Narrative Description

Abstract

On the Texas coast, mangroves regularly expand from persistent populations into salt marshes during periods with warm winters, and occasionally contract in distribution during periods with severe freezes. Over the coming decades, mangrove distributions are expected to continue expanding due to rising global temperatures and milder winters. As a result, large areas of the Texas coast that historically have been dominated by salt marshes will become dominated by mangroves. Will this matter? We hypothesize that that changes in coastal vegetation are likely to change the quality of coastal wetlands for supporting shrimp, fish and birds, and change the ability of coastal habitats to buffer wind and wave energy. We will test this hypothesis using a combination of field sampling and a manipulative experiment, working around and within the domain of the Mission-Aransas National Estuarine Research Reserve. Our work will provide information on which ecosystem services provided by coastal wetlands are most likely to be affected by the change from salt marsh to mangroves. This information will allow coastal industries such as fisheries and tourism to be adaptively managed in response to ongoing and future changes in the biological environment.

Background and Purpose

On the Texas coast, mangroves periodically expand from relict populations into salt marshes during periods with warm winters, and periodically contract during periods with severe freezes (Sherrod and McMillan 1981, McMillan 1986). In the Mission-Aransas estuary (central Texas coast), stands of black mangroves (*Avicennia germinans*) have increased in coverage from 65 acres to at least 15,000 acres in the last 20 years (Montagna et al. 2007). As a result, smooth cordgrass (*Spartina alterniflora*)-dominated marsh habitats are being converted to stands of mangrove trees (Fig. 1A) and unvegetated mudflats are being transformed into pneumatophore complexes (Fig. 1B). Over the coming decades, mangrove distributions are expected to continue expanding due to rising global temperatures and milder winters (Nielsen-Gammon 2009). Periods with extended freezes sufficient to cause populations to die back have been rare during the last 60 years, and are likely to decrease in the future. This warming trend may push the system beyond what has been the "natural" condition over the past few hundred years, with mangroves occupying a much greater percentage of the Texas coast (McKee and Rooth 2008, Montagna et al. 2009).

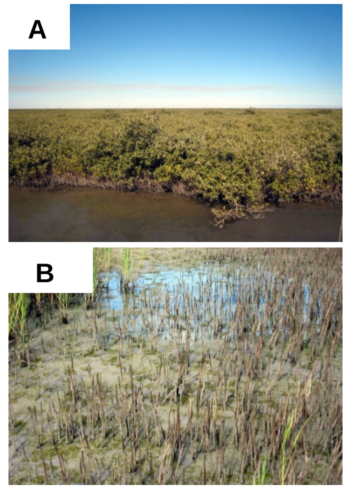

Figure 1: (A) A former salt marsh in Port Aransas, TX that is now a stand of *Avicennia germinans*. (B) Alteration of a mudflat by proliferation of *Avicennia* pneumatophores.

Mangroves and salt marshes are dominated by "foundation species"—single species that are largely responsible for creating the biotic and abiotic conditions that define their habitat. Ecological theory tells us that the loss, or change, of a foundation species is likely to shift the ecological system into a different "state" with different properties (Ellison et al. 2005). Would such a state change matter for the Texas coast?

This is an important question to resolve, because much of the coastal Texas economy relies on wetlands. Coastal wetlands support commercial and recreational fisheries (e.g., for red drum, *Sciaenops ocellatus*, and brown shrimp, *Farfantepenaeus aztecus*), improve coastal water quality, protect coastal development by reducing storm damage and erosion (Costanza et al. 2008), provide habitat for bird species that support a vigorous tourism industry, and harbor several endangered species (Butzler and Davis 2006). If these ecosystem services change as mangroves replace salt marshes, this will impact the economic welfare of the citizens of Texas.

Moreover, if wetland services change, this may require state and federal agencies to manage coastal resources differently. Although we are unlikely to directly control the geographic range expansion of mangroves, mangrove expansion might lead us to change the way we manage fisheries, water quality, building codes, and tourism to benefit commercial and recreational stakeholders.

