf pine (Pinus palustris), we found] the facilitation effect of cogongrass [Imperata cylindrica] under drought conditions waned as the invasion progressed over time. Cogongrass cover increased dramatically [and reduced pine survival due to its]…superior competition for light…While there was unexpected initial facilitation of trees growing with the invader, low pine survival after three years in plots exposed to one or both stressors demonstrates that longleaf pine is vulnerable to ongoing and predicted global changes in the region (Simberloff et al. 1997, Wang et al. 2010). [Citation: Alba et al., 2019]

3. [Our study in Gainesville Florida, U.S.] show[ed] that an aggressive nonnative plant species can facilitate a native species by ameliorating abiotic stress (see review by Rodriguez 2006). Cogongrass [Imperata cylindrica] offset drought stress for [longleaf] pine [Pinus palustris] seedlings by maintaining higher soil moisture levels, as well as higher humidity and lower temperatures (Alba et al. 2017), below its dense canopy compared to native understory plants. Especially when pines were young (2014 and 2015), and thus most susceptible to mortality (Loudermilk et al. 2016), their survival was completely decoupled from soil moisture availability in the presence of the invader. [Citation: Alba et al., 2019]

4. The [redbay ambrosia] beetle [Xyleborus glabratus] and the laurel wilt [Raffaelea lauricola] are already as far south as Homestead, Florida. The three emission storylines (A1B, A2, and B1 [which are based on three to four climate models and projections for population and economic trends]) evaluated in this study indicate a likely decline in potential suitable habitats for the redbay ambrosia beetle by 2060. The B1 storyline [which projects low population growth, high economic growth, and a shift to the service/information economy] will likely have larger areas of suitable habitat in July 2020 compared to the other storylines (Figure 6.4); by 2060, suitable habitat in southern Florida and southeastern Texas is likely to shift slightly southward in January for all storylines. [Citation: Olatinwo et al., 2014]

Category: Native Insect Pests (3) Highlights

1. Under the three storylines [which are based on three to four climate models and projections for population and economic trends], southern pine beetles [Dendroctonus frontalis] would likely maintain a considerable suitable habitat from January to July based on 2020 and 2060 projections. Much of the South would provide suitable habitat, the exception being some southern Florida counties where environmental conditions could be unsuitable for either the host (loblolly pine [Pinus taeda]) or the beetle. The pattern of suitable habitat in July will likely be similar for the three storylines, with a slight northern shift in under A2 [one of the three storylines which is based on continuous population growth and high economic growth] by 2060 (Figure 6.6). [Citation: Olatinwo et al., 2014]

2. Historical data reveal the existence of potential spatial patterns of SPB [Southern Pine Beetle (Dendroctonus frontalis)] outbreaks in the southern United States. SPB outbreaks in Louisiana and Texas were significantly correlated; infestations in Alabama, Arkansas, Florida, Georgia, Mississippi, South Carolina, North Carolina, and Tennessee seemed to move together; and Virginia displayed its unique temporal outbreak pattern. These patterns would have value for the prediction and control of future SPB outbreaks in the region. [Citation: Gan, 2004]

3. Many agree that extremes in temperature and precipitation affect SPB [Southern Pine Beetle (Dendroctonus frontalis)] populations and host trees, influencing SPB infestations. Cold winters and hot summers generally reduce SPB populations (Beal, 1929; Thatcher, 1960) while moisture deficits and surpluses could both contribute to SPB outbreaks (Kalkstein, 1974;Warning and Cobb, 1989). Of the 11 states, Alabama had the highest infestation rate and volume killed, while Florida had the lowest infestation rate and volume killed. Tennessee had the second higher SPB infestation rate, followed by South Carolina, Louisiana, Georgia, Texas, and North Carolina. [Citation: Gan, 2004]

Category: Pathogens (4) Highlights

1. In 2020, suitable July habitat [for laurel wilt (Raffaelea lauricola)]is expected to be fairly similar for all three storylines [which are based on three to four climate models and projections for population and

economic trends], with few differences in the northern limit (Figure 6.5). Suitable July habitat is projected to shrink markedly by 2060. The projections indicate a northward shift in suitable January habitat in southern Florida and the lower Coastal Plain, where only few southern-most counties could become unsuitable in 2060. However, conditions will remain suitable for the hosts, redbay [Persea borbonia] in the south and sassafras [Lauraceae]to the north. [Citation: Olatinwo et al., 2014]

2. By 2020 and 2060, the potential suitable habitat for fusiform rust [Cronartium quorum f. sp. fusiforme] will likely extend throughout most of the region with a few unsuitable habitats below the south limit in southern Florida, western Oklahoma, and parts of central and western Texas. The suitable July habitat under the A1B, A2, and B1 storylines [which are based on three to four climate models and projections for population and economic trends] in 2020 is expected to shrink by 2060 (Figure 6.3). [Citation: Olatinwo et al., 2014]

3. By 2020 and 2060, suitable July habitat for annosus root disease [Heterobasidion annosum, Fomes annosus] is expected to cover most of the South, with the exception of southern Florida, some parts of Oklahoma, and a large part of western Texas. Under the A1B storyline [which predicts climactic and consequent ecological outcomes based on a scenario of low population growth, high economic growth, and high energy use], the northern limit could shrink by 2060. The pattern of suitable July habitat will likely be similar for the three storylines [which are based on three to four climate models and projections for population and economic trends], with slightly larger January habitable areas under A2 storyline (Figure 6.2). A significant retreat of the range's southern edge is unlikely. Although the disease is found throughout much of the United States, it is more common and severe in the South. Therefore, a warmer climate and a shift in host ranges could mean that the disease will become more common in latitudes farther north. [Citation: Olatinwo et al., 2014]

4. For areas east of the Mississippi River, it was concluded from the model that much of the Appalachians were at high risk, as was a small area from Biloxi, MS [Mississippi] to Pensacola, FL [Florida]; several Mid-Atlantic States were at moderate to high risk (USDA, 2004). Again, our model is generally consistent with these results. Fowler and Magarey (2005) modeled the frequency of weather conditions suitable for infection by P. ramorum [Phytophthora ramorum] across the US and found that east of the Mississippi River, 8 or more of the past 10 y [years] had conditions suitable for infection. Our model and Fowler and Magarey (2005) predict substantially higher risk in the Gulf States and New England than suggested by the Preliminary Risk Map, but the influence of non-climatic factors on results from the Preliminary Risk Map complicates comparisons of the models. [Citation: Venette & Cohen, 2006]

Factor: Freshwater Ecosystems (8)

Freshwater Ecosystems include lakes and ponds, rivers, streams and springs, and wetlands, focusing on aquatic and riparian plants and their relations to the surrounding environment. Wetlands will be particularly vulnerable to changes in water supply due to climate change. Alterations in the length of time that wetlands hold standing water will affect both plant and animal communities. Management options focus on maintaining genetic diversity, on restoration of wetland hydrology, and control of invasive species.

