Rookery Bay National Estuarine Research Reserve

Climate Change Vulnerability Assessment Exercise Summary Information

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Management Context

Rookery Bay National Estuarine Research Reserve (RBNERR), established in 1978 by the Florida Department of Environmental Protection (DEP), is located at the northern end of the Ten Thousand Islands on the Gulf coast of Florida (Figure 1). The area represents one of the few remaining undisturbed mangrove estuaries in North America. It is also unique in that there is no actual river mouth; instead, it is located where the vast, moving sheet of water from the Florida Everglades seeps into the sea. (Source: www.rookerybay.org).

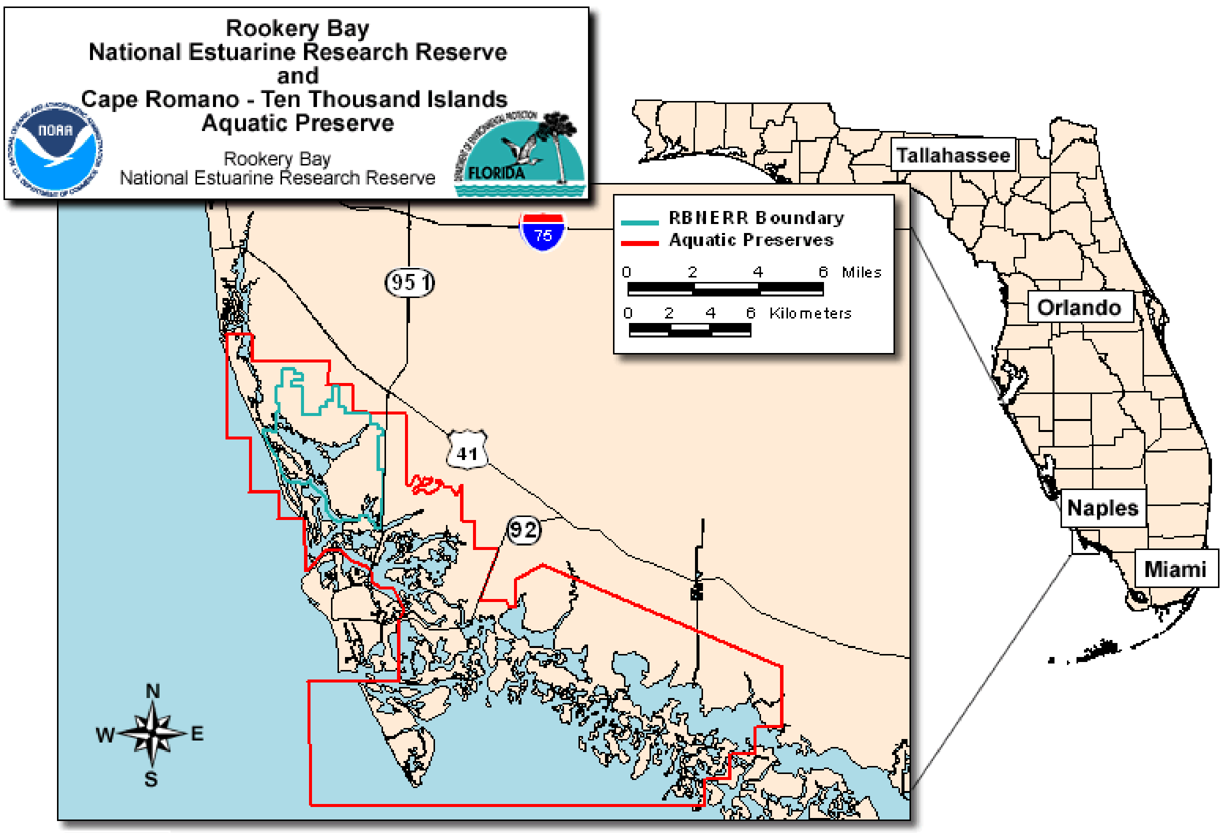


Figure 1

Jurisdictional Context

(Source: www.rookerybay.org, unless otherwise noted). Approximately 3,772 acres within the RBNERR boundaries are leased to the Department of Environmental Protection by NAS, The Nature Conservancy, and CSF. State-owned lands, including 70,000 acres of submerged lands and approximately 22,928 acres of acquired lands, are held in fee simple title by the Board of Trustees. Approximately 13,300 additional acres within the boundaries were acquired by the state as part of a settlement agreement with the Deltona Corporation. Parcels totaling approximately 500 acres represent privately-owned holdings within RBNERR.

Beyond RBNERR are a number of other state, federal, and cooperatively-managed areas and programs that help support the mission and objectives of the NERRS. For example, south of the RBNERR is the Cape Romano –Ten Thousand Islands Aquatic Preserve, which remains one of the most ecologically rich areas in Florida. Also in this area is the Ten Thousand Islands National Wildlife Refuge, located between Marco Island and Everglades City, Florida, and a small portion of Everglades National Park. To the north are Charlotte Harbor and its surrounding bays, lagoons, and upland rivers, which are part of collaborative research and conservation efforts conducted under the Charlotte Harbor National Estuary Program.

DEP has proposed for NOAA consideration that the boundaries of RBNERR be expanded to incorporate adjacent state-owned coastal and submerged lands. DEP has designated all tidally connected waters within the boundaries of RBNERR and Cape Romano/Ten Thousand Islands Aquatic Preserves as Class II and Outstanding Florida Waters (OFW). OFW designation implements that state's highest standards for proposed developments, and does not allow for direct discharges that would lower ambient water quality, or indirect discharges that would significantly degrade water quality.

Existing Mission/Goals

The mission of RBNERR is to provide a basis for informed coastal decisions through land management, restoration, research, and education. RBNERR works in partnership with local communities to promote coastal stewardship. Located adjacent to one of the fastest developing coastal areas in the United States, RBNERR is ideally suited as a regional hub for education and research on estuaries. The estuarine environment of RBNERR also provides an ideal setting for a variety of recreational activities, including sportfishing, boating, hiking, sailing, bird watching, or simply enjoying the aesthetics of the area. Recreational fishing represents a primary public use of RBNERR resources and provides significant contributions to the economy of local communities.

The 2000-2005 Management Plan for RBNERR (DEP 2000) identifies six programs, each of which has goals and objectives to help the Reserve meet its mission.

- Resource Management and Protection Program.
  - *Issue: Watershed Alterations*. Goal: To restore natural freshwater inflow quality and quantity, to the fullest extent possible, by promoting conservation of natural flowways through cooperative efforts with federal, state, and local agencies, organizations, and private landowners.
  - *Issue: Loss of Native Biodiversity*. Goals: 1) To protect and restore cultural sites and natural ecological functions within the areas managed by the Reserve through invasive species control, prescribed burn management, and hydrologic restoration of wetlands. 2) To assist in the recovery of endangered species through cooperative efforts with private landowners and local, state, and federal agencies and organizations.
  - *Issue: Public Use*. Goal: To promote compatible public use while minimizing natural and cultural resource and human use conflicts through proactive identification of sensitive habitats and cultural resources relative to public use patterns.

- Research and Monitoring Program.
    - *Issue: Watershed Alterations*. Goal: To identify natural freshwater inflow quality and quantity needed for the long-term conservation of the natural biodiversity of the estuarine habitats managed by the Reserve.
    - *Issue: Loss of Native Biodiversity*. Goals: 1) To scientifically assess the effectiveness of the Reserve's invasive species control, prescribed burn management and hydrologic restoration projects to restore natural ecological functions. 2) To assess the condition of the Reserve's listed species populations and associated habitats by establishing and implementing a monitoring program to periodically determine the effectiveness of the Reserve's management strategies.
    - *Issue: Public Use*. Goals: 1) Conduct and facilitate research to identify natural resource and human use conflicts. 2) Proactively identify the carrying capacity of sensitive habitats relative to public use patterns and mosquito control activities. 3) Facilitate and support research in the RBNERR conducted by visiting investigators, through partnerships and universities, research institutions and agencies.

- Education and Training.
    - Goals: 1) Increase public awareness of the value of estuarine ecosystems and community involvement in coastal stewardship. 2) Increase the layperson's personal awareness and understanding of coastal zone issues in Southwest Florida. 3) Assess information needs and provide technical training for professionals involved in decisions that affect coastal resources. 4) Provide opportunities for compatible public access and use of Reserve resources.

