Sea Level Rise Adaptation in the Florida Keys:

Conserving Terrestrial and Intertidal Natural Areas and Native Species

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SUBMITTED ABSTRACTS

Wildlife photos by Michelle Wisniewski

POSTER: Environmental Constraints on Establishment and Growth of Black Mangrove

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Black mangrove (*Avicennia germinans*) is an integral component of mangrove communities in the Florida Keys. Hydrogeomorphic setting is an important modulator of wetland plant species zonation that will be strongly influenced by sea-level rise. The response of mangrove communities to sea-level rise scenarios needs to be more fully understood, especially in terms of potential constraints on upslope migration.. We conducted a series of manipulative experiments in conjunction with a field survey to increase our understanding of constraints on black mangrove establishment and sustainability in Louisiana; however, our findings have applicability to other portions of the black mangrove's range. To more clearly define the environmental conditions in which black mangrove can successfully establish and grow, we determined the responses of different age classes of black mangrove seedlings to the following environmental factors: water level, salinity level, and rapid sand burial. These data were supplemented with field surveys of marsh surface elevation associated with the presence of adult mangroves, seedlings, and recently established propagules. Seedling growth response displayed non-linear trends to changes in water level, salinity level, and sand burial with optimal responses occurring as follows: marsh surface elevations of 15 to 30 cm above mean water level, 24 to 48 ppt salinity, and 0 to 10 cm of sand burial. The field survey revealed that mangroves (both adults and seedlings) occurred at a mean height of 8 cm above mean water level that corresponded with a mean flooding frequency of 26%, although many mangroves occurred at elevations of 10-25 cm above mean water level. These findings provide an increased understanding of the fundamental niche space of black mangrove that can be utilized to inform management planning on response to sea-level rise, potential constraints on upslope migration, and long-term sustainability.

Big Pine Key, Florida: Sea Level Rise Scenarios

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Sea level rise is one of the more predictable and most profound consequences of climate change. In the next one to three centuries, sea level rise is likely to undo most, if not all, that has been done over the past century to protect the terrestrial plants, animals and natural communities of the Florida Keys. In 2007 The Nature Conservancy acquired high resolution Digital Elevation Models derived from airborne Light Detection and Ranging (LIDAR) data for Big Pine Key. Future shoreline locations and distribution of major habitats of Big Pine Key in the year 2100 were estimated using sea level rise scenarios described in the scientific literature. In every scenario the island becomes smaller and marine and intertidal habitat moves upslope at the expense of upland habitat. In the best case scenario, 18 cm (7 in) of sea level rise, 1,840 acres (34%) of Big Pine Key are inundated resulting in the loss of 11% of the island's upland habitat. Three other scenarios are modeled for Big Pine Key. With are rise of 140 cm (4.6 ft), the highest modeled rise, about 5,950 acres (96%) of the island would be inundated with all upland habitat lost. Now is the time for a coordinated effort to identify the long-term impacts of sea level rise on the Florida Keys and to begin taking near-term steps to minimize the negative consequences of those impacts. Mitigation of the root causes of sea level rise must be paired with carefully planned and implemented local strategies to help terrestrial natural areas and native species resist and ultimately adapt to inevitable change. Any such strategies must take into account the fact that Florida Keys residents and the government institutions that serve them will also need to resist and adapt to sea level rise.

Potential Impacts of the Indo-Pacific Lionfish (*P. volitans* and *P. miles*) on Fish Assemblages in Near Shore Benthic Habitats of the Florida Keys

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Since the first recorded Tropical Western Atlantic sightings of the Indo-Pacific Lionfish (*P. volitans* and *P. miles*) in the 1990s, this mid-level predator has become a common component of shallow-water fish assemblages from mangrove creeks to seagrass beds and coral reefs throughout the Caribbean. Although the origins of this cryptic invasion are unknown, the recent success of lionfish, specifically in near shore habitats, has been documented through increasing abundance in the Florida Keys since the first invasion in January 2009. Coupled with the looming threat of sea level rise, this invasive species poses one of the greatest challenges to maintaining the long term biodiversity in critical near shore habitats, many of which serve as essential fish nursery habitat for commercially viable species. Although the long term impact of lionfish on near shore fish assemblages in the Keys is unknown, better understanding of how sea level rise may alter these threatened habitats is critical in the development of an invasive species management plan. This comparative study examines data from The Bahamas, where a lionfish invasion has already impacted fish communities in varying near shore habitats, and models some potential impacts that a similar invasion may have on the near shore benthic habitats of the Florida Keys. By comparing this analysis to the latest scientific models predicting sea level rise throughout the Keys, it is possible to identify the most threatened near shore habitats where both factors may severely alter native fish assemblages in the near future. With little options for mitigating future impacts of sea level rise, this data may be useful for fisheries managers who can implement best practices to regulate lionfish populations in vulnerable habitats.

GIS Based Methodology for the Evaluation and Identification of Transportation Infrastructure Vulnerability to Sea Level Rise

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The low-lying topography of regions in Florida makes the transportation in those regions vulnerable to sea level rise (SLR) and other climatic changes. Sea level rise could significantly impact transportation infrastructure through flooding and reducing the effectiveness of flood control and storm water drainage systems, some of these effects are already occurring. Transportation infrastructure not directly impacted could experience traffic operation, safety and management problems. Therefore SLR could cause a sequence of effects that would impact the entire state's transportation network. The vulnerability of physical transportation infrastructure will require the development of new design criteria and standards for more resistant and adaptive facilities and systems. Consequently, current transportation planning will need to incorporate potential impacts of SLR and associated storm surge, on the design, construction, operation, and maintenance of transportation infrastructure.