Existing data are inadequate to determine whether a shift from marsh to mangrove will affect ecosystem services on the Texas coast. Although ecosystem services of salt marshes and mangroves have been measured at a number of sites, the value of these services varies geographically as a function of the local environmental context, species composition, and human social structure. Taking storm protection as an example, there may be geographic variation in the intensity of storms, the geomorphology of the near-shore and coastal plain, the structure of mangrove stands, and the location of human settlements, all of which will affect the value of coastal protection provided by mangroves. Thus, it would be misleading to compare the ecosystem services of mangroves measured in Thailand with those of salt marshes measured in Texas. Nevertheless, given the marked differences in physical structure between mangroves and salt marshes, it seems likely that these habitats will provide different ecosystem services.

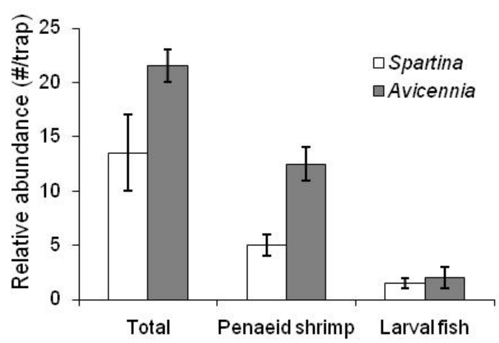

Figure 2: The relative abundance of motile epifauna captured in light traps deployed in edge habitat composed of *Spartina* stems or *Avicennia* pneumatophores. n = 2; error bars are SE. Armitage, unpublished data.

A few studies have attempted to compare the function of mangroves and salt marshes that co-occur within the same geographic region (Moseman et al. 2009). For example, Mendelssohn and colleagues found few differences in carbon cycling between salt marsh and adjacent young mangrove stands in Louisiana (Perry and Mendelssohn 2009). In contrast, Bloomfield and Gillanders (2005) found higher animal densities in mangroves versus marshes in Australia, as we did in Texas (Fig. 2). However, nekton species composition differed between the plant types, and diversity was ~50% lower among the pneumatophores than in the marsh grasses (Armitage, unpublished data), suggesting that mangroves might increase nekton abundance but reduce diversity. Contrasts in motile epifauna use of mangrove and marsh habitats may be driven by the availability of food resources—a pilot study by the Armitage lab suggested that epiphytic chlorophyll was about 20% lower on *Avicennia* pneumatophores than on *Spartina* stems.

A major weakness with these types of observational “natural experiments” is that there may be a reason (such as differences in elevation or soils) that mangrove and salt marsh stands occur in different locations at a site. Without an experimental approach, one cannot be sure that any observed differences (or lack thereof) between vegetation types truly represent the effect of the species, and not the microhabitat. Moreover, the effects of foundation species are likely to be non-linear with species density, and to vary in “thresholds” among variables (Nagelkerken et al. 2008). In the near future, many coastal areas in TX will probably not see dense mangrove forests, but rather scattered mangrove shrubs at varying densities within salt marshes (Montagna et al. 2009). The function of these mixed systems will probably differ from that of monotypic stands, and in order to assess thresholds, a range of conditions needs to be evaluated. It is likely, for example, that mixtures of mangroves and salt marsh vegetation would support higher plant and animal species diversity than pure stands of either vegetation type alone, leading to a hump-shaped relationship between diversity and mangrove cover (Fig. 3B). Other variables may show accelerating or decelerating relationships with mangrove cover (Fig. 3C).

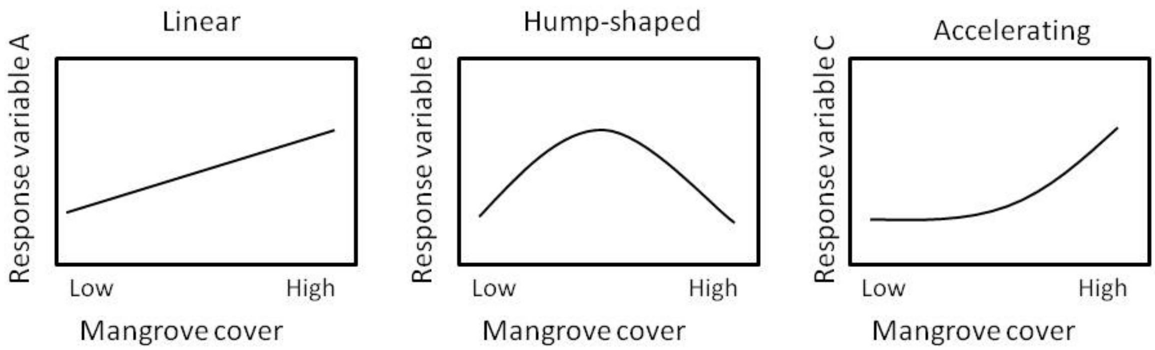

Figure 3. Some processes may respond linearly to increasing mangrove cover (Variable A). Other variables, however, may peak at intermediate mangrove cover (Variable B) or show accelerating (Variable C) or decelerating (not shown) responses.