- Public Access and Visitor Use.
    - Goals: 1) Through a community-based planning process, develop public access and visitor use projects (e.g. trails) that promote uses of Reserve resources that are compatible with the mission of the RBNERR, ensures protection of key natural and cultural resources and keeps pace with the changing needs of local communities. 2) Utilize public access and visitor use sites within the Reserve as education and interpretation opportunities that encourage coastal stewardship. 3) Using existing authority provided by local, state, and federal laws, establish appropriate policies for public access and visitor use that ensures protection of important natural and cultural resources and wildlife, conduct visitor outreach efforts to convey use policies and the need for them, and work cooperatively with partner agencies and law enforcement to provide enforcement. 4) Monitor public access and visitor use to assess impacts to environmental conditions within the Reserve, and use adaptive management methods to address potential impacts.

- Program Administration.
    - Goals: 1) Enhance and maintain communications for RBNERR, and with the local community, key partners, granting agencies, CAMA and Region offices. 2) Increase staff training opportunities – both internally and externally (Regional offices, partnerships, etc.). 3) Provide for safe and effective work environment for

staff, volunteers and the public through staff/volunteer orientations, training, or incentives. 4) Increase level of support for CAMA Southwest Florida Regional field offices at Estero Bay, Charlotte Harbor, and Tampa Bay.

- Partnerships and Regional Coordination.
    - Goal: Support and facilitate coordination of coastal science, stewardship, and education within the Southwest Florida region.

Ecological Context

The total estimated surface area of open waters encompassed within the boundaries is 70,000 acres, 64 percent of the RBNERR. The remaining 40,000 acres are composed of mangroves, fresh to brackish water marshes, and upland habitats. Rookery Bay has a surface area of 1,034 acres and a mean depth of about 1 meter. Salinities range from 18.5 to 39.4 parts per thousand (ppt), with lower values occurring during the wet season from May through October. Highest values occur during the dry seasons (winter and spring) and can exceed those of the open Gulf of Mexico (35-36 ppt). (Source: www.rookerybay.org).

Key Habitats

Rookery Bay twelve main sub-categories of habitat, classified as to physical characteristics (e.g., vegetation, soil, and hydrology) and management strategies related to fire regimes, exotic species control, and restoration. (Source: www.rookerybay.org/publications/field-guide, unless otherwise noted). The categories include:

- Cabbage Palm/Oak Hammock. Mixed hardwoods, including live oaks and myrtle oaks, red maple, red bay, cabbage palm, and a variably dense understory of shrubs. May have standing water during any part of the year, more commonly in wet season.

- Pine Flatwoods. Dominated by slash pine and saw palmetto, with cabbage palm islands and areas of grasses and sedges interspersed. Indicative of higher, drier land, but standing water may cover areas in slash pine habitat for several weeks or months during rainy period.

- Coastal Xeric Scrub. Scrub oak species occur on Reserve lands where the elevation exceeds five feet. This habitat is dominated by oak and saw palmetto. Many shrubs and weeds here are extremely drought tolerant, adapted to grow in continuously dry, sandy, nutrient-poor soil. Although these areas receive similar rainfall amounts as other areas in the Reserve, the permeable sand precludes significant water absorption or storage.

- Cypress Slough/Cypress Prairies. Dominated by pond or bald cypress with mixed understory throughout. Restricted to areas subjected to flowing fresh water (i.e., sheetflow). Intermittently exposed to surface waters flowing through Reserve uplands; quality and quantity of water is important. Nonindiginous plant species, human alterations, and water table lowering contribute to an interruption in the natural hydroperiod.

- Freshwater Marshes. Typically borders pine flatwoods and cypress assemblages. Freshwater marshes often integrate into salt marshes with little noticeable ecotonal transition. Dominant plants are bulrushes, assorted grasses and sedges, ferns, and cattails.

- Tropical Hardwood Hammock. Examples occur on coastal barrier islands in the Reserve, scattered among the shell mounds of the mangrove forest. Plants are oaks, cabbage palms, stopper, gumbo limbo, and sea grape. The understory contains a variety of lesser hardwoods, ferms, and orchids.

- Saltwater Marshes. Landward or interspersed among inland side of the mangrove fringing forests. Does not usually have a direct tidal connection, but invariably contains brackish water and is periodically inundated at the higher spring tides and during storm events. Prime feeding sites for many resident wading or migratory game birds, raptors, and several species of mammals. Provide a transition between saline and freshwater areas in the Reserve.

- Mangrove Forests and Islands. Three species of mangroves occur in the Reserve: red, black, and white. Extent of mangrove ecosystem determined by climate, salinity, tidal fluctuation, substrate, and available nutrients. In the Reserve, distinct zones occur with red mangrove living farther out into the water and black mangrove forest immediately behind. The complex branching prop roots of the red mangrove provide food and shelter for a large number of plants and animals. A variety of birds are associated with the mangrove forest, using islands as night roosts and rookeries. The constantly shedding leaves of mangroves rapidly decay to form small particulate material which is a major food source for many of the small estuarine invertebrates that inhabit the soft bottom sediments. Detritus from mangroves surrounding Rookery Bay provided 32 percent of the energy base for the organisms in that community.

- Coastal Strand. Highly adapted to harsh environment of temperature extremes, porous sandy soils, salt spray, and abrasive sand. Pioneer plants are found on the beaches and foredunes, many species of shorebirds feed and rest along the beaches, and other forms of marine life rely on this habitat for survival.

- Submerged Vegetated Bottom. Seagrasses, are not extensive in Rookery Bay but are seasonally abundant in adjacent waters. Were historically more abundant and widely distributed in Rookery Bay, but declined due to environmental and other factors. Plays vital role as a nursery area and feeding ground for many of the fishes and invertebrates inhabiting Rookery Bay and adjacent waters.

- Submerged Nonvegetated Bottom. Primarily soft mud not stabilized by vegetation. Nonvegetated bottom is more extensive in Rookery Bay than the vegetated bottom, and creates a habitat for various benthic invertebrates. Oyster beds, limited to the mid-intertidal zone, support a variety of organisms. Reef structures formed by the vermetid gastropod (*Petaloconchus* spp.) are found in the Ten Thousand Islands. No living vermetids have been observed recently, but the reefs support a live bottom community.

- Open Water. Rookery Bay, Henderson Creek, Johnson Bay, and Gullivan Bay are the dominant water bodies in the reserve. Resident and migratory birds, particularly coastal water birds, make extensive use of the open waters for feeding and resting.

Key Fish and Wildlife Species

- Birds. (Source: from www.rookerybay.org/publications/field-guide, unless otherwise noted). Rookery Bay takes its name from the important bird rookery on two islands in the middle of the Reserve. The region also provides critical nesting and/or feeding habitat for threatened sea turtles and supports thriving recreational and commercial fisheries. More than 150 species of birds occur in RBNERR, the most conspicuous of which are white ibis (*Eudocimus albus*), herons (including *Ardea herodias*, *Butorides virescens*, *Egretta caerulea*, *Egretta tricolor*, and *Nyctanassa violacea*), great and snowy egrets (*Ardea alba* and *Egretta thula*), and white and brown pelicans (*Pelecanus erythrorhynchos* and *Pelecamus occidentalis*). Most of the birds seen in the estuarine habitats depend on fish or marine invertebrates as their primary food source. For some species, such as juvenile endangered wood storks (*Mycteria americana*), mangrove conditions during periods of low water are important for foraging because organisms become concentrated in small pools, making it easier for predators to capture prey. The eastern brown pelican, a state species of special concern, nests predominantly on Overwash mangrove islands and forages over open water, mudflats, and seagrass beds in the shallow waters of estuaries, creeks, and nearshore

areas (Beever et al. 2009). Brown pelican rookeries are located on isolated red mangrove islands with a substantial water depth barrier that protects the nests from mainland predators. Mangrove canopies provide habitat for some species of songbirds that occur only in this habitat type, such as the black-whiskered vireo (*Vireo altiloquus*), mangrove cuckoo (*Coccoyzus minor*), yellow warbler (*Dedroica petechia*), and Florida prairie warbler (*D. discolor*) (Beever et al. 2009). Another species of concern at RBNERR is the least tern (*Sternula antillarum*), which relies on Florida beaches for breeding habitat in late spring and summer (www.rookerybay.org). They prefer wide, sandy beaches that are high enough to avoid tidal Overwash, have sparse vegetation that provides shade but does not harbor predators, and receive minimal disturbance from human activity. Within the Reserve, the birds rely on Key (Keewaydin) Island, an unbridged barrier island between Naples and Marco Island and Second Chance, and an emergent sandbar just SW of Cape Romano. Least terns will also nest around large lakes in Central Florida and on flat, gravel-covered rooftops. Site fidelity is high but affected by loss and alteration of the preferred habitat, increased disturbance and failure to fledge young.