The purpose of this research is to provide a methodology for assessing and mitigating the impacts of SLR on Florida transportation modes and infrastructure for planning purposes. Researchers in this study conducted a comprehensive literature review and analysis of SLR projections, past and current studies, models and methodologies; and developed a down-scaling process for evaluating the vulnerability of roadways for State, regional, and localized SLR projections. This approach integrates the Florida Department of Transportation (FDOT) information system with existing LiDAR and other GIS data to facilitate the identification of roadway sections that are most likely to be affected by frequent to continuous flooding due to SLR. This approach has been used to evaluate transportation in Florida Keys and identify State road sections that are potentially vulnerable to a projected 1.5 ft rise of sea level by 2060.

Conservation genetics of the Sargent's Cherry Palm, *Pseudophoenix sargentii*

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Pseudophoenix sargentii, once a critically endangered palm inhabiting coastal areas of Florida and the Caribbean, has shown a marked increase since reintroductions have augmented the wild populations in the Florida Keys. The habitat of the Sargent's cherry palm has been degraded by agricultural encroachment, grazing, over-harvesting and hurricane effects. To assess the genetic contribution of these reintroductions and to understand the current genetic structure of the species, ten microsatellites were analyzed from 124 individuals. The individuals sampled came from wild populations on Elliott Key, Long Key, and the Bahamas, as well as the Fairchild *ex situ* collection. The individuals on Elliott Key, where reintroductions had occurred, had age classes and wild vs. reintroduced individuals analyzed separately. Several populations displayed evidence of genetic drift, inbreeding and decreased gene flow with all populations displaying significant deviations from Hardy-Weinberg equilibrium. All populations displayed positive F_{is} values except the *ex situ* collection and the reintroduced individuals on Elliott Key. All pairwise F_{st} values were significant except comparisons between certain age classes on Elliott Key. AMOVA analysis partitioned 82.3% of the genetic variation within populations. Principal coordinate analysis based on genetic distance and Bayesian clustering analysis supported three distinct populations. The reintroductions on Elliott Key have contributed to an increase in the overall genetic diversity of the focal stand by increasing heterozygosity and lowering the inbreeding coefficient.

POSTER: Feasibility of Evaluating the Impacts of Sea Level Rise on Foraging Habitats of the Little Blue Heron in the Great White Heron National Wildlife Refuge

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Habitats in the Great White Heron National Wildlife Refuge (hereafter Refuge) sustain local avian diversity and play a large role in supporting regional or statewide populations of wading birds, many of which are in decline. A major threat to these species in the Refuge comes from likely changes in habitat as a result of sea level rise. Quantifying the degree of climate-driven habitat change for sensitive wading bird species is a precursor to long-term conservation planning, but it is fraught with difficulties. Wading birds forage heavily in the intertidal zone where estimates of future sea levels must be coupled with the predicted elevation of intertidal ground surface, which is dynamic and affected by sea levels. Here we evaluate the feasibility of predicting changes in Little Blue Heron foraging habitat as a function of sea level rise in a test area of the Refuge. We first define an envelope of Little Blue Heron foraging habitat based on water depth preferences in the Everglades and vegetation preferences from the literature. The change in foraging habitat over time will be quantified by combing sea surface elevations under several climate scenarios (including the Intergovernmental Panel on Climate Change 2001 scenarios) with estimates of intertidal ground surface elevation from the Sea Level Affecting Marshes Model (SLAMM), a widely used model for estimating the impacts of sea level rise on the Atlantic coast. Model fit will then

be assessed by comparing predicted habitat suitability in the test area based on current water levels and habitat distributions, to the distribution of Little Blue Herons observed on field surveys. Surveys will be conducted by boat using the double observer method. The presence and absence of birds in grid cells will be compared to predictions from the model using confusion matrices. Confusion matrices will be further processed to generate receiver operating characteristic (ROC) and the collective area under the curve (AUC) plots, which provide a measure of model usefulness. A sensitivity analysis will be conducted on model parameters to assess the effects of uncertainty related to habitat definitions, vegetation characterization, ground surface elevation, and sea level. Results will be used to both assess the prospects for improving the model in the future and for focusing future research efforts. The results of this project will address whether the available data and their associated uncertainties could lead to a wading bird model that is sound enough to guide management decisions in the Florida Keys related to sea level rise.

POSTER: Monitoring sea level rise impacts in mangroves of the lower Florida Keys

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Mangroves and associated lagoonal waters are one of the dominant landscapes of the lower Florida Keys. This poster describes an ongoing monitoring program in shallow (< 1/2 meter deep) mangrove and lagoonal ecosystems in the lower Florida Keys. Portions of this program began in the 1970s when sea levels were 4 inches (10cm) lower. Utilizing historical data and aerial photography from the fifties and the seventies we have identified specific shorelines where the greatest future changes may be expected. At certain of these shorelines we have installed permanent monitoring stations with vegetation plots (forest structure and function), fish & wildlife plots (forage and habitat use by imperiled species), rSETs (rod sediment elevation tables), and RTK (real time kinematic) surveys tied to tidal gauges. At these shorelines we have focused on monitoring the following three types of impact.

1) The first is along erosional shores where sediments and forests may be lost and/or significantly inundated during future storms. In certain cases, mangrove lagoons and ponds may be breached. In other cases, mangrove-dominated islands may be removed by storms.
2) The second is where marine sediments may be deposited and colonized by new stands of fringing red mangroves extending both landward and seaward. In many cases these landward migrating fringing red mangroves may displace dwarf black mangroves and salt marshes growing on muddy and rocky flats.
3) The third change may be the significant net gain/loss of associated ecosystems including seagrass beds, salt marshes, and supralittoral vegetation through succession, flooding, and/or changes in sediments and groundwater.

We continue to monitor these stations and to increase the adequacy (coverage and frequency of measurement) of the monitoring system. The purpose of this monitoring program has been to support management practices that consider sea level rise, mangroves, and the fish & wildlife associated with them in the lower Florida Keys.