This project directly addresses Texas Sea Grant Research **Topic 1** (*Projects that directly or indirectly collect, generate and/or synthesize data about the current baseline of ecosystem health for bay systems, nearshore areas and the marine environment, such as:…mangrove ecology and range extensions*), **Topic 2** (*Proposals that focus on ecosystems from an economic or sociological perspective: value of ecosystem services to residents and visitors to the coast*), and **Topic 3** (*Projects that occur in the Mission-Aransas Estuarine Research Reserve [MANERR]*).

Benefits to the State of Texas

The ecological consequences of a state change from salt marshes to mangroves in the Mission-Aransas NERR area are likely to affect several ecosystem services that support processes or industries of economic value to the state of Texas, including fisheries, tourism, water purification, and coastal protection. The variables that we propose to measure are relevant to these services, and will determine which services are most likely to be affected, how much they are likely to be affected, and how services vary with mangrove density. Improved understanding of the ecological consequences of mangrove displacement of salt marsh vegetation will improve current and future management of the available resources. In addition, this project will provide numerous outreach and education opportunities. Graduate and undergraduate student involvement activities will incorporate future local stakeholders into current and upcoming management of coastal ecosystems.

Objectives

1) To determine the ecological consequences of the transition from salt marshes to mangroves, with an emphasis on ecosystem services supporting coastal economies in Texas.

2) To educate the public about the causes and consequences of the transition from salt marshes to mangroves on the Texas Coast.

3) To initiate a long-term experiment that will attract additional funding and scientists to study the salt marsh to mangrove transition within the domain of the Mission-Aransas National Estuarine Research Reserve.

Project Plan

We will address our objectives using both sampling and a manipulative experiment. These approaches have different strengths and weaknesses, such that the combination of both will be the most powerful way to test our hypotheses. Sampling can be done relatively quickly, and can address processes that may take decades to develop following mangrove invasion by using a space-for-time substitution. In addition, because we can sample large plots, sampling will help us extrapolate experimental results to the stand scale. The weakness of sampling, as we illustrate below, is that variables other than mangrove invasion may affect the results. The manipulative experiment will be labor-intensive, and only some variables will respond within the lifetime of the experiment; however, it has the strength that mangrove cover can be unambiguously isolated from other drivers potentially affecting coastal ecosystem processes.

Sampling. We will identify ~20 relatively large (> 1 hectare) stands of coastal wetland that vary in mangrove cover, from pure salt marsh to pure mangrove, in the vicinity and within the domain of the MANERR. We will use large stands to minimize edge effects that may occur in the manipulative experiment. Plot locations will be marked using GPS. Abiotic, soil, vegetation, and faunal variables will be measured in plots (detailed methods below). We predict that many variables will respond non-linearly and with thresholds to mangrove density (Table 1).