- Fish. The estuaries of Southwest Florida support at least 384 species of bony and cartilaginous fish (Beever 1988), including the common snook (*Centropomus undecimalis*), a state listed species of special concern (Beever et al. 2009). Another species, mangrove rivulus (*Rivulus marmoratus*), is a small fish living only in and around mangrove areas as far north as Indian River County south through the Keys and north to Tampa Bay (Taylor and Snelson 1992). It is the only species of *Rivulus* in North America and has adapted to conditions of varying water levels and low oxygen levels of the mangrove community. It is an important link in the food chain, as it has been found to constitute part of the diet of many organisms including the wood stork (Ogden et al. 1976). Recreational fishermen come to southwest Florida in hopes of landing prized gamefish such as spotted seatrout (*Cynoscion nebulosus*), pinfish (*Lagodon rhomboides*), Florida pompano (*Trachinotus carolinus*), redfish (*Sciaenops ocellatus*), snook (Centropomus undecimalis), tarpon (*Megalops atlanticus*), and marlin (*Tetrapturus* spp). Some important recreational fish, like the pinfish, spotted seatrout, and pompano, spend most of their lives in estuaries. Shellfish, like crabs, oysters, and shrimp, rely on the nutrients in freshwater for their growth, making the mix of fresh and saltwater in estuaries critical to their production. For other fish, including those that spend their adult lives in the open sea, estuaries provide nursery grounds for their young. Commercially valuable fishes and shellfish in the NBERR total 16 species, with mullet (*Mugil cephalus*) the principal finfish, and blue crabs (*Callinectes sapidus*) and stone crabs (*Menippe mercanaria*) the major shellfish. Also important are pink shrimp (*Farfantepenaeus duorarum*), grouper (*Epinephelus* spp and *Mycteroperca* spp), snapper (*Lutjanus* spp), and mackerel (*Scomberomorous* spp).

- Sea Turtles and other Listed Species. Three species of sea turtle are known to inhabit the waters of southwest Florida. Kemp's ridley (*Lepidochelys kempii*) and Atlantic green (*Chelonia mydas*) sea turtles are both listed federally as Endangered species, and the loggerhead (*Dermochelys coriacea*) is listed as Threatened. Loggerhead sea turtles are the most common species in the region, and females come ashore to lay eggs each summer (from May through August). Loggerheads are decreasing worldwide due to loss of nesting habitat, predation of eggs by raccoons and other animals, ingestion of floating trash, and entanglement in fishing line or other marine debris. Green sea turtles are found in association with mangrove-lined shorelines along tidal passes and within estuarine embayments (Beever et al. 2009). Some other notable species that depend on the Reserve and surrounding areas include West Indian manatee (*Trichechus manatus*), gopher tortoise (*Gopherus polyphemus*), American crocodile (*Crocodylus acutus*) Florida scrub jay (*Aphelocoma coerulescens*), and Florida panther (*Puma concolor*).

Key Ecosystem Processes

- Estuarine System. The overarching system is an estuary, which is defined as a coastal body of water with measurable freshwater inflow (DEP 2000). High primary and secondary productivity associated with estuaries is a consequence of physical, chemical, and biological factors. Variations in salinity, as a result of seasonal or tidal effects, have a

significant influence on estuarine fauna. Lifecycles of many estuarine-dependent organisms, such as the pink shrimp and tarpon, are linked to salinity regimes based on these natural fluctuations. Most marine flora and fauna penetrate estuaries to their limits of tolerance to low and rapidly changing salinities. Relatively few species have evolved mechanisms to tolerate salinity extremes.

- Freshwater Flows. The watershed, or drainage basin, of an estuary represents the source of freshwater inflow into the system. Rivers, tidal creeks, sheetflow, and sub-surface flow discharge freshwater from land drainage along with sediments and particulate and dissolved material. The Rookery Bay and Ten Thousand Islands estuarine ecosystem contains bays, interconnected tidal embayments, lagoons and tidal streams. Sources of freshwater drainage include sloughs, strands, a series of tidal creeks and channels, surface and sub-surface sheetflow, and canals.

- Tidal Influence. Rookery Bay has a mixed semi-diurnal tide. Tidal range averages 0.6 m with higher and lower extremes during periods of spring tides. Approximately 75 million cubic feet of water, estimated to be half of the volume of water in the Bay, moves into and out of Rookery Bay over each tidal cycle through the northern and southern openings. Two thirds of this water passes through the southern entrance, which has a deeper channel and a swifter current. Although southwest Florida tide ranges are relatively small, tidal effects extend far inland because much of the stat is so low in relative elevation and flat in topography (Beever et al. 2009).

Rookery Bay Planned Burns 2012

- Fire. Both pine flatwoods and cabbage palm/oak habitats are fire dependent systems, surviving or benefiting from periodic fires. During the dry season, these habitats may be subject to natural or man-induced fires. Fire is beneficial at removing dry understory, recycling nutrients to soils, inducing seed disbursal and germination in many plants, and halting successional changes that would result in development of a different association of plants and animals.

- Marsh Processes. A number of processes influence the elevation of coastal marshes, including mangroves (Gilman et al. 2008). For example, sediment accretion and erosion in mangroves are determined by the geomorphic setting, which affects the sources of sediment, sediment composition, and method of delivery. Fine sediment particles are carried in suspension into mangrove systems from coastal waters during tidal inundation, form large flocs (cohesive clay and fine silt), which settle in the forest during slack high tide as the friction caused by the high mangrove vegetation density slows tidal currents. Wrack or plant litter on the soil surface can also trap mineral sediment, and contribute to vertical accretion. Storms and extreme high water events can alter the mangrove sediment elevation through soil erosion and deposition. Sedimentation varies by mangrove species and their root type. Belowground primary production also may affect elevation. When belowground root growth exceeds root decomposition, soil organic matter accumulates, causing a net increase in soil volume and contributes to a rise in sediment elevation. Root growth, or lack thereof, has been shown to be a substantial control on mangrove soil elevation at some sites.

Existing Threats/Stressors

- Development Pressures. Urban development and agricultural land use, and their associated run off within the Reserve's watersheds, are the primary threat to the ecological integrity of the Reserve. Development of adjacent coastal lands can threaten the ecological integrity of the RBNERR. Proposed coastal development including marinas, docks, or single or multi-family housing has the potential for negative impacts to water quality, wetlands habitat, and endangered species. Development on barrier islands can result in accelerated erosion processes due to "hardening" of naturally dynamic systems.

- Altered Freshwater Inflow. Prior to development, sheetflow was the primary source of surface runoff in the drainage basins for Rookery Bay and the Ten Thousand Islands. Significant alterations in the natural drainage patterns of the Belle Meade, Water Management No. 6, and Southern Golden Gate Estates Basins have occurred as the result of road and canal construction. Dredge and fill operations associated with planned future developments threaten to further alter the hydroperiods of these basins. U.S. 41 and S.R. 951 are major roads adjacent to the Reserve that abstruct traditional sheetflow patterns.

- Water Quality. Stormwater runoff contributes to substantial increases in sedimentation and turbidity, resulting in an influx of organic and inorganic materials including nutrients from agriculture and sewage outfalls, pesticides, and heavy metals. Significant alterations in estuarine salinity regimes due to changes in timing of freshwater discharge can have a profound negative impact on estuarine-dependent organisms. Estuarine waters are also affected by nutrients from land-based sources of pollution (Wilkinson and Souter 2008).