POSTER: Trapping results from long-term monitoring of the endangered Key Largo cotton mouse (*Peromyscus gossypinus allapaticola*) and Key Largo woodrat (*Neotoma floridana smalli*)

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The Key Largo cotton mouse (KLCM: *Peromyscus gossypinus allapaticola*) and Key Largo woodrat (KLWR: *Neotoma floridana smalli*), both subspecies of the cotton mouse and Eastern woodrat, are endemic to Key Largo, Florida. Both subspecies were listed as endangered in 1984 in response to habitat loss and fragmentation from development. Since 2007, I have monitored 12-34 trapping grids distributed throughout the island's hardwood hammocks using 7x7 trapping grids. Results for both subspecies have indicated potential declines in their populations. Due to fluctuations in the Key Largo cotton mouse populations, the current trend and status are unknown, but the minimum number known alive increased from 93 to 120 on 12 grids from March to December, 2007, but have recently decreased to 65 and 80 mice in December, 2010 and 2011, respectively. Using closed capture models and Pollock's robust design, estimates of the total population size of KLCM has decreased from approximately 20,000 (November-Dec, 2007) to 11,000 mice (December, 2010). For the Key Largo woodrat, there has been a continuous decline in the population, with the minimum number known alive on 12 grids decreasing from 17 animals (November-December, 2007) to 3 (December 2010). The exact causes for the decline of these subspecies are still unknown, but since 2007, the presence of non-native predators have been observed within the study area, and the depredation of both subspecies has been documented.

POSTER: A Probabilistic Method for Estimating Sea Level Rise Exceedances

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A method for estimating the probability of exceeding given stages of sea level rise at given times during the 21st Century is presented based on published semi-empirical correlations of historic sea level rise and global climate change model forecasts for a range of plausible IPCC scenarios. Tide gauge measurements in Florida are shown to be statistically indistinguishable from global average sea level rise. Projected probabilities that sea level could rise by 3, 4, and 5 feet by 2100 are approximately 89%, 42%, and 6% respectively. Sea level rise of 3 feet or more could have dire consequences to Florida's coasts, the Everglades, the Keys, and low-lying urban South Florida.

POSTER: Constraints on Coastal Vegetation Response to Environmental Change

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To increase our ability to make informed management decisions of mangrove community response to predicted climate change and sea-level rise scenarios, it is imperative to utilize both empirical data and conceptual ecological frameworks of plant responses to the environment. The distribution and abundance of a species in a given area is determined at three levels: 1) dispersal to the area, 2) physiological tolerance to abiotic conditions, and 3) biotic interactions, including competition, predation and pathogens, that ultimately shape the realized niche of the species. Achieving a solid understanding of a species' fundamental niche is an essential starting point in determining the range of environmental conditions in which that species may potentially establish and persist. Hydrology is considered to be the 'master variable' in wetland plant ecology. As such, determining marsh surface elevation relative to a standard tidal datum (e.g., NAVD88) is required to predict frequency, depth, and duration of flooding at a site under various sea-level rise scenarios. The rate of marsh surface elevation change (net surface elevation change) is controlled by rates of sediment accretion and subsidence, which can be accurately determined via rod surface elevation tables (RSETs). The effects of tropical storm and hurricane disturbance on local sediment deposition or erosion are important drivers of post-storm hydrogeomorphic setting. To understand future responses of mangrove communities in the lower Florida Keys, we suggest implementing an integrated approach of establishing transects across mangrove communities (from sub-tidal to supra-tidal), installing RSETs at key positions along transects that are tied into RTK elevation surveys and a local tidal datum. Mangrove community composition dynamics, species-specific indicators of plant health, and soil response/soil development metrics should be characterized along transects and integrated with manipulative field experiments to provide greater insights on the potential constraints of upslope migration of mangrove communities in response to sea-level rise.

Lower Keys marsh rabbit conservation status, with overview of the silver rice rat

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All native Lower Keys mammals other than bats exhibit local endemism, and all but the local raccoon (*Procyon lotor*) subspecies are reasonably considered imperiled to some degree. Throughout the Keys, a strong majority of all quadrupeds and snakes share one if not both of these characteristics. The Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*)(LKMR) and silver rice rat (*Oryzomys palustris natator*)(SRR) were Federally listed as endangered in 1990 and 1991, respectively. Many of the problems that these species face were set in motion many decades ago with the development of coastal and inland subdivisions, canals, mosquito ditches, and roads which resulted in habitat fragmentation and degradation. Development intensity declined with the advent of wastewater and evacuation issues and the National Key Deer Refuge, Clean Water Act, Federal listings (including critical habitat in the case of SRR), and Monroe County and State growth management endeavors. Though reduced, those threats are not gone, and secondary impacts continue to plague both species. LKMR have continued to exhibit ongoing decline due to deterministic threats (cat predation, vehicle strikes) and presumably, greater imminence of stochastic threats, both demographic and genetic, due to small and declining population size. Some advocates of free-ranging cats suggest that the existence of historical impacts from development diffuses the importance of cats in the ongoing decline of LKMR. However, all such impacts (e.g., increased isolation, dispersal barriers, restricted range) are specifically magnified by cats. Cats are quintessentially proficient at accessing a broad range of niches and can profoundly influence vulnerable prey, particularly in small island settings. Additional omnivores invariably have the capacity to prey on vulnerable young, at least opportunistically. They do not pose the threats that cats do; however, if subsidized and overabundant, they could pose a substantial threat. All of these mammals have the capacity to exert non-lethal effects on LKMR; such interactions should be explored throughout the assemblage. Impacts to the floral landscape that resulted from the major development period were not well documented. The magnitude of threats from relatively slower, ongoing changes in flora forced by sea level rise and fire controls remain poorly understood. Habitat management for ecosystem sustainability has been conducted, most notably fire in pine rockland communities. That has been a difficult occupation at times, but of critical importance. However, retaining fire within the bounds of pine rockland fire units has resulted in opportunity tradeoffs at the landscape level. Largely precluding this process in adjacent ecotones and communities forwent potential benefits to those systems and LKMR, and limited our capacity to learn about those systems and explore fire and sea level effects and interactions. LKMR largely inhabit relatively low elevation habitats in coastal belts and inland basins, plus ecotones. Accordingly, sea level will have a profound influence on them (as well as SRR [in mangrove]), as may storm surges. LKMR exhibit metapopulation structuring. The potential range of the LKMR has yet to be adequately quantified and even the occupied range is difficult to fully elucidate in any given year. Additionally, realized habitat relationships are influenced by cats and by the altered spectrum of habitat components relative to what existed in the past. All of these conditions have important ramifications for regulatory, recovery, and research frameworks. These conditions dictate the need for a well structured, adaptive response. The attendant uncertainties dictate that an experimental component is critical. The employment of decision support tools indicated that strategies for LKMR conservation should include both integrated predator management and habitat enhancement. Adaptive management that allows for probing the influence of practical habitat resiliency and predator management options on detectable components of LKMR viability is likely crucial for stability or recovery. The good news is that we have learned a lot, and we can do things to benefit LKMR and simultaneously reduce uncertainties. Recent findings (habitat, range, genetics) will be summarized in addition to our adaptive management strategy; the development of new LKMR habitat maps; and a brief overview of SRR issues.