Category: Freshwater Wetlands (4) Highlights

1. We found that drought resulted in the [Florida Everglades freshwater marsh] system being a net source of carbon to the atmosphere. The capacity for the system to serve as a source of CO_2 [carbon dioxide] was influenced by changes in physiological potential of the vegetation due to water stress and changes in ecosystem respiration through enhanced diffusion and higher soil respiration rates. The CH_4 [methane] source potential was likely influenced by both CH_4 production during inundation and changes in diffusion rates out of the soil following rapid modifications in water levels. [Citation: Malone et al., 2013]

2. Another recent study specifically predicts the loss of T. distichum [Taxodium distichum] from swamp ecosystems in south Florida under scenarios of 2 °C annual climatic warming, based on the current distributional envelope (Crumpacker et al., 2001). The latter prediction is supported by our data indicating that production of bald cypress swamps at latitudes of 25–27° N would decrease to zero if temperatures increase by 2 °C. Additionally, our analysis shows that southern swamps with impaired hydrology are most vulnerable to temperature change (Fig. 4). [Citation: Middleton & McKee, 2004]

3. Florida lakes, particularly those in the northern areas, are likely to undergo significant changes with climatic warming. Warming will shift the warm temperate lakes of north Florida to subtropical conditions, resulting in a reduction in length of mixing, an increase in productivity and nutrient cycling rates, simplification and reduction of the macrozooplankton community, and an increase in protozoa and bacteria. Management problems caused by blooms of the blue-green alga Microcystis, and by growths of the exotic macrophyte Hydrilla verticillata, primarily confined to the subtropical lakes, would expand northwards with a similar shift in subtropical conditions. Many of the native, temperate fish species will be lost and replaced with exotic, subtropical species, as has occurred in southern Florida. [Citation: Mulholland et al., 1997]

4. At the landscape scale, depressional wetlands that receive surface water and ground water from surrounding uplands are most likely sensitive to land disturbances and climate change. [Citation: Lu et al., 2009]

Category: Interactions With Other Factors (1) Highlight

1. A regional analysis based on an empirical model predicts that 2-9% of streams in the southern Appalachians, and up to 55% of the streams in the north-western and north-central areas of Florida, experience episodic acidification (Eshleman, 1988). Increased clustering of storms will most likely lead to longer and/or more severe acidic episodes in these streams. This could lead to elimination of key, acid-sensitive species, particularly trout, and many of the common macroinvertebrates in the southern Appalachians, where historical acidification has been minimal (Mulholland et al., 1992). [Citation: Mulholland et al., 1997]

Category: Lakes and Ponds (2) Highlights

1. We postulated that both high and low water events could affect the intensity of cyanobacteria blooms in subtropical shallow lakes, and found supporting evidence by studying an 18-year dataset from seven shallow lakes in central Florida, USA. Blooms were less intense during wet years when water levels were higher and most intense during drought years, when water levels were lower. [Citation: Havens et al., 2019]

2. [L]akes with underlying conditions that favor cyanobacteria blooms (high [nitrogen] and [phosphorus], small zooplankton, the presence of bloom forming species) may experience more extreme wax and wane of noxious and potentially toxic cyanobacteria blooms in the future. It has been documented that increased water temperature caused by climate change may lead to a greater occurrence of toxic algae blooms in lakes (Paerl & Huisman, 2009; Kosten et al., 2012; Paerl & Otten, 2013). Here, [in central Florida, USA] we confirmed that climate variability and change may also affect other processes in lakes known to be favorable for bloom formation including increased nutrient availability and reduced flushing rate (Reynolds, 2006). [Citation: Havens et al., 2019]

Category: Riparian Areas (1) Highlight

1. The South Florida change cluster [which is a cluster of watersheds where the rainfall-runoff erosivity factor, or R-factor, change is projected to exceed either the positive or negative threshold] is unusual in that its watersheds exhibit both notable increases and decreases over a relatively small geographic area. The locus of the cluster consists of three watersheds on the eastern side of the southern Florida peninsula and illustrates the extreme contrasts projected to occur in the future (Figure 9.10). Two of the watersheds exhibit consistent R-factor decreases ranging from −122 to −219, whereas the adjoining watershed to the south (encompassing the Florida Keys) exhibits increases of 111–177. If not attributable to model error, these remarkable differences indicate tremendous climatic variability over short distances. All three time periods reflect this marked geographic variability. By 2030, seven watersheds show notable changes with two decreasing and five increasing. By 2050, only the watersheds within the cluster locus are affected; by 2070 one additional watershed joins the increase total. [Citation: Marion et al., 2013]

Factor: General Biodiversity (5)

Biodiversity, short for biological diversity, refers to the variation among living organisms, species, and populations. It also encompasses the interrelated nature of genetics, species, and ecosystems and their distributions across the landscape. The influence of climate change on biodiversity will result in unique management challenges relating to migrating species, shifting ecosystems, and potential for extinction. Management options range from landscape planning to the selective genetic sourcing of planting and seeding material.

Category: Interactions With Other Factors (1) Highlight

1. The results of our analyses indicate that Sphaerodactylus notatus [Florida reef gecko] is a species of high conservation risk, due to factors including habitat loss, fragmentation, and range reduction, and is the herpetofauna most at risk from sea level rise in the entire U.S. [Citation: Clements et al 2021]

Category: Range Shifts (4) Highlights

1. The oaks (Quercus spp.) show highest richness in the far south central portion of the [United States], maxing out at 21 species; lowest oak richness was in both the northwestern and the northeastern portions of the study area [(national forests and grasslands in the eastern U.S.)], as well as southern Florida (Figure 6B)…In comparison with the current oak distribution (Figure 6B), the future (~2100) models [RCP 4.5, (representative concentration pathways)] show potentials for subtle decreases in oak species counts in the south and slight increases towards the north. This trend is more prominent with RCP 8.5 (Figure 6D). [Citation: Iverson et al., 2019]

2. Species in the Gulf Coast Region that are already endangered such as the Cape Sable seaside sparrow and Florida panther could become more vulnerable as their preferred habitats change or shift with global warming. Current water-management practices and human development create additional challenges for species migration and adaptation. [Citation: Twilley et al., 2001]

3. For flowering dogwood [Cornus florida], we repeated this analysis [identifying areas of future environmental equivalence and potential adaptability to the Hadley B1 climate scenario] for an example ecoregion currently existing in North Carolina and South Carolina (Fig. 4b inset). In 2050, environmentally equivalent areas [of C. florida] were projected to move north into Virginia and west into Tennessee; areas throughout the southeastern United States and in western Pennsylvania were projected to be environmentally similar, but not identical, to the current conditions of the source ecoregion (Fig. 4b). [Citation: Potter & Hargrove, 2012]

4. Given the documented range of dogwood [Cornus florida] prior to 1971 (Little, 1971) and its substantial decline from the 1980s to the present [based on state-level data from the Forest Inventory and Analysis (FIA) program], we hypothesize that future dogwood populations will continue to wane. The deleterious effects of [Discula destructive (dogwood anthracnose)], combined with inter- and intra-specific competition, defoliators, and little emphasis on restoration and management engenders little hope for slowing the decline of C. florida populations on the landscape. Additionally, climate change effects might be expected to negatively affect C. florida populations. The relatively widespread C. florida range could ensure its stability in limited southern locations, while the majority of its extent in the middle and high latitudes may face increased competition due to climate-change induced species migration (Woodall et al., 2009). Some evidence from this study suggests that range shifts may already be occurring in C. florida populations given that the greatest losses in biomass occurred in the species' northern range and greatest gains occurred in its southern range. However, range shifts were not the focus of this study and further investigation and monitoring over time will be necessary to corroborate those initial observations. [Citation: Oswalt et al., 2012]

Factor: Invasive Species (18)

Invasive species refers to animals or plants whose introduction causes, or is likely to cause environmental, ecological, or economic harm. Both native species and exotic species not indigenous to the area may be considered invasive if they threaten local biodiversity. Climate change can give certain invasive species a competitive advantage, produce difficult to predict species interactions, and allow pests to expand their ranges beyond historical precedent. Management options focus on early eradication and restoration.