- Invasive Species. The biodiversity associated with native plant and wildlife communities within and adjacent to RBNERR boundaries is threatened by invasive non-native plants and animals, and suppression of natural fires. Invasive non-native plants, including Brazilian pepper (*Schinus terebinthifolius*), melaleuca (*Melaleuca quinquenervia*), Australian pine (*Casuarina* spp.), downy rosemyrtle (*Rhodomyrtus tomentosa*), and lather leaf (*Chamaedaphne calyculata*), have become established within RBNERR and adjacent lands. These plants displace native species, and do not provide essential habitat and food for native wildlife.

- Fire Suppression. A consequence of urbanization adjacent to the Reserve is the suppression of natural fires to prevent destruction of residential and commercial areas. Restriction of periodic fires disrupts the natural fire ecology necessary to maintain biodiversity of upland habitats within RBNERR.

- Incompatible Consumptive Uses. While the Reserve provides important opportunities for compatible recreational use such as hiking, boating, and fishing, the intensity of public use and the frequency of incompatible public use are increasing. Boating, for example, can result in significant impacts to RBNERR wildlife and resources, such as the West Indian manatee, wading bird rookeries, and seagrass beds.

- Catastrophic Events, Harmful Algal Blooms. Natural resources within the RBNERR are changed as a result of catastrophic events such as periodic hurricanes and harmful algal blooms (HABs) such as red tide events. For example, historical records indicate that mangrove forested wetlands in Rookery Bay were severely damaged as a result of hurricanes in 1918 and 1960. Hurricane Andrew impacted mangrove forests and hardwood hammocks in the Ten Thousand Islands in 1992. And red tide events such as the February 1996 event in Southwest Florida can result in mass mortality of species such as the endangered West Indian manatee.

Climate Change Context

The following scenarios are from multiple sources, as indicated. There are notable inconsistencies across various studies.

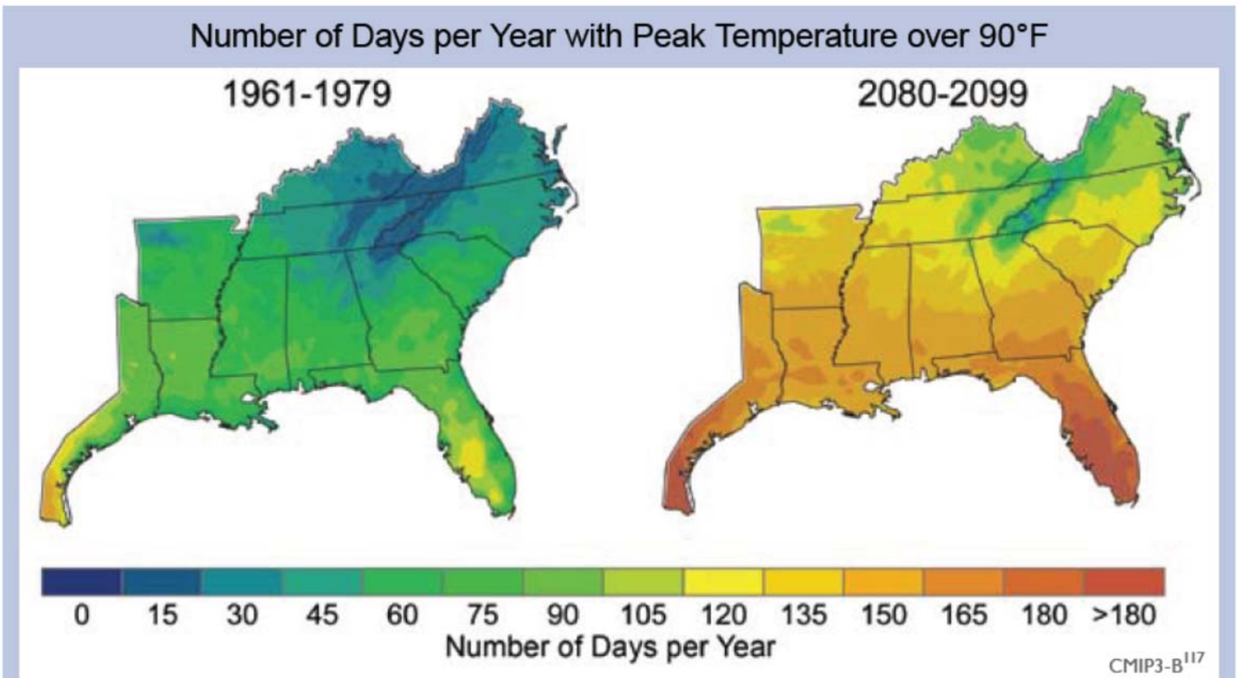
Air Temperature

- Recent Changes. The climate of the Southeast is warm and wet, with mild winters and high humidity, compared to the rest of the continental United States (Karl et al. 2009). The number of freezing days in the Southeast has declined by four to seven days per year for most of the region since the mid-1970s.

Table 1. Average Change in Temperature in the Southeast		
	Temperature Change in Degrees F	
	1901-2008	1970-2008
Annual	0.3	1.6
Winter	0.2	2.7
Spring	0.4	1.2
Summer	0.4	1.6
Fall	0.2	1.1

Obeysekera et al. (2011) found: 1) An increase in the number of days above 80º F during the year and during the wet season at many locations, and 2) A widespread decrease in the daily temperature range at urbanized stations for the post-1950 period which is mainly due to increased daily minimum temperature and appears consistent with the urban heat island effect.

- Projections. Continued warming in all seasons across the Southeast and an increase in the rate of warming through the end of this century (Karl et al. 2009), with the greatest temperature increases in the summer months. The number of very hot days is projected to rise at a greater rate than the average temperature (Figure 2). Under a lower emissions scenario, average temperatures in the region are projected to rise by about 4.5º F by the 2080s, while a higher emissions scenario yields about 9º F of average warming (with about a 10º F increase in summer and a much higher heat index.



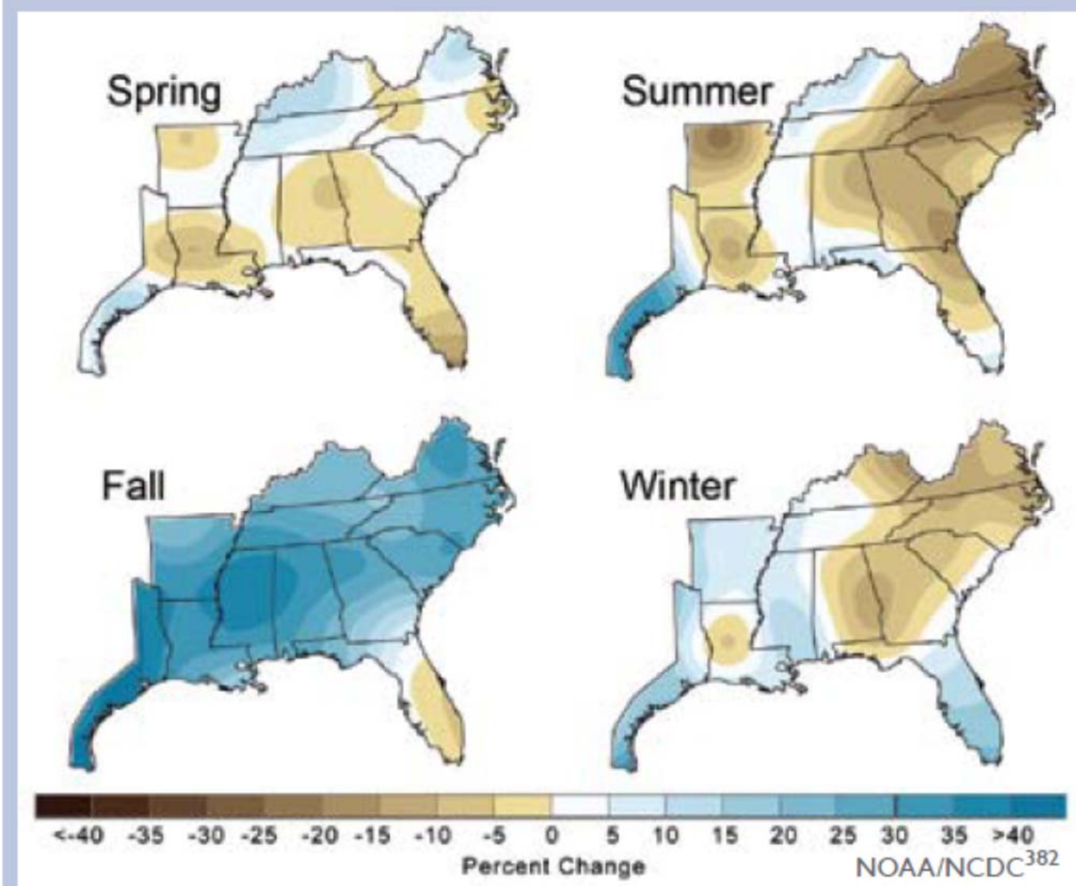
The number of days per year with peak temperature over 90°F is expected to rise significantly, especially under a higher emissions scenario[91] as shown in the map above. By the end of the century, projections indicate that North Florida will have more than 165 days (nearly six months) per year over 90°F, up from roughly 60 days in the 1960s and 1970s. The increase in very hot days will have consequences for human health, drought, and wildfires.