Status of Freshwater Resources and Future Management Implications of Sea Level Rise in the Lower Florida Keys

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The Miami oolite limestone formation found in the lower Florida Keys allows for the development of subsurface freshwater lenses as well as extensive surface freshwater wetlands. Rainwater collects in shallow, impermeable limestone basins and solution holes distributed throughout the lower Keys, supporting a diversity of endemic flora and fauna. Two hundred seventy-seven freshwater wetlands in the lower Florida Keys (No Name Key to Sugarloaf Key) were re-surveyed during January 2010-January 2011. Water chemistry data collected included salinity, temperature, and dissolved oxygen. Evidence of fish and wildlife was recorded for each wetland and in the surrounding vicinity and included birds, fish, mammals, reptiles and amphibians. Presence of invasive exotic flora and fauna were also documented. This data was compared to baseline inventories from the late 1980's to assess whether the holes still existed, their condition (salinity changes, sedimentation, human impacts), and continued suitability for native fish and wildlife. Future impacts of sea level rise, saltwater intrusion, and storm surges on quality and quantity of freshwater will also be evaluated to develop strategies for restoration and protection of this vital resource.

Sea Level Rise and Storm Surge in the USVI: Visualizing Risk and Vulnerability for Effective Coastal Ecosystem Management

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Islands of the Caribbean, including the United States Virgin Islands (USVI) are characterized by extremely high levels of biodiversity and endemism, which are threatened by climate change, including sea level rise (SLR). The loss of this biodiversity and endemism can be mitigated by ecosystem based adaptation strategies. This in turn will help support healthy and functional coastal ecosystems like beaches and mangroves that businesses and communities are dependent upon. One barrier to ecosystem based adaptation is the limited access to data and tools and absence of conversation about sustainable coastal zone management. With generous funding from the National Oceanic and Atmospheric Administration (NOAA) and the Royal Caribbean Ocean Fund, The Nature Conservancy (TNC) mapped sea level rise scenarios for the USVI using the International Panel on Climate Change (IPCC) A1B global circulation model (GCM) (ipcc.ch). A Sea, Lake, and Overland Surge from Hurricanes (SLOSH) analyses was also performed, which modeled a 1989 Hurricane Hugo type storm taking into account projected sea level rise scenarios for the year 2100. The outputs from these analyses were placed into a online user-friendly visualization tool for key stakeholders so they can begin the conversation about proactively planning and initiating sustainable measures to address the impacts of climate change in the USVI. TNC's Global Coastal Resilience website (coastalresilience.org)is a high-profile, user-friendly website developed to provide communities, planners, businesses, civil society and officials with easy access to information on projected changes in sea level and coastal storm impacts. Several SLR scenarios from varying geographies are showcased, one of the first being Long Island Sound. Using a similar analysis, the USVI effort modeled work done in Long Island Sound. Accompany the website is the web map (http://dev.global.coastalresilience.org/). Both are being refined and improved based on partner feedback regarding clarity and ease of use.

High Soil Salinity Threatens Key Tree Cactus in the Florida Keys

Joyce Maschinski and Devon Powell, Fairchild Tropical Botanic Garden

Understanding reasons for biodiversity loss is essential for developing conservation and management strategies and is becoming increasingly urgent with climate change. Growing at elevations <1.4 m in the Florida Keys, U.S.A., the endangered Key tree cactus (*Pilosocereus robinii*) recently has experienced precipitous population decline. From 1994 to 2007 eight extant populations lost 81 percent of plants and 84 percent of stems. Concurrently, seven hurricanes with wind velocities >100 mph and storm surges exceeding 2 m occurred. Since 2007, four populations have declined further, and four have had increased numbers of stems. Previous studies suggested that high soil salinity was associated with Key tree cactus mortality in the lower Florida Keys. With increasing threats of sea level rise and storms, the future of Key tree cactus in the Florida Keys may teeter on its ability to tolerate salinity.