Category: Interactions With Other Factors (2) Highlights

1. [In our study of the Asian tiger mosquito (Aedes albopictus) in Florida and New Jersey, U.S.]…one consequence of warming was faster growth rates of individual females, who often achieved high mass under short photoperiods. Such changes in growth appear to be the norm rather than the exception for ectotherms, where inherent physiological processes like growth rates are strongly tied to external temperatures (Deutsch et al. 2008). [Citation: Yee et al., 2017]

2. In addition to plants, warmer winter air temperatures will also affect the movement and interactions between many different kinds of organisms. For example, certain insect species, including mosquitoes

and tree-damaging beetles, are expected to move northward in response to climate change, which could affect human health and timber supplies... For example, in South Florida, the Burmese python (Python bivittatus) and the Brazilian pepper tree (Schinus terebinthifolius Raddi) are two freeze-sensitive, nonnative species that have, respectively, decimated mammal populations and transformed native plant communities within Everglades National Park. In the future, warmer winter temperatures are expected to facilitate the northward movement of these problematic invasive species, which would transform natural systems north of their current distribution. [Citation: Carter et al., 2018]

Category: Invasive Animals: Aquatic (5) Highlights

1. The new records [from the collections of the Southeastern Regional Taxonomic Center in Charleston, SC] of Creedonia succinea and Microtralia ovula [non-native ellobiid snails] presented here provide evidence that the two species are now established in South Carolina waters. Further collecting within their newly extended range should reveal their occurrence in additional localities. Similar northward expansion of the ranges of the anomuran decapod Petrolisthes armatus (Gibbes, 1850) and the amphipod Caprella scaura Templeton, both from south Florida and northwestern Atlantic tropical waters into South Carolina, have recently been documented (Foster et al. 2004, Knott et al. 2000). These observations conform to the speculation of Engle and Summers (1999) that distributional shifts of estuarine benthic fauna are likely to occur along the Atlantic coast, given current climate-change scenarios that predict increased global temperatures of up to 2 °C. It is also likely that the ranges of some species will be extended into South Carolina simply as a result of increased scrutiny of the biodiversity of that region. [Citation: Harrison & Knott, 2007]

2. The results of the present study [surveying mussels following unusually cold weather events in Tampa Bay, Florida] suggest that physiological stress driven by extreme weather may be responsible for limiting the invasion success of the green mussel [Perna viridis] in a subtropical area. [Citation: Firth et al., 2011]

3. Two of the predictions accompanying discussions of global climate change are (1) a rise in the mean sea surface temperature globally and (2) an increase in the occurrence, intensity and magnitude of extreme weather events (IPCC, 2007). Stachowicz et al. (2002) proposed that changing maximum and minimum temperatures rather than shifts in annual means could account for the greatest impacts of climate change on marine communities. Our findings on the [invasive] green mussel [Perna viridis] [showing die back events with low water temperatures in Tampa Bay, Florida] provide support for this proposal. Future studies on changes in community assemblages that follow assemblages across years both with and without extreme weather events are necessary. [Citation: Firth et al., 2011]

4. Furthermore [in addition to the lack of information on the effects of cool thermal stress], despite many intertidal organisms being exposed to aerial conditions during low water, less attention has been directed at assessing the effects of extreme air temperatures in comparison to extreme water temperatures. This focus is perhaps surprising as larger fluctuations in temperature are more likely to occur in aerial environments than aquatic environments due to the buffering capacity of water (Marshall and Plumb, 2008). In a subtropical setting such as described here [studying the invasive green mussel (Perna viridis) in Tampa Bay, Florida], low aerial temperatures may be an important mechanism by which mussels are prevented from excluding other fouling organisms, such as oysters and barnacles. [Citation: Firth et al., 2011]

5. In freshwater systems climate change is associated with earlier breeding in amphibians (Beebee 1995), earlier emergence of dragonflies (Odonata) (Hassall et al. 2007), and compositional shifts of entire insect communities (Burgmer et al. 2007). There is speculation that the recent establishment of 2 species of tropical dragonflies in Florida represents a natural invasion from Cuba and the Bahamas that is related to climate change (Paulson 2001). [Citation: Rahel & Olden, 2008]

Category: Invasive Animals: Terrestrial (4) Highlights

1. Melanaspis tenebricosa [Gloomy Scale] is an armored scale insect native to the eastern United States. It is a primary insect pest of Acer spp. [maple], particularly A. rubrum [red maple] (Frank 2019).... [L]ow densities and poorer thermal tolerance in the south may lead to a range contraction at the southern distribution edge [(specifically Florida, U.S.)] with additional warming. [Citation: Just & Frank, 2020]

2. Extensive open grassland and forest areas in South Texas and South Florida could become more vulnerable to damaging invasion by Chinese tallow trees. Those in South Florida could in addition be threatened by melaleuca and casuarina trees. [Citation: Twilley et al., 2001]

3. Our projections onto anthropogenic climate-change scenarios indicate a possible extension of the current potential distribution of the Cuban treefrog [Osteopilus septentrionalis] in Northern America. However, successful colonization of newly arising suitable areas may depend on the propagation speed of O. septentrionalis. Time series suggest that the frog was able to expand its range at about 10kmy21 in Florida (e.g., Key West– Miami, ,250 km/21y; Miami–Indian River Country, ,250 km/28y; Miami–Duval Country, 570 km/51y) and, assuming this spread rate, it could reach Louisiana and Virginia within the next 80 years. [Citation: Rödder & Weinsheimer, 2009]

4. Stopping the spread [of the Burmese Python (Python molurus)] in the relatively narrow confines of the Florida peninsula would appear to be easier than controlling a much wider invasion front that may occur if the python spreads beyond peninsular Florida, as this work suggests is climatically possible. Nonetheless, there appear to be no precedents for containing an expanding continental snake population. The large potential range of the python in the New World suggests that early control may be a preferred option. [Citation: Rodda et al., 2009]

Category: Invasive Plants: Aquatic & Riparian (1) Highlight

1. Increasing winter minimum temperatures (or more probably reduction in the frequency and severity of freezing conditions) will most likely produce a northward shift in the range of subtropical species [in Florida]. Range shifts would be expected for several recently introduced invasive species, such as the tree Melaleuca quinquenervia (Cajeput) and the shrub Schinus terebinthifolius (Brazilian pepper), that can quickly suppress native species. In central and northern portions of the state, freshwater marshes may become dominated by Melaleuca and hardwood swamps by Schinus, as has occurred in the south. [Citation: Mulholland et al., 1997]

Category: Invasive Plants: Terrestrial (6) Highlights

1. Our analyses indicate that Brazilian pepper [(Schinus terebinthifolius), an invasive plant,] is present in at least 923 discrete protected areas in Florida, [US]. [Citation: Osland & Feher, 2019]

2. Our future scenario analyses [(i.e., +2°C, +4°C, and +6°C scenarios)] indicate that, in response to warming winter temperatures [in the US], Brazilian pepper [Schinus terebinthifolius] is expected to expand northward and invade ecosystems in north Florida and coastal Texas first, followed by expansion across much of the Gulf of Mexico and south Atlantic coasts of the United States (Figure 3). [Citation: Osland & Feher, 2019]