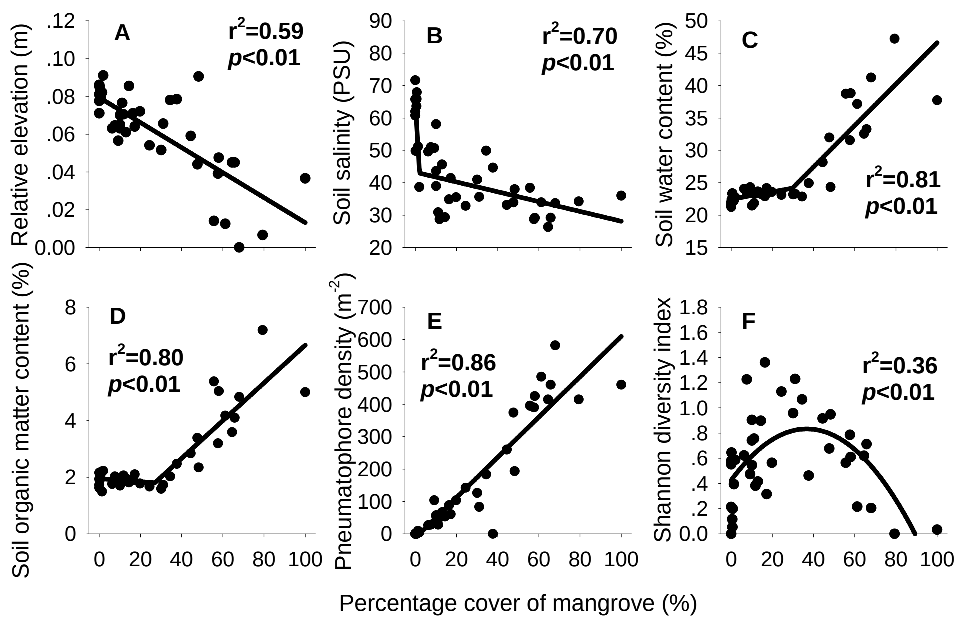

Figure 4. Relative elevation (A), soil characteristics (B, C and D), mangrove pneumatophore density (E) and plant diversity (F) along a gradient of mangrove percent cover in sampling plots (regressions in A and E are linear; regressions in B, C and D are piecewise linear; and the regression in F is quadratic).

Pilot sampling efforts using small (4 m^2) plots on Harbor Island demonstrate both the strengths and weaknesses of this approach (Fig. 4). With increasing mangrove canopy cover, there was a linear increase in pneumatophore density (Fig. 4E). Many other variables, however, responded non-linearly, or with strong thresholds. Plant diversity was greatest at intermediate levels of mangrove cover, when mangroves and salt marsh plants coexisted (Fig. 4F). Soil salinity (Fig. 4B) declined rapidly at low levels of mangrove cover, but much more slowly once mangrove canopy cover was >5%. In contrast, soil water and organic content (Fig. 4C and D) were low when mangrove cover was <30% and increased sharply at higher levels of mangrove cover.

Despite efforts to minimize elevational variation, however, plots with high mangrove cover were lower in elevation than plots with low mangrove cover (Fig. 4A). Thus, it is not clear whether differences in soil characteristics and plant diversity were driven by mangrove cover or by elevation. Analysis of the data using structural equation modeling suggested that both elevation and mangrove cover played a role in mediating soil traits and plant diversity (Fig. 5). Although SEM can help disentangle these relationships, our conclusions would be far more robust if we could eliminate confounding variables. This concern over causality will be even greater when we compare large stands as proposed above, because these large stands will by necessity be further apart, and represent a wider range of abiotic conditions. Therefore, our sampling approach will be augmented with a field experiment that will rigorously control for extraneous variables.

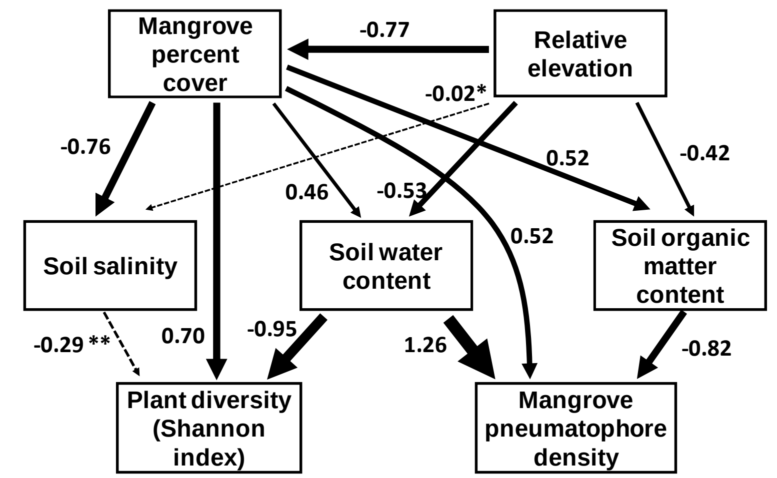

Figure 5. Structural Equation Model of variables measured in pilot field survey (the numbers denote the standardized coefficient for each path; the dotted lines indicate non-significant paths (* p = 0.28, ** p = 0.09)).

