A. PROJECT SUMMARY

1) University of Central Florida

2) Project lead: Betsy Von Holle; C**o-participants**: John Weishampel, Kaveh Madani, Jennifer Irish, Scott Hagen, Mark Dodd, Matthew Godfrey, Llewelyn Ehrhart, John Stiner, Tim Keyes, Felicia Sanders, Sara Schweitzer, Janell Brush, Alice Bard, and I. Jack Stout.

3) University of Central Florida
Department of Biology
4000 Central Florida Blvd
Orlando, FL; 32816
Tel: 407.823.0916
vonholle@ucf.edu

4) Project title: Investigation of the effects of sea level rise on sea turtle, shorebird, seabird, and beach mouse nesting distributions within the South Atlantic Landscape Conservation Cooperative region.

5) Focal Issue addressed: Integrative projects that meet all aspects of the SALCC niche.

6) Project duration: 2 years; 9/1/2011 – 8/31/2013

7) Project Abstract:

Sea level rise (SLR) and disturbances from increased storm activity are expected to diminish coastal habitats available for sea turtle, seabird, shorebird, and beach mouse nesting by removing habitat as well as inundating nests during critical incubation periods. The goal of our proposed research is to evaluate past nesting patterns of fourteen coastal nesting species and predict future effects of sea level rise on nesting beaches along the South Atlantic Bight. Maps of coastal vulnerability to SLR combined with historical data sets of long-term and spatially extensive nesting habitat will lead to models that enhance our understanding of the complex environmental changes occurring from global climate change and their effects on globally imperiled species. The results from this study will equip policy makers and natural area managers with the ability to prioritize those areas which will need the greatest conservation intervention.

The coastal study areas include nesting beaches for fourteen species from North Carolina south to Melbourne, Florida. Our study will link long-term survey data for four species of sea turtle, three species of shorebird, five species of seabird, and two beach mouse species to maps of coastal vulnerability to sea level rise (SLR) in order to understand the effects of sea level rise on population viability and socioeconomic effects. First, we will create habitat suitability maps for coastal nesting species along the South Atlantic Bight. Second, we will integrate a model of SLR along with long term field biological observations in order to predict vulnerability to nesting habitat loss for sea turtle, seabird and shorebird, and beach mouse species within our study region. Third, habitat loss vulnerability maps under different predictions of SLR, considering local SLR and eustatic SLR induced by climate change, will allow natural area managers to construct strategies for mitigating the impacts of a changing climate on these coastal nesting species, many of which are threatened and endangered. Fourth, we will estimate the socioeconomic costs of changes in coastal nesting habitats and the benefits of implementing different mitigation strategies for our study region. Last, we will estimate future populations of these species with SLR, given survivorship under different development scenarios.

With the results from our study, planners and decision makers will be able to choose from a portfolio of mitigation techniques for policies relevant to coastal nesting species. There is an urgent need to determine long-term plans so that the most cost-effective strategies of reducing the effects of sea level rise on coastal species can be determined.

B. PROJECT DESCRIPTION

1) Objectives

a - We will create habitat suitability maps for fourteen coastal nesting species.

b - We will integrate the USGS SLR Coastal Vulnerability Index with known distributions of coastal nesting species to visually present coastal nesting species habitat vulnerability across the South Atlantic Bight.

c- We will explore the socioeconomic costs of the effects of sea level rise on coastal nesting species and the socioeconomic benefits of adaptation strategies

2) Narrative

Climate change varies around the world and concomitant ecological responses are likely to differ by region (Walther et al. 2002). When studied at the regional scale, climatic changes have been found to be spatially and temporally complex, and as a result have differing impacts on organisms (Helmuth et al. 2006, Von Holle et al. 2010). Sea level rise (SLR) is expected to diminish coastal habitats available for nesting by removing habitat as well as inundating nests during critical incubation periods (Hawkes et al. 2007, Fish et al. 2008). Inundation due to SLR will convert intertidal to subtidal habitats, which will reduce foraging areas available to shorebirds, especially in those areas where the tidal zone movement is inhibited by topography or human structures, such as seawalls (Galbraith et al. 2002). We propose to research the effect of both local SLR, due for example to subsidence, and eustatic SLR, as influenced by global warming, on important beach mouse, sea turtle, seabird, and shorebird nesting habitat across the South Atlantic Landscape Conservation Cooperative region. With this project, we will integrate selected future SLR scenarios with long term field biological observations in order to predict vulnerable nesting habitat for these species. Additionally, we will provide maps of habitat loss vulnerability under different future SLR scenarios which will allow natural area managers to construct strategies for mitigating the impacts of a changing climate on these coastal nesting species. Last, we will estimate the socioeconomic costs of changes in nesting habitats and the benefits of implementing different mitigation strategies across the South Atlantic Landscape Conservation Cooperative Area.