3. Potential for Japanese climbing fern [Lygodium japonicum] becomes higher as temperature and rainfall increase, although this effect diminishes at the extremes of both. The negative relationship to elevation may be an artifact of the dataset limitations, as populations currently only occur at low elevations. The potential distributions under the varying climate forecasts seem primarily driven by rainfall, with reduced rainfall within the current potential distribution and in Cornerstones [which project various scenarios for future climate, timber prices, and forest coverage and usage,] A, E, and B limiting distribution (fig. 15.31). Under Cornerstone A, B, and E the areas of high potential are lower than the status quo prediction (fig. 15.32). Under Cornerstone C the area of moderate potential extends to as far as Tennessee—the result of sustained rainfall patterns from the central Gulf to Appalachia coupled with a minimal increase in temperature. Under Cornerstones D and F cooler temperatures in winter are expected to reduce the potential significantly, pushing the distribution mainly into Florida. [Citation: Miller et al., 2013]

4. Under the significantly warmer and drier climate of Cornerstones [which project various scenarios for future climate, timber prices, and forest coverage and usage,] A and E, tallowtree [Triadica sebifera] could move up the Mississippi Alluvial Valley but would remain in Mississippi and Alabama, with decreased rainfall reducing the potential for occupation eastward into Florida, and along the Atlantic Coast. The moderate warming and similar rainfall to current in the mid-Mississippi valley, Florida and along the Atlantic Coast under Cornerstone B would allow tallowtree to exist in these locations. A predicted drier zone in Coastal Alabama and along northern Florida would nullify invasion potential in these areas. The areas of increase potential are related to rainfall. Cornerstone C would have the largest potential distribution of tallowtree with high or moderate potential of occurrence on 43 percent of forestland (fig. 15.26), a range that could expand westward from the Atlantic Coast and northward from the Gulf of Mexico, and an increase in inland pockets with medium potential. Cornerstones D and F, with decreasing minimum temperatures and a slightly drier Gulf Coastal Plain would have the lowest potential distribution (13 percent, combined higher and moderate potential), but still higher than the current occupation. Similar local conditions as now would confine tallowtree to Florida and the coastal areas of Alabama, Mississippi, and Louisiana. [Citation: Miller et al., 2013]

5. Surveys indicate dense infestations [of Melaleuca (Melaleuca quinquenervia)] in southern Florida forests with known outliers in central Florida (Ferriter 2007), where the actual coverage on all lands of this invasive exceeded half a million acres by 1993 (University of Florida Institute of Food and Agricultural Sciences 2007). Also it has been recorded as an escape along the south shores of Lake Pontchartrain near New Orleans (USDA Natural Resource Conservation Service 2010). This species could spread northward with warming climate at an estimated rate of 65 percent more coverage in 50 years, being the highest percentage increase for an invasive tree (table 15.1). [Citation: Miller et al., 2013]

6. In general, cogongrass [Imperata cylindrical] is favored by a warming climate. All three climate change storylines [which are based on three to four climate models and projections for population and economic trends] predict that potential habitat for cogongrass will cover the majority of the South in 2020 (Figure 6.13); exceptions are western Texas (constrained by low precipitation) and southern Florida (constrained

by high summer temperatures). Predicted potential cogongrass habitats in 2060 are very similar to the 2020 predictions, with only minor discrepancies at the western and southern edges of the range. [Citation: Olatinwo et al., 2014]

Factor: Land Use and Planning (2)

Land use refers to the products or benefits obtained from the land, in addition to the land management activities that produce those products or benefits. Change in land use condition from forest to other land cover types may result in habitat fragmentation, loss of open space, and areas of wildland-urban interface. Changes in climatic conditions as well as population growth will inevitably affect both land use and land cover. Forestland conversion and climate change have implications with regard to biodiversity management, species migration, forest pests, and wildfire management.

Category: Ecological Restoration (1) Highlight

1. Integrating changing climate conditions into seed transfer decision-making, however, will represent a major challenge, particularly when little is known about existing patterns of adaptive variation across the range of a species. We suggest that a reasonable seed transfer strategy for such species [flowering dogwood, Cornus florida, and longleaf pine, Pinus palustris] incorporates ecoregions that are quantitatively defined in current time, and are then projected into the future based on climate change projections. This approach objectively defines ecologically similar areas, both currently and in the future, to a given plant establishment site or to a plant source location, irrespective of geographic distance from the original seed source location or planting site. Although generally more complicated than determining geographic distance between seed source and planting site, site similarity based on large-scale environmental factors including climate, geology and geomorphology is a more useful predictor of potential seed source adaptedness to a restoration site (McKay et al. 2005; Vander Mijnsbrugge et al. 2010). [Citation: Potter & Hargrove, 2012]

Category: Urban Areas (1) Highlight

1. Across the United States, 60 wastewater treatment plants, serving over 4 million people, are exposed to flooding with 1 ft of SLR [sea level rise; using geographic information systems to assess the exposure of wastewater infrastructure to various sea level rise projections]. The largest increases in exposure occur from 3 to 4 ft of SLR, when an additional 83 plants serving 5.9 million people become exposed, and 4 to 5 ft of SLR, when an additional 91 plants serving 9.9 million people become exposed. By 6 ft of SLR, a total of 394 plants is exposed, and over 31 million people could be impacted by loss of wastewater services. At low levels of SLR, California, New York, New Jersey, and Virginia have the greatest exposure, each with more than 500,000 residents impacted after just 1 ft of SLR. A combined 5.4 million people in these states would be at risk of losing services at 2 ft of SLR. Other states, including Massachusetts, Florida, Maryland, and Texas, experience large increases in their exposure at 3, 4, 5, and 6 ft of SLR, respectively. [Citation: Hummel et al., 2018]

Factor: Plant Communities (4)

Plant Communities encompasses all vegetation groups in a particular area and their relation to the surrounding environment. The effects of climate change on plant communities and populations will act primarily through altering physical environments, increasing competition and causing species ranges to shift. Specific effects will vary by taxa and habitat requirements. Management strategies to abate the effects of climate change focus on increasing species diversity and targeted habitat restoration. Non-forest communities.

Category: General Impacts (1) Highlight

1. Little change (less than 10%) in tree richness would be expected in most of the central and southeastern US (Figure 5), although model predictions about northern Florida are quite variable. Large increases are predicted in the Pacific Northwest and the northern Rockies, mainly because of predicted increases in summer temperature. [Citation: Currie, 2001]

Category: Temperate Forests (3) Highlights

1. Changes in tree species diversity at the county level in the Coastal Plain indicate that the largest declines would occur in the Middle Gulf-West section. In that section, average diversity across all climate scenarios could decrease by 10 species for Morris and Smith Counties in Texas. Large decreases could also occur for Osceola County and Glades County in Florida, the Florida Peninsular section, and San Jacinto County and Montgomery County in the Texas portion of the Western Gulf section. Diversity was predicted to increase in small areas of the Middle Gulf-East section, where species richness would be greater by 2-to-4 species for Marshall County and Calloway County in Kentucky. Diversity will also likely increase slightly, by several species, for Green County in North Carolina and Lexington County in South Carolina. Overall, the MIROC3.2 A1B scenario [which uses a climate model and projects low population and high economic growth and high-energy use] consistently predicts decreased tree species diversity in 2060, but predictions by the other climate scenarios [which use climate models and project moderate growth and low-energy use] are variable, ranging from little or no change to small increases. Future diversity averaged across the four climate scenarios indicated a decrease throughout most of the Coastal Plain (Figure 10.12). [McNab et al., 2013]