To determine the salinity tolerance of Key tree cactus, under controlled greenhouse conditions we tested growth, physiological, and intercellular indications of salt tolerance of two Key tree cactus maternal lines - one growing in cultivation and a second collected from a high mortality site in the lower Keys. We used five salt concentrations: none; 2 mM NaCl equal to salinity at one proposed reintroduction site; 15 mM NaCl equal to salinity detected where plants had low mortality between 1994 and 2007; 40 mM NaCl equal to the threshold for osmotic stress in salt-sensitive plants and comparable to soil salinity associated with high mortality; and 80 mM NaCl equal to twice the sodium concentrations inducing osmotic stress, but below a lethal dose. Tolerance to salinity varied between the maternal lines. Maternal 1 stem growth increased with higher salinity, while maternal 2 had reduced growth in salt levels above 40 mM NaCl. Root: shoot ratios did not change with salinity for maternal 1, but decreased at 80 mM NaCl for maternal 2. Maternal 2 had slower growth, less transpiration, and greater water use efficiency, and was less salt tolerant than maternal 1. Neither cellular conductivity nor potassium ion concentrations varied across salinity levels or maternal lines, but tissue sodium ion concentrations of maternal 2 increased in the 80 mM NaCl treatment group. Reasons for the differences in salt tolerance between maternal lines may either be genetic or environmental and will require further research. Within the next two decades, the degree to which salinity threatens Key tree cactus may lie in its genetic diversity.

Worldwide rare species restricted to fragmented, low-elevation island habitats, with little or no connection to higher ground will require traditional conservation actions and movement to new locations. For the conservation of Key tree cactus we recommend continued monitoring of all populations and trial reintroductions. Reducing any stresses to existing populations would be beneficial. Specifically, we recommend fencing to protect plants from herbivory. Prior to any reintroduction within historic range or managed relocation outside of range, it will be important to assess soil salinity at a recipient site to determine its suitability for supporting Key tree cactus.

POSTER: Coastal Areas Climate Change Education Partnership (CACCE) (The CACCE Climate Education Partnership for the Southeast US and Caribbean Sea)

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The Coastal Area Climate Change Education (CACCE) Partnership, funded by the National Science Foundation, seeks to develop new ways to educate citizens about global climate change. The core theme is sea level and impacts of climate change in the southeastern United States and the Caribbean Sea. We describe an innovative educational and research model, namely Multiple Outcome Interdisciplinary Research and Learning (MOIRL), in which stakeholders engage in varied research and learning activities leading to multiple outcomes. In the CACCE Partnership the stakeholders include: students (K-16 and graduate); teachers and education researchers; informal science educators; scientists and engineers; business and industry; policy makers; and community members. CACCE combines interdisciplinary research with action research and community-based participatory research in a way that is best described as “transdisciplinary”. Learning occurs in all spheres of interactions among stakeholders as they engage in scientific, educational, community and business activities through their legitimate peripheral participation in research communities of practice. We will describe the process of seeking and building partnerships, and call for a dialogue with groups pursuing climate and climate change education.

Hurricanes and Butterfly Trends in the Florida Keys: Implications for Sea Level Rise

Marc C. Minno, consultant

At least 120 different kinds of butterflies have been reported from the Florida Keys. However, butterflies have been disappearing from the Keys since the 1980s due to a number of factors likely including extreme weather events. There are currently more imperiled butterflies in southern Florida and the Keys than any other region of the United States (nearly 20 taxa).
2004 land cover data for the Keys were generalized into urban, upland, and wetland categories using a GIS. This information was then combined with a digital elevation model to predict changes in the extent of the generalized land cover types with 1-, 5-, and 10-foot increases in sea level.
Wetlands occupy more than half of the Keys and urban areas cover about 60% of the uplands. Some 85% of the wetlands, 25% of the uplands, but only about 10% of the urban area in the Keys would be inundated by a 1-foot rise above current sea level. A 5-foot increase would flood 100% of the wetlands, 80% of the uplands, and 75% of the urban areas. Nearly 100% of the Keys would be inundated by a 10-

foot increase in sea level. Hurricane Andrew in August 1992 and Hurricane Wilma in October 2005 caused flooding similar to the 5-foot scenario.

Known butterfly losses in the Keys include 3 species gone in the 1980s, 1 in the 1990s, and 12 in the 2000s (2 extinctions and 2 extirpations from the U.S.), all of which were upland species. At least 9 imperiled butterflies that occur in uplands in the Keys and 1 that occurs in wetlands are at-risk from hurricanes, and could be wiped out by just one major storm. Sea level rise will only increase the risk to the imperiled butterflies in the Keys from extreme storms.

Research on the factors contributing to the decline and loss of imperiled butterflies in the Keys is an urgent priority. Short- and long-term conservation strategies considering sea level rise and extreme weather impacts to the butterflies are also needed.

Adaptation Behavior in the Face of Global Climate Change: Survey Responses from Decision Makers Serving the Florida Keys

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We conduct a survey to elicit responses from decision makers serving the Florida Keys regarding vulnerability posed by global climate change and sea-level rise. Survey findings reveal deep concern among decision makers about adverse impacts at the local level. A large majority of respondents recognize the increasing likelihood of potentially irreversible socioeconomic and ecological repercussions in the Florida Keys. Yet very few federal, state and local experts report that their respective agencies have developed formal adaptation plans. Decision makers point out institutional and social barriers to adaptation and also convey their support for a host of measures to facilitate adaptation on an urgent basis. As a specific component, we investigate decision makers' willingness to support a proposed 'Community Adaptation Fund' (CAF) in the Florida Keys to marshal resources and lay the foundation for formal adaptation initiatives. We also explore potential sources for establishing the proposed CAF, and test the feasibility of a diverse set of financing mechanisms. In the face of rising vulnerability, novel decision–making criteria, regulatory mechanisms and institutional structures need to be pursued for coastal communities to effectively adapt. We discuss implications of our findings in the context of enhancing adaptive capacity in the Florida Keys and beyond.

Impacts of climate change and sea level rise in peninsular Florida – Can we adapt?