Sea turtle, shorebird, seabird, and beach mouse spatial data

We have compiled spatial location data for sea turtle, seabird and shorebird, and beach mouse species along the coastline abutting the South Atlantic Bight (coastal US between Cape Hatteras, NC and Melbourne Beach, FL) using historic beach mice, sea turtle, seabird, and shorebird nesting data. Our study species include four species of sea turtle [loggerhead (*Caretta caretta*), green (*Chelonia mydas)*, leatherback (*Dermochelys coriacea*), and hawksbill (*Eretmochelys imbricate)*], two species of beach mouse [Anastasia Island beach mouse (*Peromyscus polionotus phasma*), southeastern beach mouse (*Peromyscus polionotus niveiventris*)], three species of shorebirds [American oystercatcher (*Haematopus palliates*), piping plover (*Charadrius melodus*), Wilson's plover (*Charadrius wilsonia*)], and five species of seabirds [black skimmer (*Rynchops niger*), gull-billed terns (*Sterna nilotica*), royal terns, (*Sterna maxima*), sandwich terns (*Sterna sandvicensis*), and the brown pelican (*Pelecanus occidentalis*)]. All of our sea turtle and beach mouse species are listed as threatened or endangered under the Endangered Species Act (1973). The piping plover is listed as threatened, and the American oystercatcher and black skimmer are considered species of concern. Sea turtles are iteroparous, making reproductive migrations once every few years. Female sea turtle nesting efforts leave conspicuous marks in the sand identified by trained surveyors at the species level (Witherington et al. 2009). In our region, survey frequencies differ by study species, and we list these along with the contributing collaborators (identified by their initials): **Sea turtles**: Annual surveys for the coastlines of Florida (*LE, JS*), Georgia (*MD*), and North Carolina (*MG*). For our final project, we may be able to incorporate sea turtle data from South Carolina. **Shorebird and seabird** nests or territorial pair coordinates are located and marked with GPS and are surveyed approximately every five years across the entire coastline of Florida (*JB*), Georgia (*TK*), North Carolina (*SS*), and South Carolina (*FS*). Trapping locations of **beach mice** have been mapped in Florida (*AB, JS*) using a hand-held GPS unit and are surveyed annually within our study area.

Objectives and Approach

Objective a: We will create habitat suitability maps for fourteen coastal nesting species.

Coastal nesting habitats are highly dynamic systems that are subject to disturbance, i.e., erosion, accretion, and overwash, as a result of regular tidal and extreme storm events. Seawater inundation leads to the failure of sea turtle nests to produce hatchlings as embryonic development is halted due to reduced oxygen exchange (Ragotzkie 1959, Martin 1996). Nests of shorebird and seabird species are regularly washed out with storm surges within our study area (T. Keyes, *personal observation*). Lowered reproductive success inevitably affects population levels. The spatial (location along a beach, elevation and distance from the high water line, as well as nest depth) and temporal (time of year in relation to seasonal storm events, i.e., hurricanes) nesting behaviors influence the susceptibility of different sea turtle (Pike and Stiner 2007) shorebird and seabird (Convertino et al. 2011), and beach mouse (Pries et al. 2009) species to flooding. In addition to simply reducing the available nesting habitat, the frequency and extent of these disturbance events are thought to be exacerbated as a result of SLR (Zhang et al. 2004); thus, storm surge events expected every 100 years may become 40-year events (McInnes et al. 2003).

SLR estimates vary geographically depending largely on mesoscale hydrodynamics and geology. Thermal expansion is estimated to produce an 18-60 cm rise by 2100 with an average of 4.2 mm per year until 2080 (Gregory et al. 2001, Meehl et al. 2005). Recent evidence suggests that sea level may rise more rapidly than previously predicted, due to an accelerated rate of ice loss from the Greenland Ice Sheet (Rignot and Kanagaratnam 2006). Low lying narrow coastal and island beaches are particularly sensitive to SLR (Daniels et al. 1993, Fish et al. 2005, Baker et al. 2006) and are especially vulnerable when coastal development prevents landward migration of beaches (Fish et al. 2008). This “coastal squeeze” will most likely be amplified as current population trends project increasing human densities along the coasts (Small and Nicholls 2003).