2. Overall effects of future climate change will likely be variable among the seven sections of the Coastal Plain. The highest threats to forest tree species are predicted to occur in the Florida Peninsular, Southern Gulf, and Middle Gulf-West sections. The lowest threats are likely to occur in the Northern Atlantic and Middle Gulf-East sections. Tree species most vulnerable to climate change in the Coastal Plain could include slash pine, southern red oak, Shumard's oak [Quercus shumardii], and water oak [Quercus nigra]. Among climate scenarios, the MIROC3.2 A1B scenario [which uses a climate model and projects low population and high economic growth with high-energy use] forecasts the highest threats to plants resulting from possible climate change by 2060; the lowest threats are associated with the CSIROMK2 B2 and HadCM3 B2 scenarios [which each use a different climate model, and project moderate growth and low-energy use]. [Citation: McNab et al., 2013]

3. Effects of climate change on the occurrence of selected tree species in the Coastal Plain [in a study on thirty-seven tree species used for assessment of the effects of precipitation on forests in the Coastal Plain] are likely to be highest in the Florida Peninsular section. In Lee and Lakeland Counties, for example, precipitation is predicted to be 400 mm less than the current level of 1700 mm. Temperature for those counties is predicted to decrease by an average of 1°C, which, when considered with reduced precipitation, will possibly affect several of the tree species that have the largest annual water requirements, such as sweetbay [Magnolia virginiana] and water oak [Quercus nigra]. [Citation: McNab et al., 2013]

Factor: Soil & Geologic Resources (1)

Geologic resources in forested ecosystems may be managed to include ecosystem services such as maintaining soil health, carbon stocks, and biofuel production that have the potential to both abate climate change and reduce dependence on petroleum fuels. Traditional energy production on forest lands also acts to manipulate the carbon cycle, and the understanding of their impacts are important to adaptive management. The influence of climate change on soil resources will act through primary impacts on soil chemistry, and secondary impacts on soil organisms, structure, and fertility. Mitigation strategies, including reducing disturbances on soil and geologic resources, will act to buffer these effects.

Category: Soil Carbon (1) Highlight

1. The annual C [carbon] balance in wetlands is sensitive to minor changes in climatic conditions that alter the hydrologic regime. Temperature affects the rate of a number of processes that in turn affect soil C dynamics. The higher temperature at FL [Florida] site caused a decrease in SOC [soil organic carbon] (8074 kg C ha-1 yr-1) because of a greater proportion of C was respired during decomposition of soil pools. [Citation: Cui et al., 2005]

Factor: Vegetation Management (28)

Vegetation management refers to the manipulation of vegetation through silvicultural treatments to produce a higher quantity or quality of desired products or conditions, such as timber production or carbon sequestration. Under climate change, consideration should be given to the impacts of traditional vegetation management practices and their interactions with climate related stresses. Understanding of fluctuations in vegetation growth and yield patterns will help guide management in a changing climate. In addition, mixed management for carbon sequestration in forests will also act to alter management strategies on a wide scale, and may help offset the cost of climate mitigation.

Category: Carbon Sequestration (7) Highlights

1. We estimated a total SOC stock (1991–2010) [for Mexico and the conterminous US] of 47 Pg (Figure 5a) that varies from 41 to 55 Pg of SOC for the models 1991–2000 (Figure 5b) and 2001–2010 (Figure 5c), respectively. For the years 1991–2010, the residual error map suggested 10.4±5.1 Pg of SOC variance associated with the use of multiple pedotransfer functions for BD and consequently calculating SOC stocks. The larger variance of associated with BD was found across the surroundings of the Great Lakes, in the states of Vermont, New York, and borders between Pennsylvania and Ohio, in CONUS (Figure 6a). The residual error map of our models against two fully independent datasets (RaCA and Mexican Forest Service) suggested a higher value of 28.8 ± 9.1 Pg of SOC variance. The large variance associated with the independent datasets was found also across the surroundings of the Great Lakes, but in the states of Wisconsin and Minnesota (Figure 6b). Another large variance from the independent validation was found across the state of Florida, specifically across the south section in the everglades area where there are limited observations for the training dataset (Figure 1). [Citation: Guevara et al., 2020]

2. Tropical cyclones cause extensive tree mortality and damage to forested ecosystems. A number of patterns in tropical cyclone frequency and intensity have been identified. There exist, however, few studies on the dynamic impacts of historical tropical cyclones at a continental scale. Here, we synthesized field measurements, satellite image analyses, and empirical models to evaluate forest and carbon cycle impacts for historical tropical cyclones from 1851 to 2000 over the continental U.S. Results demonstrated

an average of 97 million trees affected each year over the entire United States, with a 53-Tg annual biomass loss, and an average carbon release of 25 Tg y^{-1}. Over the period 1980–1990, released CO_2 potentially offset the carbon sink in forest trees by 9–18% over the entire United States. U.S. forests also experienced twice the impact before 1900 than after 1900 because of more active tropical cyclones and a larger extent of forested areas. Forest impacts were primarily located in Gulf Coast areas, particularly southern Texas and Louisiana and south Florida, while significant impacts also occurred in eastern North Carolina. Results serve as an important baseline for evaluating how potential future changes in hurricane frequency and intensity will impact forest tree mortality and carbon balance. [Citation: Zeng et al., 2009]

3. Carbon markets would encourage forest landowners to increase rotation ages of their plantations. Emerging wood-based energy markets would increase prices of small-diameter timber products, thereby encouraging forest landowners to possibly opt for shorter rotation ages. We developed a comprehensive forest carbon model to track four carbon pools (carbon related to silvicultural activities, carbon sequestered on forestlands, carbon sequestered in wood products and wood present in landfills, and avoided carbon emissions) at the stand level to determine efficacy of carbon and bioenergy markets in mitigating carbon emissions with and without any change in rotation ages. Slash pine (Pinus elliottii) – a common species planted across the Coastal Plain of Georgia and Florida was taken as a representative species. We find that an increase in rotation age does not necessarily transform into additional carbon savings relative to some base rotation ages over a planning horizon of 100 years. Similarly, a decrease in the rotation age is not necessarily beneficial from carbon perspective either with respect to some base rotation ages. The utilization of all timber products for manufacturing of wood pellets to generate electricity in the United Kingdom maximizes carbon savings without any change in the rotation age. Suitable safeguards need to be incorporated in existing forest and bioenergy certification schemes to ensure efficacy of reforested lands in mitigating carbon emissions. Climate policies should emphasize on a systemic approach to maintain carbon mitigation potential of the forestry sector over time. [Citation: Dwivedi et al., 2016]

4. These plantations [at our study site on a commercial slash pine (Pinus elliottii var. elliottii) plantation near Gainesville, Florida] returned to being carbon sinks after four years, with maximum net carbon uptake reached before age 10. Aboveground tree NPP [net primary production] was the major sink for carbon uptake, with >100 Mg C/ha accumulated before the next harvest. [Citation: Bracho et al., 2012]

5. The major disturbance produced by harvesting [at our study site on a commercial slash pine (Pinus elliottii var. elliottii) plantation near Gainesville, Florida] shifted the previous plantation from being a carbon sink to a strong carbon source due to the elimination of tree LAI [leaf area index] and a very large consequent reduction in GEE [gross ecosystem carbon exchange]. Early in stand development, aggrading LAI and intercepted PAR [Photosynthetically active radiation] were the dominant controls on carbon accrual. After canopy closure, water availability was an important environmental regulator of annual carbon uptake and ecosystem balance, although over a much lower amplitude. [Citation: Bracho et al., 2012]
6. The timing and magnitude of droughts had differing effects on the processes controlling ecosystem carbon balance [at our study site on a commercial slash pine (Pinus elliottii var. elliottii) plantation near Gainesville, Florida]. Water availability regulated net carbon uptake through its effect on both LAI [leaf area index] and on radiation-use efficiency. Drought impacted LAI by inducing early needle drop and/or by restraining needle growth. Radiation-use efficiency was controlled by physiological controls on gas exchange (stomata opening) during severe droughts. Drought had a much stronger impact on GEE [gross

ecosystem carbon exchange] than on Re [ecosystem respiration], resulting in a clear reduction in NEE [net carbon uptake]. [Citation: Bracho et al., 2012]