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Florida has an excellent record of past climate change from fossil pollen, vertebrate fossils, and other sources, going back thousands to millions of years. Fossil pollen shows relative vegetation stability, with cycles of pine vs. oak dominance in the peninsula over the past 65,000 years. Vertebrate fossils show a long sequence of grassland, savanna, and scrub adapted animals in a probable warm-temperate to subtropical environment in the peninsular for over 10 million years. Projections by the IPCC of temperature change during the next century show Florida warming less than anywhere else in continental North America. Over the last several decades, records show an increase in temperature variability, with a trend toward colder winters and springs and warmer summers and falls. This increased variability will place more stress on native species and agricultural crops, but in general, the good news is that temperature-related impacts of global climate change may be less severe in Florida than in most other regions of the continent and the world.

On the other hand, Florida is at huge risk of significant impacts from sea level rise. Florida is particularly susceptible due to a combination of low land elevations, a high water table, peninsular geography, vulnerability to tropical storms, and a large and growing human population that is largely concentrated near the coasts. Recent models project rises in sea level globally on the order of 75-190 cm for the period 1990-2100 under the range of future temperatures predicted by the IPCC, with higher levels (ca. 3 m) possible if polar ice sheet dynamics become highly nonlinear. Sea level rise in Florida, which lacks substantial areas of uplift or subsidence, is occurring at approximately the same rate as the global average. Coupled with interacting impacts from human population shifts and land-use changes – which will be exacerbated by sea level rise – this may constitute the most fundamental challenge facing biodiversity conservation in Florida.

Impacts of sea level rise in Florida have been observed for several decades, for example a decline of salt-sensitive tree species in low-lying areas of the Gulf Coast and inland migration of mangroves in South Florida. Projected sea level increases over coming decades will magnify these impacts on many taxa and natural communities. Ecologically-oriented options for adaptation to sea level rise in Florida include restoration and enhancement of habitat connectivity along coastal-inland gradients, protection of discrete movement corridors for some focal species, habitat restoration/creation in strategic areas, population translocation (assisted colonization) into appropriate habitat in areas high enough in elevation to escape projected inundation, avoidance of new development in areas critical for adaptation of natural communities and native species, and abandonment or relocation of existing development and infrastructure in areas that will likely be inundated. Ex situ conservation in zoos, botanical gardens, and seed/gene banks may be the only option, besides extinction, for some taxa if other measures fail.

POSTER: **The Influence of Disturbance, Seasonality, and Hydrologic Controls on Plant Community Boundary Dynamics in the Lower Florida Keys**

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Lowland coastal forests worldwide are being threatened by the possibility of rapid increases in sea level and the impacts of hurricanes. Anticipated changes to vegetation communities and the resources that structure them as a result of climate change are at the forefront of current ecosystem research. While coastal forests have evolved along with sea-level rise and a particular frequency of hurricane activity, the increased sea-level rise of the past century (~23cm at Key West, NOAA 2001) along with possible increases in the frequency of major hurricanes will favor more salt-tolerant species at the expense of species reliant on fresh water. Plant succession leading to changes in communities and community boundaries will be driven by the legacies (nutrient pools and vegetation) remaining from disturbance events, set against a background of seasonal changes in the ever-dwindling resource supply. This research addresses the spatial and temporal relationships between pine rockland, hardwood hammock, and buttonwood community boundaries and nutrient and water availability on the low-lying islands of Big Pine and Sugarloaf Keys. Specific objectives to be addressed by this research include the following: I. a comparison of current and historic plant community boundaries and quantification of storm surge effects by community type from both Hurricane Wilma (2005) and Hurricane Georges (1998), II. identification of the seasonal lateral extent of the freshwater lens and its spatial relationship to vegetation community boundaries, and III. a determination of how water and nutrient availability vary with seasonal changes in freshwater lens extent and how this is reflected in terms of plant stress within the dominant species comprising each community type. The results of this research will provide insight into the inter-relationships and feedback mechanisms between community boundaries, available water and nutrient resources, and disturbance regimes in the face of accelerated sea level rise.

POSTER: **Effects of salinity on common woody species of Buttonwood Forest and Coastal Hardwood Hammocks in Everglades National Park**

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We examine the effects of salinity on a rare plant species and five indicator species of Buttonwood Forests and Coastal Hardwood Hammocks of Everglades National Park (ENP) using experimental and observational data. We use juvenile trees (1-2 years) of *Piscidia piscipula* and *Swietenia mahogany* indicator species of the Coastal Hardwood Hammocks, *Conocarpus erectus* and *Capparis flexuosa* indicators of Buttonwood Forests, and *Eugenia foetida* a species transitional between buttonwoods and hardwoods, to salinity treatments consisting of 5, 15 and 30 parts per thousand of sea-salt and a control. Based on results of stomatal conductance, growth rate, and leaf turnover, we classify study species into two groups: salt sensitive (*Piscidia piscipula, Swietenia mahogany*) and salt tolerant (*Conocarpus erectus, Capparis flexuosa, Eugenia foetida*). Two salt tolerant species exhibited no mortality whatsoever and showed some decline in stomatal conductance and growth rates in response to high salinity levels (≥ 15‰). Buttonwood responded dramatically to salinity treatments at the outset, but within 7 month all but plants in 30 ppt had similar rates of stomatal conductance. *Eugenia foetida* did not adjust its conductance rates and showed significantly higher rates of conductance in low salinity and control compared to high salinity. *Capparis flexuosa*, had greater number of leaves in high compared to low salinity levels and control. While salt-sensitive species had significantly lower stomatal conductance rates in all salinity

treatments compared to control and showed up to 50% mortality in 30 ppt salinity. Thus salinity levels of 30ppt are dangerously high for two hardwood hammock species, other species survive high salinity levels up to period of 7 months.