Figure 2

Statistically and dynamically downscaled projections from Obeysekera et al. (2011) suggest that future temperature will be warmer by 1 to 2º C at 2050.

Precipitation

- Recent Changes. Average autumn precipitation has increased by 30 percent for the region since 1901 (Figure 3). The decline in fall precipitation in South Florida contrasts strongly with the regional average. There has been an increase in heavy downpours in many parts of the region, while the percentage of the region experiencing moderate to severe drought increased over the past three decades.



While average fall precipitation in the Southeast increased by 30 percent since the early 1900s, summer and winter precipitation declined by nearly 10 percent in the eastern part of the region. Southern Florida has experienced a nearly 10 percent drop in precipitation in spring, summer, and fall. The percentage of the Southeast region in drought has increased over recent decades.

Figure 3

In terms of Florida-specific precipitation trends from Obeysekera et al. (2011), two most noteworthy results were: 1) A general decrease in wet season precipitation, which is most evident for the month of May and possibly tied to a delayed onset of the wet season in Florida, and 2) An increase in the number of wet days during the dry season, especially during November, December, and January.

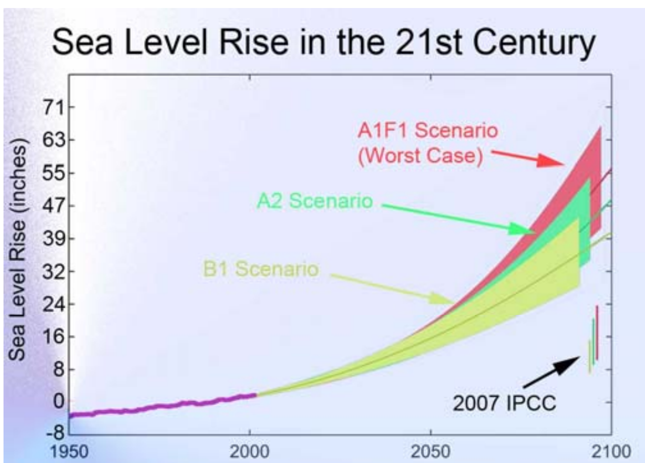
- Projections. Spring and summer rainfall is projected to decline in South Florida (Karl et al. 2009). Climate models provide divergent results for future precipitation for the Southeast. Gulf Coast states will tend to have less rainfall in winter and spring, compared with the more northern states in the region. Precipitation projections are more ambiguous than those for temperature, with the Global Climate Model (GCM) finding a change of -10 percent to +10 percent , the statistically downscaled data a change of -5 percent and

+5 percent, and the dynamically downscaled data range of -3 to +2 inches per year. The dynamically downscaled data yield an estimated change in ET of +3 to +6 inches per year.

Sea level Rise

- Recent Changes. The average global (eustatic) sea level rise was 6.7 inches over the 20th century, at an average rate of 0.07 inches (1.7 mm) per year, 10 times faster than the average rate during the last 3,000 years (IPCC 2007). The average rate of sea-level rise is expected to accelerate. For coastal management purposes, it is important to also understand the potential changes in relative sea level, which includes the eustatic rate as well as localized factors that determine changes in vertical land elevation, such as land subsidence, sedimentation, and marsh accretion. Around Florida, relative sea level has been rising at a slow but consistent rate, about an inch or less per decade (Maul and Martin 1993; FOCC 2009, from Beever). The historic (1947-2009) sea level rise in southwest Florida measured at St. Petersburg is 2.3 mm/yr (Walton 2007, FOCC 2009).

- Projections. The most recent estimates from the 2007 IPCC assessment show an additional 18 to 59 cm (7- to 23-inch) rise in global average sea level by the 2090s, with an additional 10 to 20 cm possible by taking into consideration the current rate of ice flow from Greenland and Antarctica. There is compelling new evidence, however, that because these figures ignored the recent dynamic changes in Greenland and Antarctica ice flow, it is likely to that they significantly underestimate the rate of global sea-level rise we will experience in the coming decades (Jevrejeva et al. 2010; Otto-Bliesner et al. 2006; Overpeck et al. 2006; Overpeck and Weiss 2009; Rahmstorf 2007; Rignot and Kanagaratnam 2006; Vermeer and Rahmstorf 2009) (Figure 4). While future projections vary, Rahmstorf (2007) proposes that, taking into account possible model error, a feasible range by 2100 is a rise of 50-140 cm. More recently, this work was updated and the ranges were increased to 75 to 190 cm (Vermeer and Rahmstorf 2009).



New modeling, based on the temperature / sea level relationship for the last 1,000 years, shows up to three times the sea level rise as predicted by the 2007 IPCC. The model was confirmed with tide gauge and temperature data from 1880 to 2000 with a correlation of greater than 0.99 (very accurate.)
Vermeer and Rahmstorf, Global sea level linked to global temperature, PNAS, 2009.

Figure 4

Hurricanes

- Recent Changes. Several studies have found a correlation between warmer average ocean temperatures and an increase in the intensity of tropical storms and hurricanes (Trenberth 2007; Webster et al. 2005; Emanuel 2005).

- Projections. A number of scientists project that the trend toward more-intense storms will continue in the coming decades as oceans warm further (Trenberth 2007; Oouchi et al. 2006; Knutson and Tuleya 2004; Walsh, Nguyen, and McGregor 2004). However, there are many factors that contribute to both the frequency and intensity of hurricanes, and some uncertainty remains about how these storms will be affected by climate change in the future (Pielke et al. 2005). Regardless of whether or not climate change will have a direct impact on hurricane frequency and intensity, there is little question that these storms will become more destructive in the future due to a combination of increased coastal development as well as higher storm surges exacerbated by sea-level rise (Anthes et al. 2006).

Sea Surface Temperature and Chemistry

- Recent Changes. Water temperatures at the sea surface rose by an average of 0.3º C between the 1950s and 1990s in tropical and subtropical waters (Wilkinson and Souter 2008; FOCC 2009). In addition, as oceanic carbon dioxide has increased in recent decades, the world's oceans have become more acidic, with pH decreasing by 0.1 standard units since 1750 (Archer 2005). This represents a 30 percent increase in ocean acidity.

- Projections. Sea surface temperatures will continue to rise at least at the rate they have been rising for the past 100 years (IPCC 2007). It is probable that water temperatures at the sea's surface will continue to increase at the average rate of 0.3º C over 40 years in tropical and subtropical waters (FOCC 2009). If Florida's ocean temperatures increase at the same rate that IPCC models project for the Gulf of Mexico and Atlantic as a whole, they would increase by 2º C over the next 100 years. Further, the average pH of the world's oceans may decrease by as much as 0,1 to 0.4 pH units over the next 90 years, due to increasing absorption and solution of carbon dioxide into warmer ocean waters (Royal Society 2005; Kuffner et al. 2008; Ishimatsu et al. 2005).