7. Land use, land-cover type, and precipitation were the primary determinants of C [carbon] density, which increased from west to east [of the Southern United States] (Figure 8). The highest C storage, generally greater than 25 kg/m2, was in wetland areas. Total C storage was also determined for each state (Figure 7C). During the 2007 regional drought, Texas had the highest terrestrial ecosystem C storage of any state (4.17 ± 0.39 Pg) due to its large land area. This was followed by Florida (3.81 ± 0.36 Pg), which has a large wetland area (about 18% of the total land area) (Figure 1). Kentucky had the lowest C storage (1.46 ± 0.14 Pg). [Citation: Tian et al., 2012]

Category: Factors Limiting Productivity (3) Highlights

1. After canopy closure, the annual variability in NEE [net ecosystem exchange] of these [Pinus elliottii var elliottii plantation] sites [near Gainesville, Florida] was most closely related to the departure of growing season precipitation from long-term averages (r2 = 0.54, P<0.01; Fig. 7a). [Citation: Bracho et al., 2012]

2. However, if low precipitation extends through the growing season during severe and extreme drought conditions, elongation of newly formed needles is also reduced, as observed for Pinus radiata by (Linder et al. 1987) and (Sands and Correll 1976) and in our stands [Pinus elliottii var. elliottii plantation near Gainesville, Florida] in 2006-2007. [Citation: Bracho et al., 2012]

3. Water deficits during the growing season actually had two effects on LAI [leaf area index] [of a Pinus elliottii var. elliottii plantation near Gainesville, Florida]: i) early needle drop as compared with wet years, and ii) a reduction in needle growth. Two pulses of needle fall were recorded during drought years (data not shown), a smaller one in late spring and early summer, in addition to the normal more major event in the late fall, as observed for similar stands by Gholz et al. (1991). [Citation: Bracho et al., 2012]

Category: General Impacts (3) Highlights

1. As atmospheric carbon dioxide concentration is rising, plants can and do reduce water loss by reducing maximal stomatal conductance while maintaining carbon uptake [Beerling & Franks, 2010; Brodribb et al., 2005]. Further decreases in stomatal conductance have been observed at CO2 rising above present levels in FACE [free-air carbon enrichment] short-term experiments [Ainsworth& Rogers, 2007] and in fossil leaves over geological timescales [Franks & Beerling. 2009]. Both lines of evidence, however, fall beyond or below the timescales of the projected rate of continuing CO2 increase, which is likely to surpass the time needed for adaptation via natural selection. Consequently, the adaptation within the phenotypic plasticity is likely to constrain epidermis structural adaptation in the near future when phenotypic response limits are reached [Kürschner, 1997; De Boer et al., 2011]. Current increase in CO2 and the coinciding reduction in plant transpiration already results in increased continental run-off [Gedne et al., 2006], and climate models predict surface temperature increases arising from reduced evaporative cooling [Andres et al., 2010; Cao et al., 2010]. [Citation: Lammertsma et al., 2011]

2. Because the construction of an extended vascular network is coupled to high carbon costs [Beerling & Franks, 2010; McKown et al., 2010], it was hypothesized before that angiosperms reduce gsmax [stomatal conductance] more than conifers and ferns. However, our data [from our study of CO2 effects on stomatal conductance in Florida trees; red maple (Acer rubrum), Southern Wax myrtle (Myrica cerifera),

Dahoon holly (Ilex cassine), swamp laurel oak (Quercus laurifolia), water oak (Quercus nigra), slash pine (Pinus elliottii), loblolly pine (Pinus taeda), baldcypress (Taxodium distichum), and the Royal fern (Osmunda regalis)] show a highly comparable sensitivity to the industrial CO2 rise in all groups sampled and thereby demonstrate the underlying principle that plants generally optimize their leaf structure in response to rising CO2, apparently irrespective of their leaf architecture. [Citation: Lammertsma et al., 2011]

3. A fundamental response of C3 plants to increasing atmospheric CO2 concentration(CO2) is to minimize transpirational water loss by reducing diffusive stomatal conductance (gs) and simultaneously increasing assimilation rates [Cowan & Farquhar, 1997]. The resulting increased intrinsic water-use efficiency (iWUE: the ratio of assimilation to gs) improves the vegetation's drought resistance and reduces the cost associated with the leaf's water transport system like leaf venation [Raven, 2002; Beerling & Franks, 2010]. On a regional to global scale, decreasing rates of transpiration concurrently affect climate through reduced cloud formation and precipitation [Bonan, 2008] and with this exert a physiological feedback on climate and hydrology on top of the radiative forcing of increasing CO2 [Betts et al., 2007; Andres et al., 2010; Cao et al., 2010]. [Citation: Lammertsma et al., 2011]

Category: Growth and Yield (15) Highlights

1. [In our dendroclimatological study of historic longleaf pine (Pinus palustris) growth in east Texas, Florida, and South Carolina,] The correlation between longleaf pine growth and Palmer [drought severity] indices was the highest among all climate variables. The most significant correlations between ring width and precipitation occurred with precipitation in the current spring and summer months. Although the correlation between longleaf pine growth and temperature was rather weak, warm summer temperatures in the current year negatively affected tree growth at most sites. The climate/ growth response in Texas was generally stronger than at sites farther to the east, possibly because of the higher evapotranspiration rates at the far western extent of the species. [Citation: Henderson & Grissino-Mayer, 2009]

2. The longleaf pine [Pinus palustris] trees in Florida and South Carolina grow in Quartzipsamment soils that have low moisture retention, while the soils in the Big Thicket are loamier. On dry soils like Quartzipsamments, the soil can become extremely dry within 1 week without substantial rainfall (Outcalt, 1993; Mike Leslie, personal communication). The effectiveness of a particular precipitation event is probably less on the sandy sites because the water tends to drain more quickly through the soil profile to the groundwater table. As a result, the amount of water that a longleaf pine tree would be able to take up in its root system would be less than in a more loamy soil. [Citation: Henderson & Grissino-Mayer, 2009]

3. Eastern Texas is approximately 1°C hotter than the Florida panhandle in the summer, and rainfall is critical at the far western edge of the range of longleaf pine [Pinus palustris] (Schmidtling and Hipkins, 1998). Consequently, longleaf pines in the Texas region are more susceptible to rainfall deficiencies and the related costs of high respiration and tissue maintenance. This finding illustrates the importance of the concept of ecological amplitude, which states that climate becomes highly limiting to tree growth near the margins of a species' natural range (Fritts, 2001). [Citation: Henderson & Grissino-Mayer, 2009]

4. Following the same trend as the precipitation variable, the Palmer [drought severity] indices were not as strongly correlated with longleaf pine [Pinus palustris] growth in the spring as in the summer and late fall

[in our dendroclimatological study of historic longleaf pine growth in east Texas, Florida, and South Carolina], which indicates that moisture conditions are much more critical late in the growing season. Late summer and early fall droughts can affect the rate of carbohydrate conversion to new tissues, and even with substantial carbohydrate reserves, cambial growth can be slowed (Kozlowski, 1971). [Citation: Henderson & Grissino-Mayer, 2009]