POSTER: Climate Adaptation Knowledge Exchange

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The Climate Adaptation Knowledge Exchange (CAKE, www.cakex.org) is a joint effort by EcoAdapt and Island Press to create an innovative community of practice on climate change adaptation. CAKE, an interactive online destination, is about supporting the changes that conservation and restoration have to make to keep up with the changing planet. CAKE is intended to support individuals interested in developing the discipline of adaptation to climate change by facilitating the identification of important information and its accessibility; building a community via an interactive online platform; connecting practitioners to share knowledge and strategies; and networking with other relevant materials around the web. This poster will showcase the different components of CAKE, including the availability of a georeferenced database of adaptation case studies, a directory of adaptation-interested people, a virtual library of resources that can support adaptation efforts, advice for conservation and information exchange, and links to tools and data that are available to support and build the adaptation community. We invite you to learn from and join CAKE.

POSTER: SFWMD Regional Geospatial Data Updates that Support SLR Vulnerability Studies in the Florida Keys

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To support modeling and planning efforts, including sea level rise (SLR) studies, the South Florida Water Management District (SFWMD) has been updating several regional geospatial datasets, including topographic digital elevation models (DEMs), tidal surfaces and land cover/ land use layers. Also, in coordination with several agencies, including NOAA's Coastal Services Center (CSC), SFWMD is assisting with SLR vulnerability analysis activities by the Southeast Florida Regional Climate Change Compact Counties (Monroe, Miami-Dade, Broward and Palm Beach). This poster depicts examples of these efforts and associated work products within the Florida Keys, including: DEMs using the 2007-08 LiDAR data from the Florida Division of Emergency Management (FDEM); NOAA's VDatum tidal surface and the initial Mean Higher High Water (MHHW) tidal surface extrapolated inland by CSC (currently under revision by SFWMD); SLR vulnerability probability surfaces developed from Z-scores and documented elevation uncertainty; and comparison of SFWMD's latest (2009) Land Cover/ Land Use dataset to historical datasets.

POSTER: Participatory Stakeholder-Driven Scenarios for Climate Change & Urbanization in the Greater Everglades Landscape

Juan Carlos Vargas-Moreno and M. Flaxman,. Deparment of Urban Studies and Planning. MIT.

Addressing the Challenges of Climate Change in the Greater Everglades Landscape. Project Sheet November, 2010.

Accelerating Sea-Level Rise – Projections and Implications for South Florida

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Accelerating greenhouse gas buildup, ice sheet melt, summer Arctic pack ice thinning, Arctic tundra melt, and methane hydrate melt will cause accelerating sea level rise through this century. Combined ocean warming and expansion, glacier melt, and ice sheet melt should produce at least 150-180cm sea level rise this century. Planning for this century must include adapting to a sea level rise that will be at least 150-180cm by 2100 – and accelerating. This will result in abandonment of all sandy barrier islands; essential abandonment of Monroe, Miami-Dade and Broward Counties; and inundation of significant portions of the world's major deltas. If this sea level rise has reached 150cm at the end of the century, it will be rising 30 cm per decade and accelerating. We will have to adapt the coastal infrastructure to a rapidly shifting coastline. In addition, anticipated accelerated warming and ice melt leads to the significant probability that ice sheet sectors will collapse and result in one or more pulses of very rapid sea level rise. Rapid pulses of rise occurred repeatedly over the past 18,000 years as climate moved from the last ice age to the present interglacial and sea level rose from –120 meters to the present. Past sea level response to climate change demonstrates that very rapid sea level rise pulses are a normal and expected response to significant climate change, and they must be anticipated in the future near. Biological and cultural assets too valuable to lose (e.g. seed banks, Library of Congress, unique coherent cultural hubs) or too critical to be inundated or disrupted (e.g. nuclear power and waste disposal sites, critical military and transportation centers, agricultural centers) should be moved above the reach of any possible major sea level rise pulses and associated chaos. The authors suggest above 50 meters elevation.

POSTER: Species at risk from climate change: the case of Florida Keys endemics

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Species distributions are a response to multiple factors, including climate, habitat, and interactions with other species. Threatened and endangered species often have small geographic ranges, either as a function of natural processes or because of human activities. Because many endangered species are often range-limited, recovery efforts largely focus on maintaining or restoring suitable habitat. Twenty-first century climate change stands to exert significant additional challenges to maintaining suitable habitat for species via direct effects (e.g. changes in temperature and precipitation) and indirect effects (e.g. changes in availability of habitat because of changes in land use, sea level rise, and effects of climate on vegetation communities). As a first step towards development of integrated predictive models, we are constructing climate envelope models for threatened and endangered species occurring in peninsular Florida. These models focus on effects of temperature and precipitation and can be linked with models of changes in land use, sea level rise, and ecological communities. Here we present preliminary predictions of twenty-first century climate change on two species endemic to the Florida Keys, Key Deer (*Odocoileus virginianus clavium*), and Key Largo Woodrat (*Neotoma floridana smalli*), as well as a species whose range in the USA is limited to coastal areas along the extreme southern peninsula of Florida, American Crocodile (*Crocodylus acutus*). The models generally predict an expansion of climatically suitable areas in peninsular Florida by the end of the century, although for some species climate 'bottlenecks' may occur during mid-century. These spatially-explicit models integrated with habitat requirements, changes in land use, and sea level rise provide a tool to help us predict where climate may be suitable for a species and can help us to identify where we may need to think critically about how to provide suitable corridors or migration pathways that facilitate long-term species sustainability.