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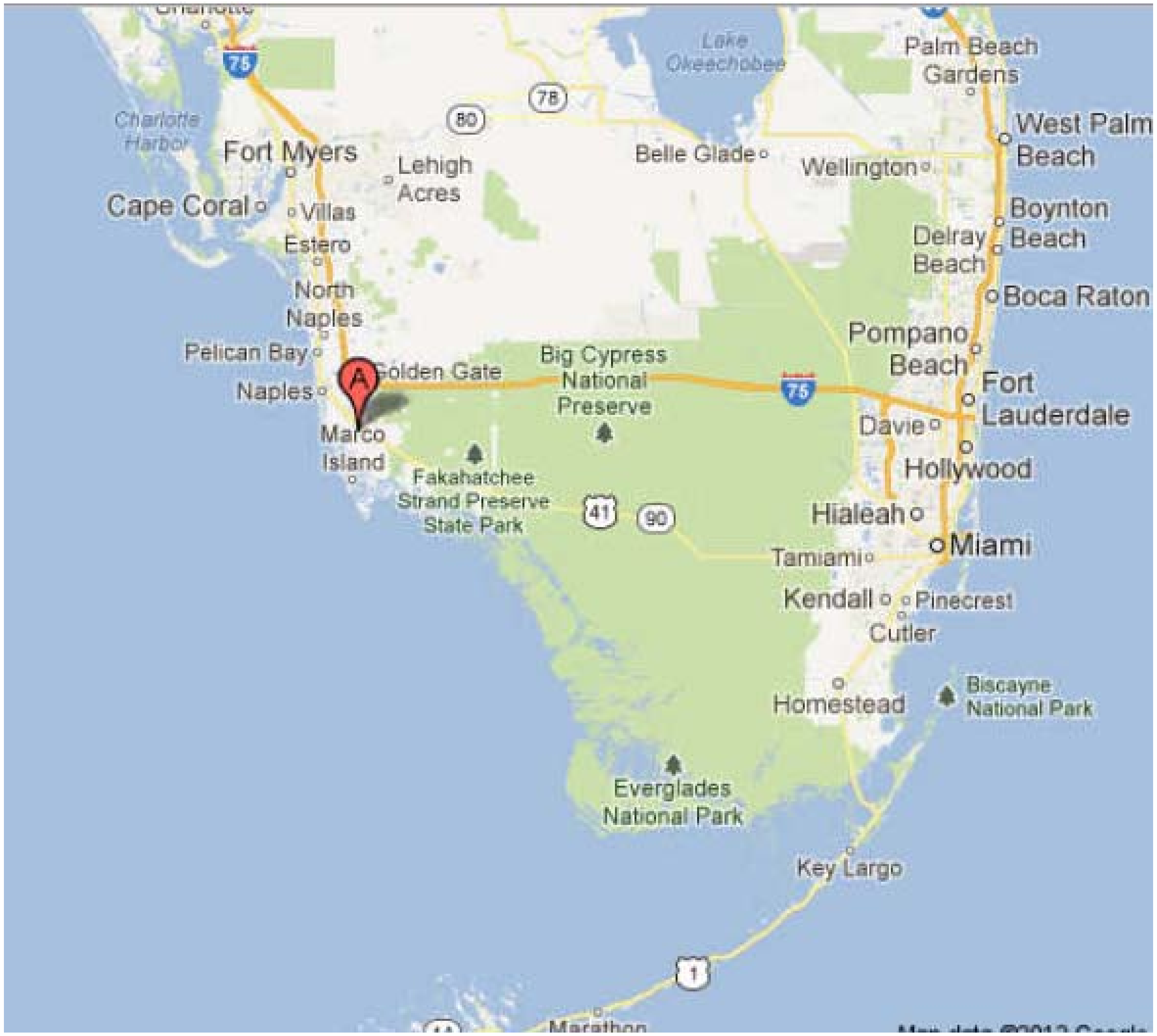
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Boca Raton
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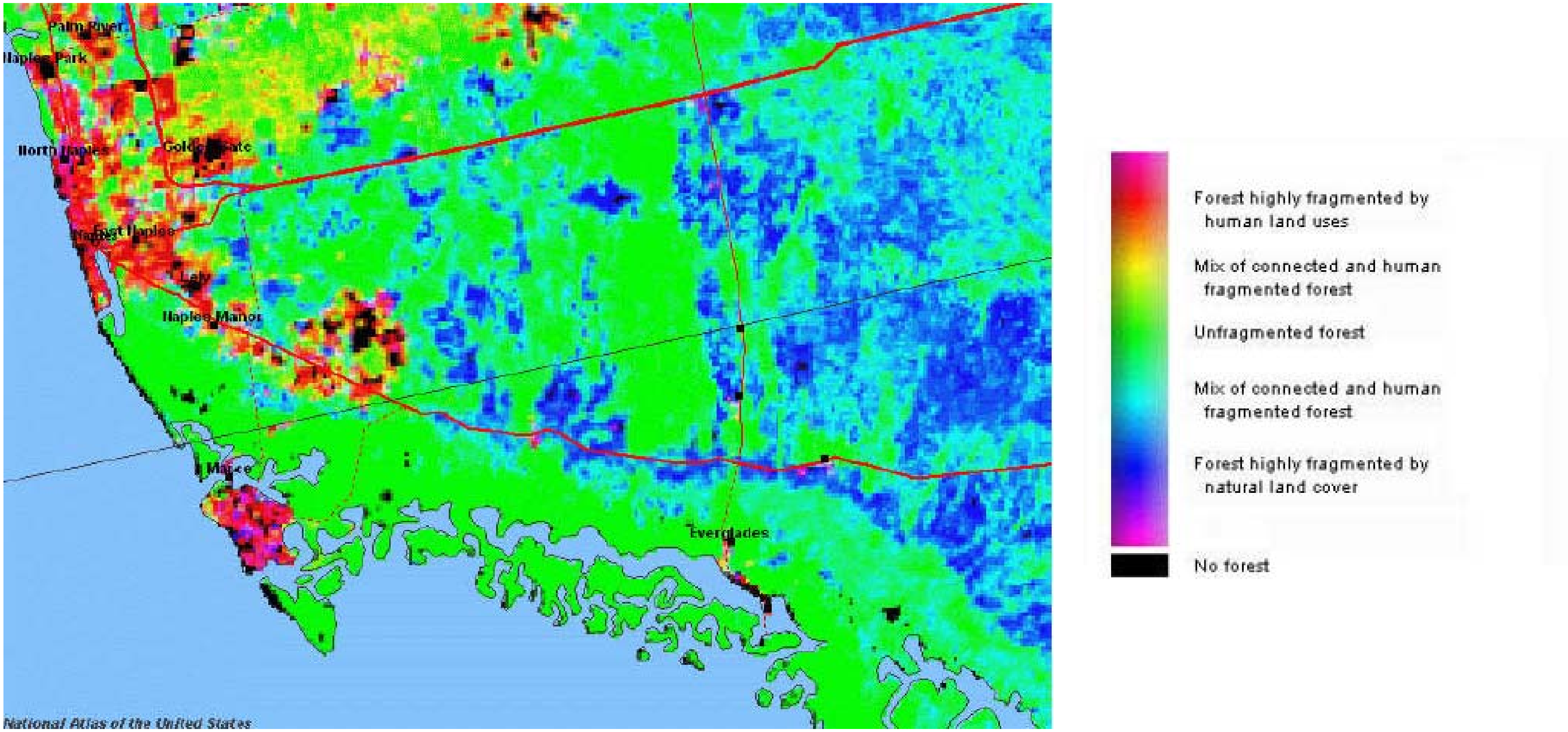
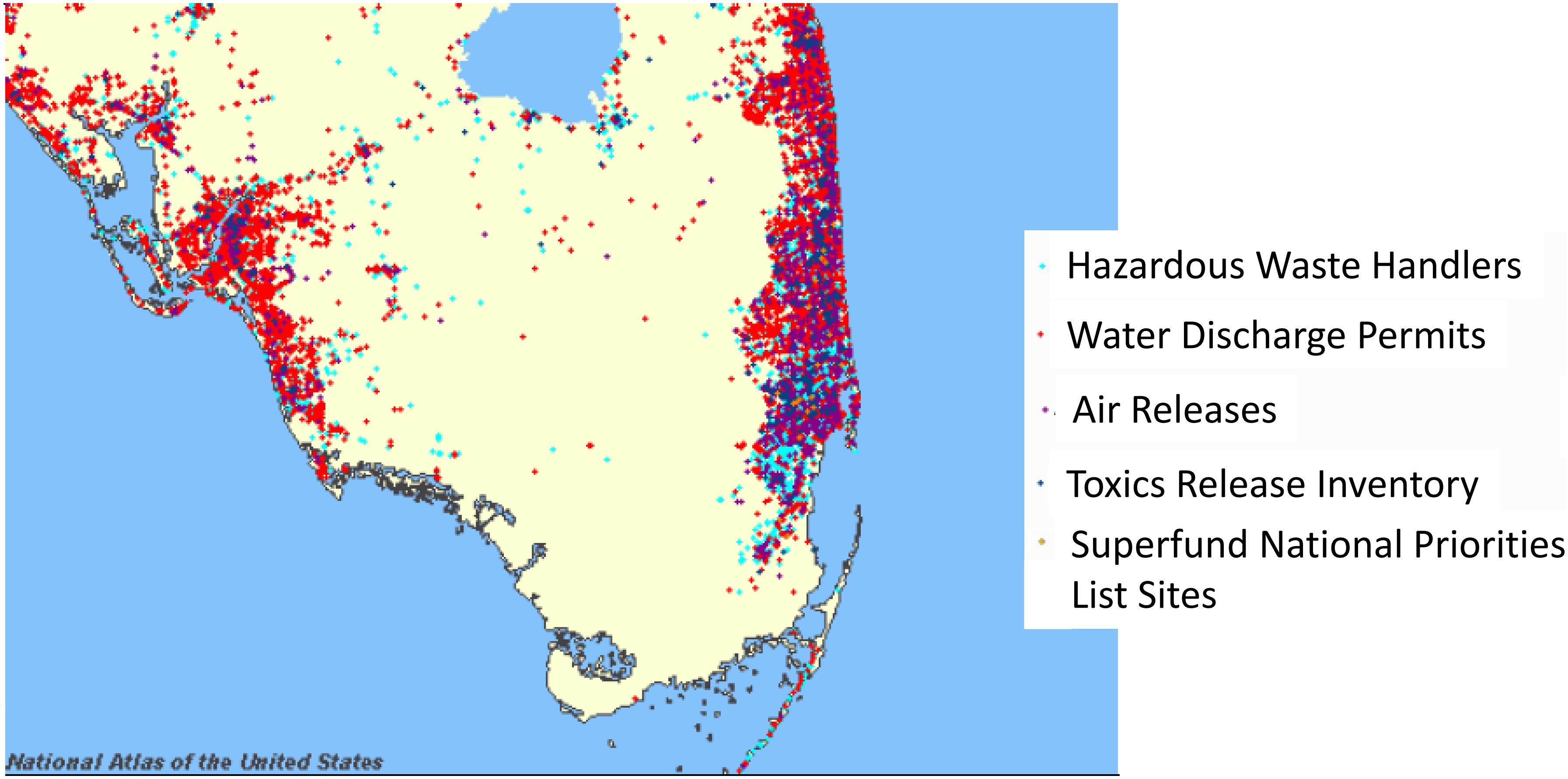