5. The most consistent trend in this [dendroclimatological] study [of historic longleaf pine (Pinus palustris) growth in east Texas, Florida, and South Carolina,] was the negative influence of warm summer temperatures on cambial growth, particularly for the Texas region. Warm summer temperatures in the current year adversely affected latewood growth in Texas and South Carolina. The correlations between July temperature and latewood width for Texas (r =, 0.42, p<0.0001) and South Carolina (r =, 0.33, p<0.0005) were statistically significant. [Citation: Henderson & Grissino-Mayer, 2009]

6. [In our dendroclimatological study of historic longleaf pine (Pinus palustris) growth in east Texas, Florida, and South Carolina,] An interesting trend in the correlation analysis shows that the relationship between precipitation and tree growth is not constant throughout the spring and summer growing season. March, April, and July precipitations appear to be consistently influential for tree growth, while rainfall in the months of May and June is generally less important. These patterns may reflect the seasonal growth flushes that occur in longleaf pine. [Citation: Henderson & Grissino-Mayer, 2009]

7. [In our dendroclimatological study of historic longleaf pine (Pinus palustris) growth in east Texas, Florida, and South Carolina,] The highest correlations between tree growth and precipitation in the prior year occurred with previous September precipitation and EWW [earlywood width] (for South Carolina) (r = 0.24, p<0.01) and previous November precipitation and LWW [latewood width] (for Texas) (r = 0.23, p<0.02). Earlywood growth responds positively to rainfall in fall of the prior year, presumably because longleaf pine builds carbohydrate reserves during the fall that are used in the growth flush in the following spring. These findings contrast those found by Foster and Brooks (2001), who found a significant positive relationship between previous June and July precipitation and TRW [total ring width]. [Citation: Henderson & Grissino-Mayer, 2009]

8. [In our dendroclimatological study of historic longleaf pine (Pinus palustris) growth in east Texas, Florida, and South Carolina,] The correlation between longleaf pine growth and precipitation was moderate to high, and tree growth was most affected by rainfall in the current spring and summer (Fig. 3). These results are generally consistent with other dendroclimatic studies on longleaf pine (Devall et al., 1991; Meldahl et al., 1999; Foster and Brooks, 2001). Earlywood formation was most strongly correlated with current spring precipitation, and latewood formation depended heavily on current summer precipitation. The correlations were highest between summer precipitation and LWW [latewood width] in Texas (r = 0.54, p<0.0001) and South Carolina (r = 0.49, p<0.0001). Longleaf pine growth in Florida correlated most strongly with precipitation in the spring season (r = 0.32, p<0.001), but the results for Florida only included an analysis of TRW [total ring width]. [Citation: Henderson & Grissino-Mayer, 2009]

9. The responses of tree growth to elevated CO2 are variable among species (Bazzaz, 1990; Saxe et al., 1998; Penuelas et al., 2001; Korner et al., 2005; Seiler et al., 2009; Dawes et al., 2011), and differential species responses have commonly been observed in CO2-enrichment experiments (Table S1). For example, of the three codominant canopy tree species (Fagus sylvatica, Quercus petraea, Carpinus betulus) in the mature deciduous forest exposed to elevated CO2, shade-tolerant Fagus exhibited increased annual basal area

increments in response to CO2 in two of four treatment years, whereas growth of the other species remained the same or declined (Korner et al., 2005). Similarly, proportional species' contributions to whole-ecosystem productivity shifted in a Florida scrub–oak ecosystem exposed to elevated CO2: dominant Quercus myrtifolia exhibited strong biomass growth, [Quercus chapmanii] exhibited less of an effect, and subdominant [Quercus geminata] showed no growth stimulation (Dijkstra et al., 2002). Thus, differential species growth responses consistently alter proportional species' contributions to whole-ecosystem productivity and will likely change the composition of future communities. [Citation: Anderson-Teixeira et al., 2013]

10. NPP [net primary production], although highly variable [at our study site on a commercial slash pine (Pinus elliottii var. elliottii) plantation near Gainesville, Florida], was also positively related to growing season precipitation, changing by .4 Mg C/ha over 600 mm range (r, 0.05; Fig. 7b). This suggests that drought effects on annual carbon fluxes resulted not only from decreased annual precipitation, but even more so by changes in its seasonal distribution; particularly, below average precipitation during the growing season induced lower carbon uptake. Other studies have shown that growth of slash pine stands is positively correlated with water balance during the current growing season (Ford and Brooks 2003) and aboveground NPP in a longleaf pine [Pinus palustris]–wiregrass [Aristida stricta] ecosystem was also positively correlated with seasonal water availability (Mitchell et al. 1999). [Citation: Bracho et al., 2012]

11. Across all four climate scenarios, the percentage change in GSV/ha [growing stock volume per hectare] [of loblolly pine (Pinus taeda) plantations] ranges from −31% to 16%. The prediction under the A1 scenario is slightly lower and the prediction under the B2 scenario is slightly higher than for other scenarios. Recall that the Hadley III A1 model predicts the largest increase in temperature and B2 predicts the smallest increase in temperature. The SGM results imply that a less warm climate would be preferable to a warmer climate for loblolly pine plantations in the southern United States. Although the magnitude of the prediction varies for different scenarios, the spatial pattern of the growth change is consistent across the four scenarios. Georgia, South Carolina, North Carolina, Arkansas, and eastern Texas are projected to experience a larger increase in loblolly pine growth. A larger decrease in the GSV is projected to occur in Florida, southern Louisiana, and southern Alabama. [Citation: Huang et al., 2011]

12. The MCC Scenario [historic site climate + combined increases in air temperature and precipitation] predicted that NPP [net primary productivity] [of loblolly pine (Pinus taeda] at the VA [Virginia] site would increase, while predicted NPP at the three other sites decreased. The MCC Scenario for the VA site did not increase average growing season air temperature beyond optimal levels for photosynthesis (Strain et al. 1976), and increased precipitation reduced water stress. Conversely, the effects of increased temperature at the FL [Florida] and TX [Texas] sites were not offset by increased precipitation, so NPP decreased. Finally, the MS [Mississippi] site, which had the highest precipitation and intermediate air temperature, showed the smallest increase in NPP when precipitation was increased by 20% and exhibited a moderate reduction in NPP under the MCC Scenario. [Citation: McNulty et al., 1996]

13. McNulty et al. (1996) pointed out that increasing monthly minimum and maximum temperature by 2 °C, NPP of loblolly pine [Pinus taeda] forests decreased 30% in the Florida site. [Citation: Wang et al., 2011]

14. The reduction of NPP [Net Primary Production] in northern AR [Arkansas] was a result of the transition of species composition by the reductions of Q. alba, Q. velutina, Q. rubra, Cornus florida, J. virginiana and

Carya texana and increases of Pinus taeda, inus. elliottii, and Quercus nigra (Figure 3). The net changes as a result of this transition of species composition ranged from −2% to −6%. [Citation: Chiang et al., 2008]

15. Mean growing season temperature had a very large effect on [loblolly pine (Pinus taeda)] seedling biomass accumulation in this study. Total biomass accumulation was highest at the Athens [Georgia] site, and it was 18% less at the Macon [Georgia] site, 43% less at the Gainesville [Florida] site and 48% less at the Coweeta [North Carolina] site. [Citation: Nedlo et al., 2009]

Factor: Water Resources (12)

Water Resources refers to the quantity, quality, and dynamics of surface water and groundwater. Climate change, especially climate variability producing drought and flood events, may alter hydrologic characteristics of watersheds with implications for wildlife, forest productivity, and human use. Climate change impacts on watershed conditions can be evaluated by considering aquatic, terrestrial, biological and physical indicators. These indicators can help managers identify vulnerable watersheds, understand watershed responses to changing climate, and inform management objectives and practices.