We will integrate all GIS and location-specific data of sea turtle, seabird, and shorebird nests as well as beach mouse burrows collected across our study region into a data layer for this study. We will use 2005-2010 annual surveys for sea turtle nests, 2-3 survey years (depending on subregion) for seabird and shorebird locations, and 2005-2010 annual surveys for beach mouse distributions to map the extent of nesting locations for each species along the coastline of our study area. Coastal habitat will be ranked based on relative density of nests, nesting pairs, or burrows, which will determine its relative importance, or habitat suitability, for each species (following the methods of FNAI 2010).

Objective b: We will integrate the USGS SLR Coastal Vulnerability Index with known distributions of coastal nesting species to visually present coastal nesting species habitat vulnerability across the South Atlantic Bight.

Sea turtles seabirds, shorebirds, and beach mice generally have a high level of nesting site fidelity. We will produce spatially explicit nest density maps with GPS data for the different species across the coastline abutting the South Atlantic Bight using historic beach mice, sea turtle, seabird, and shorebird nesting data. These will provide primary locations along the shoreline and from high tide lines along with elevation information derived from existing, recent airborne LiDAR. Airborne LiDAR is regularly used to monitor hurricane induced beach dynamics and has been related to nesting patterns (Long et al. 2011).

Several studies thus far have examined the potential effect of SLR on sea turtle nesting beaches using high precision Digital Elevation Models (DEMs) coupled to simple passive inundation (‘bathtub’) models (e.g., Baker et al. 2006). However, this approach does not take into account the dynamics of the coast, e.g. winds, waves, tides (Hawkes et al. 2009). Following this simplistic approach, a Hawaiian study (Baker et al. 2006) predicted that up to 40% of low profile, green turtle (*Chelonia mydas*) nesting beaches could be flooded with 0.9 m of SLR. Another study for Barbados (Fish et al. 2008)and Bonaire (Fish et al. 2005) suggested similar losses (~50%) of hawksbill turtle (*Eretmochelys imbricate)* nesting habitat. We will create maps of coastal nesting habitat likely to be lost due to SLR using LiDAR remote sensing and existing spatially explicit maps of SLR in our study region (Hammar-Klose and Thieler 2001).

SLR will strongly affect the populations of coastal nesting species, and we can predict which species those will be as well as the habitats which will experience the greatest losses from SLR. It is critical for management of these rare species to predict the habitats likely to be lost due to SLR. We will create GIS map layers of coastal nesting habitat likely to be lost due to SLR as informed by the U.S. Geological Survey's Coastal Vulnerability Index (CVI), created for the Atlantic coast of the U.S. (Thieler and Hammar-Klose 1999), which provides an overall assessment of a coastal area's vulnerability to erosion and inundation as a function of SLR. The CVI method assigns coastline segments, at 5-km resolution, a ranking of low, moderate, high, or very high vulnerability, based on a numerical weighting which includes six factors influencing coastal vulnerability: geomorphology, coastal slope, relative (local plus eustatic) SLR rate, shoreline erosion rate, mean tide range, and mean wave height. The published CVI is based on historical trends of SLR, and does not consider future SLR projections with global warming. However, we will use the CVI framework to develop CVI for selected future Intergovernmental Panel on Climate change (IPCC) SLR scenarios to assess changes in CVI with changes in SLR rates. The modified CVI will be combined with coastal nesting density maps of our focal species to create habitat vulnerability maps for selected future SLR scenarios. For example, we define a 'high' habitat vulnerability to SLR as a combination of a 'high' coastal vulnerability to SLR and 'high' nesting densities of our study species.

Maps of habitat loss vulnerability under different predictions of SLR and future climate change scenarios will assist conservation and beach restoration strategies such as suggesting "setback regulations", or the minimum distance from the mean high tide line for future development, or suggesting areas for beach restoration of low-lying beaches to counteract sand loss due to rising sea levels or storm erosion (Fish et al. 2008, Brock and Purkis 2009, Long et al. 2011).