Forest cover
From the National Atlas
http://www.nationalatlas.gov/



Point sources of pollution
From the National Atlas
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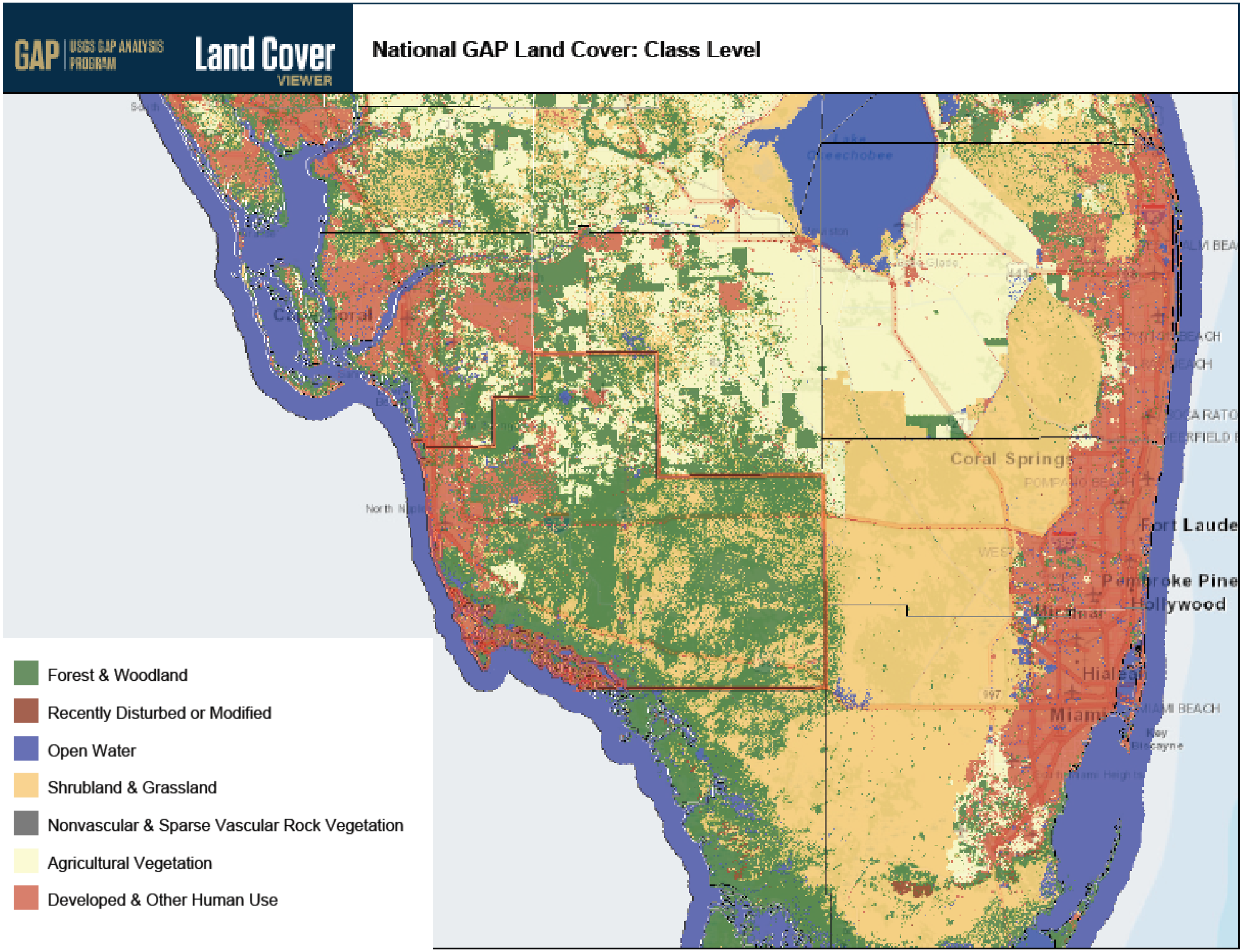
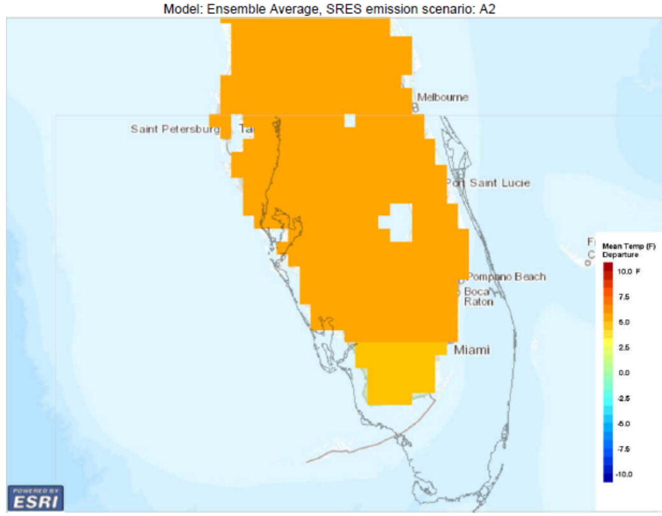

GAP | USGS GAP ANALYSIS PROGRAM
Land Cover VIEWER
National GAP Land Cover: Class Level
Forest & Woodland
Recently Disturbed or Modified
Open Water
Shrubland & Grassland
Nonvascular & Sparse Vascular Rock Vegetation
Agricultural Vegetation
Developed & Other Human Use
Coral Springs
Fort Laude
Pembroke Pine
Hollywood
Hialeah
Miami
MIAMI BEACH
Key Biscayne