POSTER: Mapping of Freshwater Aquifers of Small Oceanic Islands

Mike Wightman
GeoView

POSTER: Elevation as a critical factor in the establishment of Black Mangroves

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Understanding the environmental constraints on the establishment of black mangrove propagules is a crucial component for predicting black mangrove habitat sustainability, particularly when faced with both acute and chronic events such as hurricane landfalls and global sea-level rise. How various environmental factors limit black mangrove propagule establishment are not fully understood. We employed a natural elevation gradient occurring in a back-barrier salt marsh in conjunction with a continuously recording water-level gauge to assess the effects of elevation on the establishment of black mangrove propagules under field conditions. Experimental plots were established with or without enclosures at four elevations (low, mid-low, mid-high, high) in five blocks yielding twenty total experimental units. Use of enclosed and unenclosed plots enabled us to evaluate loss of propagules from plots through tidal action. Experimental plots were monitored monthly from November of 2005 to September of 2006 for black mangrove propagule establishment, survival and growth of established propagules, and loss of unrooted propagules from plots. Soil moisture, salinity, conductivity, and pH were determined monthly during the study. Soil organic matter and texture were determined at beginning and end of the study. Treatment elevation significantly affected final propagule establishment, whereas enclosure did not have a significant effect. Establishment was greatest at the high elevation in both the enclosed and unenclosed plots (70% and 72% establishment, respectively). The mid-low elevation demonstrated the lowest establishment success in the enclosed and unenclosed plots at 38% and 4%, respectively. Survival was greatest in the unenclosed plots at the high and mid-high elevations with 47.3% and 39.8% of the propagules that established surviving, respectively. No propagules survived in the unenclosed plots at the two lower elevations. Critical factors in black mangrove propagule establishment appear to be sufficient stranding time (to allow for rooting) and adequate soil moisture in a relatively low-energy environment.

White-crowned Pigeon Nest Surveys, 2000-2010: Impact of the 2005 Hurricanes and Post-hurricane Recovery

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In the U.S., the frugivorous White-crowned Pigeon (WCPI) nests solely in the Florida Keys on backcountry mangrove islands. Nesting birds fly to mainline keys (islands linked by US Highway 1) to forage in uplands with fruit-bearing trees. From 2000-2010, 372 flight line counts were performed at selected mangrove islands in the lower Florida Keys to obtain an index to the nesting population and population trend. The 2005 hurricane season drastically impacted WCPI nesting. Hurricane Dennis (9 July) caused the virtual cessation of nesting for the year and greatly reduced annual recruitment. Hurricane Wilma (24 October) severely damaged the bird's upland foraging areas and further devastated the mangrove nesting areas. In 2006, the number of nests in the study area was lower than in any other year. In KWNWR, the number of WCPI nests was lower (46%) every year from 2006-2010 than any year before the 2005 hurricane season. In contrast, nesting rose sharply in GWHNWR after 2007, and from 2008-2010 the number of nests was higher each year than any of the other previous 8 years. Possible reasons for the marked difference between these 2 refuges in the post hurricane recovery of the nesting populations are discussed. Owing to climate change, eustatic sea level rise and a projected rise in hurricane frequency and intensity acutely threaten the bird's remaining upland foraging areas, already forever greatly reduced by development in the Florida Keys.

POSTER: Severe Long-term Decline in the Number of Loggerhead Turtle Nests in the Key West National Wildlife Refuge

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Loggerhead turtle (*Caretta caretta*) nests were systematically monitored from 1990- 2009 on Woman, Boca Grande and Marquesas Keys in the Key West National Wildlife Refuge (KWNWR). Time-series trend analysis for the 20-year period revealed a downward trend in the number of nests ($P < 0.0001$). More nests were found annually from 1990-1999 (Period 1) than 2000-2009 (Period 2) ($P < 0.001$). At all beaches, the percent of crawls that were nests was lower during Period 2 than Period 1. The number of nests, eggs laid, and hatchlings produced declined 52%, 56%, and 49%, respectively during Period 2, with the steepest declines occurring in the Marquesas Keys. Significantly fewer nests were found during Period 2 than Period 1 on Boca Grande Key ($P = 0.04$) and at 3 of 4 beaches in the Marquesas Keys: Long ($P = 0.002$), Main ($P = 0.002$), and Short ($P = 0.008$). For 803 nests of a known outcome, 467 (58%) nests were on dunes and 336 (42%) were on beaches. Turtles that nested in the dunes produced more hatchlings per nest than those that nested on beaches ($P < 0.001$). As a group, dune nests produced 15.6 more hatchlings per nest than beach nests. Assuming a 2-year nesting interval and 3 annual clutches per breeder, the number of breeders declined by 53% during Period 2. The hatching rate (45%) was low and the proportion of false crawls (63%) was high during the study period. Sea water inundation of nests negatively affected hatching rates and productivity. The marked decline in the number of breeders and nests, low productivity, a high proportion of false crawls, tidal flooding coupled with ongoing beach erosion, and sea level rise collectively threaten the nesting loggerhead turtle population in KWNWR.

POSTER: Green Iguana Proliferation in the Key West National Wildlife Refuge: A Hurricane By-product and a Threat to the Imperiled Miami Blue Butterfly?

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The green iguana (*Iguana iguana*) is a neotropical folivore that is exotic to and widely distributed in southern Florida. Prior to my study, its distribution in the Key West National Wildlife Refuge (KWNWR) was unknown. During 2011, green iguana burrows and tracks were found on 12 islands, and 3 large gravid females (42-61 eggs) were captured on 1 island. Iguana burrows were found from Crawfish Key to the westernmost island in the Marquesas Keys, a distance of 28 km. In 2005, Hurricane Wilma's storm surge in the KWNWR removed the dense vegetation from both the dunes and the sand berms landward of the mangroves. All iguana burrows were found in remnants of the once-large clearings created by this hurricane. Because green iguanas do not nest in heavily shaded areas hurricanes may be important for creating or maintaining openings in an otherwise densely vegetated landscape. Iguana burrows and tracks were found on all 8 areas that harbor the imperiled Miami blue butterfly (*Cyclargus thomasi bethunebakeri*). Once widespread in southern Florida, this butterfly is now restricted to islands in the KWNWR, where its lays eggs only on emerging Blackbead (*Pithecellobuim guadalepense*) leaves. That the green iguana is syntopic with the Miami blue may merit concern. Were this reptile to consume blackbead leaves, it could consume Miami blue eggs and larvae. The inherent problems that confound control of green iguanas on remote islands spread over a large area are discussed.