Objective c: We will explore the socioeconomic costs of the effects of sea level rise and storm surges on coastal nesting species and the socioeconomic benefits of adaptation strategies.

We hypothesize that the regions with the greatest levels of coastal nesting species and highest chance of inundation due to SLR will experience the greatest economic losses. It is vital to understand how ecosystem changes due to SLR will affect human systems. To complete our understanding of the effects of SLR on coastal species nesting distribution we will: 1) estimate the socioeconomic costs of changes on turtle, shorebird, seabird and beach mouse nesting distribution; and 2) estimate the socioeconomic benefits of some adaptation/response strategies. Socioeconomic costs include, but are not limited to, the costs associated with losses of: sea turtle, shorebird, seabird, and beach mice populations, ecosystem services, tourist attractions, housing, land, and jobs as well as the resulting social effects on citizens' lives (e.g., migration, change of jobs, etc.). To minimize the negative impacts of SLR on coastal nesting distributions and the associated socioeconomic costs we will propose some strategic adaption/response strategies. Those will include structural measures (e.g., beach restoration) and non-structural measures (e.g., limiting development within a certain distance of coastlines, "setback regulations"). We will identify the best adaptation/response strategies by estimating and comparing their socioeconomic costs (e.g. cost of stopping development in an area due to setback regulations) and benefits (e.g., sustaining ecosystem services), by considering the uncertainties in future climatic conditions and SLR. The outcome of our model will be the level of survivorship of our study species under different mitigation strategies, which can be used to estimate the benefits of implementing various mitigation techniques. Furthermore, we will provide an online tool which allows the users to change the values of ecosystem services (e.g., land value, organism value) and come up with their own cost and benefit estimations, considering the results of our vulnerability-based approach. This will give natural area managers, policy makers, and conservation planners a portfolio of options available to mitigate the effects of climate change on important sea turtle, shorebird, and beach mouse nesting sites.

3) Relationship to the LCC niche

- Landscape-scale: Our study region encompasses the entire South Atlantic LCC region (SALCC), with the exception of southern VA. Our study region extends beyond the southern extent of the SALCC, south to Cape Canaveral National Seashore and Archie Carr National Wildlife Refuge, in order to encompass these important beach mouse and sea turtle nesting areas.
- Cross-taxa: Our research concerns the habitat suitability, future range shifts, and habitat vulnerability to SLR for multiple taxa that utilize coastal habitat: sea turtles, shorebirds and seabirds, and beach mice. Additionally, we will be employing a socio-economic analysis of the costs and benefits of mitigation for SLR for these taxa, which will be a way of quantifying their cultural importance.
- Forward looking: This research will predict range shifts of these coastal species under several future climate projections for the next 20, 50 and 90 years. Additionally, we will identify important habitats vulnerable to SLR for each species, with a vulnerability analysis combining coastal vulnerability as a function of SLR with habitat suitability.
- Decision focused: We will provide a portfolio of mitigation techniques for SLR to resource managers, policy makers and conservation planners, based on the results of our socio-economic model.
- Adaptive: We will integrate additional data sources into our research program, as they become available, as indicated by our methods.
- Making connections and filling gaps: Our proposal team is comprised of natural resource managers, ecological modelers, coastal engineers, a remote sensing scientist, and a socio-economic modeler. Many of us are working on similar projects and ideas within our research or natural resource programs and will be able to directly integrate these across our academic institutions as well as our respective state and federal agencies.

4) Project timeline

Table 1. Timetable of general, two-year work plan. Colors correspond to institutions, with initials of collaborators identified with each institution. Green = UCF Biology *(BVH, JW,LE, IJS)* **and organismal biologists** *(MD, MG, JS, TK, FS, SS, JB, AB)***; blue=Texas A&M Coastal and Ocean Engineering Division** *(JI)***; orange = UCF Civil, Environmental, & Construction Engineering** *(SH, KM).*

Task	2011		2012				2013		
	Su	F	W	Sp	Su	F	W	Sp	Su
Integrate spatial data for all taxa across all sites									
Construct habitat suitability maps & future range shifts, for each species									
Develop coastal habitat vulnerability maps to SLR									
Develop a socio-economic model of costs and benefits of various mitigation techniques									
Disseminate results to scientific & public audiences with scientific and popular media articles & a web page describing our activities									

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