Change in Annual Temperature by the 2080s

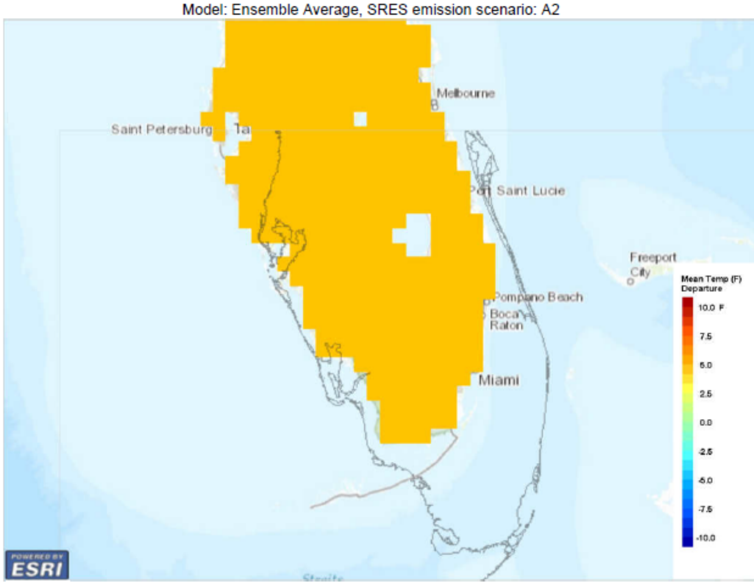
Model: Ensemble Average, SRES emission scenario: A2



Map data Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community
Data Source: Base climate projections downscaled by Maurer, et al. (2007) Santa Clara University. For more information see About Us.

Change in Dec-Feb Temperature by the 2080s

Model: Ensemble Average, SRES emission scenario: A2



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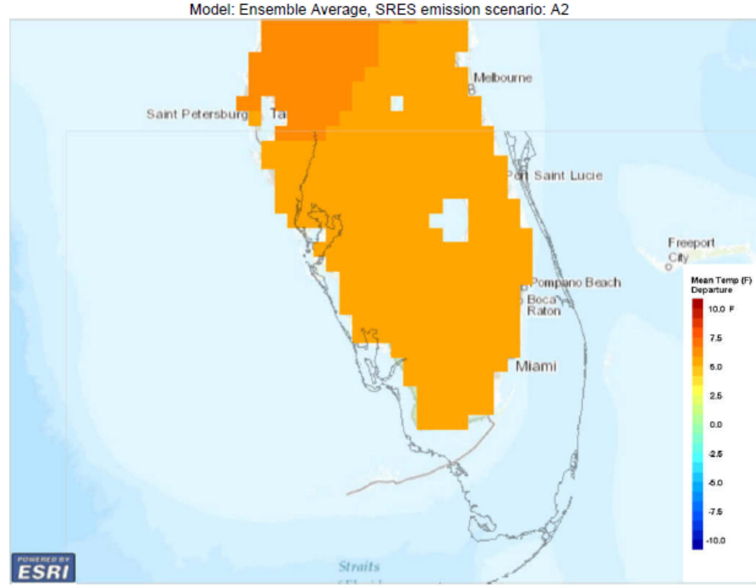
Change in Jun-Aug Temperature by the 2080s

Model: Ensemble Average, SRES emission scenario: A2



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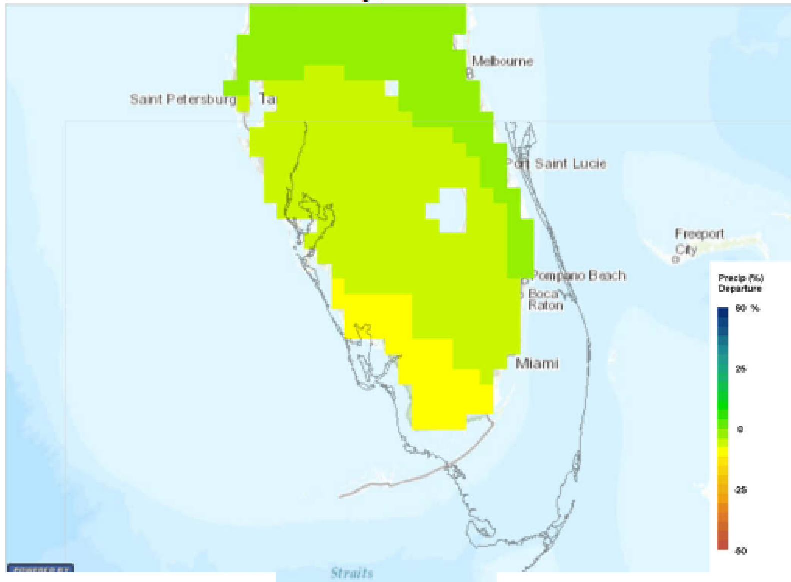
Change in Annual Precipitation by the 2080s

Model: Ensemble Average, SRES emission scenario: A2



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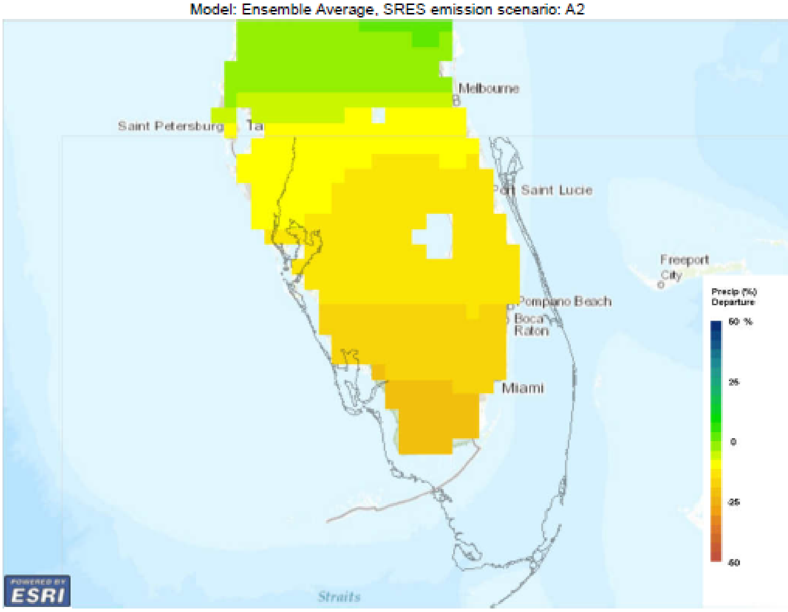
Change in Dec-Feb Precipitation by the 2080s

Model: Ensemble Average, SRES emission scenario: A2



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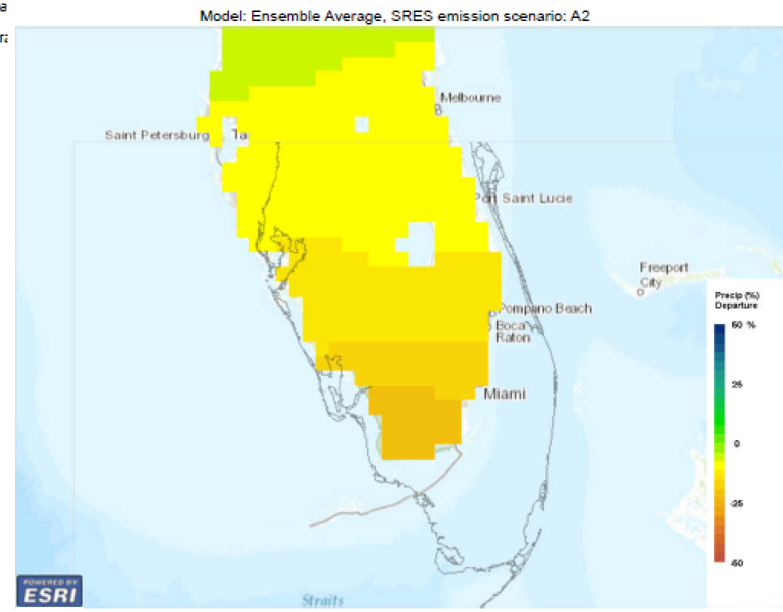
Change in Jun-Aug Precipitation by the 2080s

Model: Ensemble Average, SRES emission scenario: A2



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