Category: General Impacts (1) Highlight

1. With a warming of 4°C, the thermal regime of a stream will become similar to that presently characteristic of streams 640 km to the south (Sweeney et al., 1992). For example, the thermal regimes of streams in Virginia, North Carolina and Tennessee would become similar to those now in southern Alabama, southern Georgia and northern Florida. [Citation: Mulholland et al., 1997]

Category: Groundwater (6) Highlights

1. In large regions of the Southwest, Great Plains, Midwest, Florida, and some other coastal areas, groundwater is the primary water supply. Groundwater aquifers in these areas are susceptible to the combined stresses of climate and water-use changes. For example, during the 2006–2009 California drought, when the source of irrigation shifted from surface water to predominantly groundwater, groundwater storage in California's Central Valley declined by an amount roughly equivalent to the storage capacity of Lake Mead, the largest reservoir in the United States (Famiglietti, et al., 2011). [Citation: Georgakakos et al., 2014]

2. Even if sea level does not rise in the future, model simulations suggest that corrective actions would likely be required to protect the [shallow coastal] aquifer [in the Pompano Beach well-field and southeastern Florida area] from salinization. Corrective actions would be required as much as 21 years sooner depending on the future rate of sea-level rise. [Citation: Langevin & Zygnerski, 2012]

3. However, during the dry periods when the water table was well below the ground surface, impacts were stronger, which suggests that the water table is more sensitive to climate change during dry periods. [Citation: Lu et al., 2009]

4. An increase in air temperature by 2°C increased PET [potential evapotranspiration], and thus increased water loss [in a pine flat-woods site in Florida]. An increase in water loss resulted in a further drop of the water table level. [Citation: Lu et al., 2009]

5. When temperature increased 2°C or precipitation decreased 10%, the water table dropped deeper than the base line scenario. [Citation: Lu et al., 2009]

6. The coastal plain region may be more susceptible to disturbances due to its unique hydrology that is dominated by shallow ground-water tables (Amatya and Skaggs 2001). The shallow ground-water tables reflect the dynamic balances between evapotranspiration (ET) and precipitation (Sun et al. 2002). About 70–80% of annual precipitation returns to the atmosphere as ET in coastal watersheds (Gholz and Clark 2002, Lu et al. 2003, 2005). Therefore, any changes to ET and precipitation will have direct impacts on the ground-water table fluctuation patterns, and potentially the biotic functions. [Citation: Lu et al., 2009]

Category: Surface Water (1) Highlight

1. Figure 1 illustrates that Floridian catchments are different from other catchments. This is confirmed in Figure 3, as the light-blue/dark-blue region consumes the entire eastern half of the continent, excluding Florida. In Figure 13 (top left), we observe fairly similar precipitation signatures (slightly more rain is received after 1980). However, the quantity of runoff observed is lower at every date. This seems well explained by the maximum precipitation/runoff signatures (Figure 13, bottom left), as the maximum precipitation values obtained are lower at essentially every date, yielding lower peak runoff, especially during the summer and fall. This suggests that runoff, previously driven by unusually large storms, now has been diminished by slightly less-intense storms. Observations of seasonal variability of runoff (Figure 13, top left) illustrate that after 1980, the variability of runoff has increased, perhaps due to decreased hydrologic residence times, especially during the first few months of the year. This shift may be caused by precipitation exiting the watershed more rapidly, causing higher variability than the gradual release of runoff. Water users and regulators may begin to grapple with the possibility of limited streamflow. [from an analysis of hydroclimate data from over four hundred catchments in the US over a 55 year period] [Citation: Coopersmith et al., 2014]

Category: Water Quality (1) Highlight

1. More frequent or longer lasting droughts and reduced freshwater inflows could increase the incidence of extreme salt concentrations in coastal ecosystems (on the Gulf Coast) resulting in a decline of valuable habitats such as the mangroves and seagrasses in Florida Bay or South Texas lagoons. [Citation: Twilley et al., 2001]

Category: Water Supply (3) Highlights

1. Although there remains substantial uncertainty about future precipitation and thus water yield, climate change and population growth are likely to present serious challenges in some regions of the U.S., notably the central and southern Great Plains, the Southwest and central Rocky Mountain States, and California, and also some areas in the South (especially Florida) and Midwest. The continued reductions in per-capita water withdrawal rates assumed here, which follow trends established over the past three decades, are essential but insufficient to avoid impending shortages. Attention will therefore focus on the other options examined here—additional reservoir storage capacity, groundwater mining, instream flow reduction, and ag-to-urban transfers—all of which have serious external costs. Of these four options, the first has limited promise, especially where most needed. Simulations show that major additions to storage capacity are ineffectual in the most vulnerable basins due to a lack of water to fill the reservoirs. The other three options, however, can be quite effective in many locations, indicating that pressures to implement them will mount as shortages become more severe. If further reductions in groundwater

storage and instream flow are to be avoided, improvements in irrigation efficiency beyond those assumed here will become a high priority, but in addition transfers from agriculture to other sectors probably will be essential (Tanaka et al., 2006). While not without external costs, such transfers fortunately occur voluntarily and would primarily involve water formerly used to grow relatively low-value crops. As has been argued elsewhere (Binder et al., 2010), an important adaptation strategy will be to reduce institutional impediments to such transfers. [Citation: Brown et al., 2019]

2. Projected water yields, which reflect most importantly the GCM-based projections of temperature and precipitation, vary substantially among the 14 futures [created by matching two future greenhouse gas emission scenarios with seven global climate models] and show no consistent trends (supporting information Figure S2). For the U.S. as a whole, from the past period (years 1985 to 2010) to the midfuture period (years 2046 to 2070), six futures show increases and eight show decreases. Changes in mean annual yields from the past to the mid future period range from −2.6 cm (IPSL85) to 1.5 cm (MPI45). However, the RCP [representative concentration pathways] averages, each computed across seven futures, are in close agreement, with mean annual yield projected to initially decrease and then stabilize in middle to late century. RCP average changes in mean annual yield from the past period to the midfuture period are −0.3 cm for RCP 4.5 and −0.7 cm for RCP 8.5 (Figure S2). The projected RCP yields are similar largely because, relative to RCP 4.5, increases in precipitation with RCP 8.5 act to compensate for the effects of temperature increases on water yield (Mahat et al., 2017). Projected changes in yield are highly variable across basins. Averaging across the 14 futures, from the past to the midfuture period, 145 basins show decreases in yield and 59 show increases, with the most severe decreases occurring in the Southwest, the middle to southern Great Plains, and Florida, and the greatest increases occurring in the larger Northwest, Great Basin, and California (Figure 2b). [Citation: Brown et al., 2019]

3. Based on WaSSI model [Water Supply Stress Index, a model used to project the effects of human, atmospheric and landscape dynamics on water supply stress] results under the four future climate scenarios considered in this chapter, streamflows and water supply will generally decrease and become more variable over the next 50 to 100 years. However, magnitudes and even the signs of changes in streamflows resulting from climate change will vary considerably across the region, with some small areas, such as western Texas, experiencing increases in water supply. Other areas will likely experience decreases in supply, particularly in Florida, Oklahoma, and northern Texas. Overall, climate-induced decreases in water supply and increased demand from a growing human population will likely result in an increase in water supply stress into the next century. [Citation: Lockaby et al., 2013]