Field Experiment. We will conduct a large, manipulative experiment within the domain of the MANERR (Fig. 6). The experiment will consist of relatively large (1,000 m^2) plots that will be manipulated to contain a gradient of mangrove:salt marsh mixtures, ranging from pure mangrove to pure salt marsh. By using large plots, we will be able to realistically measure a variety of ecosystem functions. By examining a range of densities from pure salt marsh through mixtures to pure mangrove, we will address non-linear effects and thresholds. The location was chosen based on remote sensing work by John Schalles (Creighton University) and direct site visits. Plots will be oriented towards the prevailing winds (Fig. 7), which will be ideal for determining how mangrove density affects wind speed and wave height. Sea level at the site peaks in the spring and fall (Fig. 8), and measurements of wave dampening will be taken at these times.

Figure 6. Potential location of manipulative experiment on Harbor Island within the boundaries of the MANERR. Plots would be located along the main channel facing Southeast into the direction of prevailing winds (Figure 7).

Our approach will mimic dieback of mangrove stands following a freeze that kills or partially kills some or all of the mangroves at a site. Mangrove stands will be thinned to a range of densities with a chain saw and clippers, and maintained by repeat thinning as needed each winter. Salt marsh plants will be encouraged to invade thinned plots through plug transplants. Similar techniques are often used to transplant plants in salt marsh restoration projects, and commonly achieve full coverage of marsh vegetation within 1-2 years. We will install leg assemblies within plots to support portable aluminum boardwalks that will allow repeated sampling of plots with minimal disturbance. Abiotic, soil, vegetation, and faunal variables will be measured in plots (detailed methods below). We predict that many variables will respond non-linearly and with thresholds to mangrove density (Table 1).

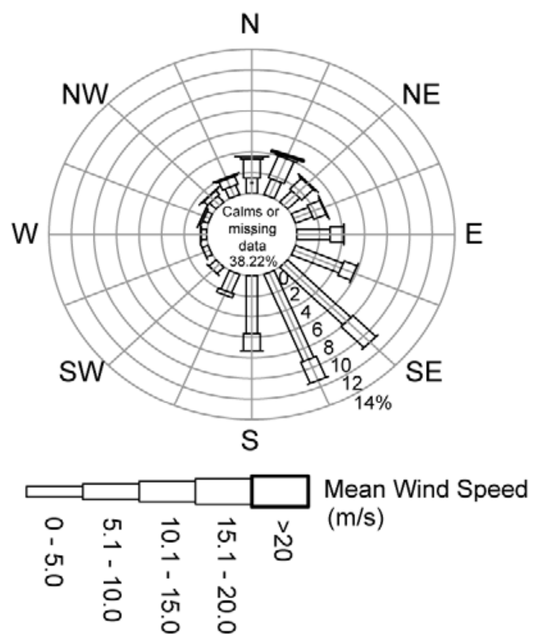

Figure 7. Wind rose for Port Aransas. Data from NOAA tide station, 2002-2011. Prevailing winds are out of the southeast.

Some ecosystem functions will respond to this manipulation more rapidly than others. We anticipate that effects on abiotic conditions (light, temperature, humidity, wind speed, wave dampening) will be almost immediate, measurable within days. We anticipate that effects on plant and animal abundance and diversity will be moderately rapid, and will be informative by the second year of the project. In contrast, we anticipate that effects on soils and soil biota will take much longer to become apparent. As described below, however, we intend to maintain the plots, measure more variables over time, and attract additional collaborators to work with us at the site. A manipulative experiment at this spatial scale, directly comparing mangroves and salt marshes, has never been conducted anywhere in the world, and will be a novel contribution to the scientific and management literature.

An obvious concern with this proposal is that the experiment will have to be sustained beyond the duration of a single Sea Grant proposal in order to maximize its value. We have two responses that ameliorate this concern. First, in the worst-case scenario, we will still learn a great deal within the time frame of this project by combining the sampling and experimental approaches, because at least some variables will respond quickly to the experimental manipulation, and a complete range of variables can be measured using the sampling approach.

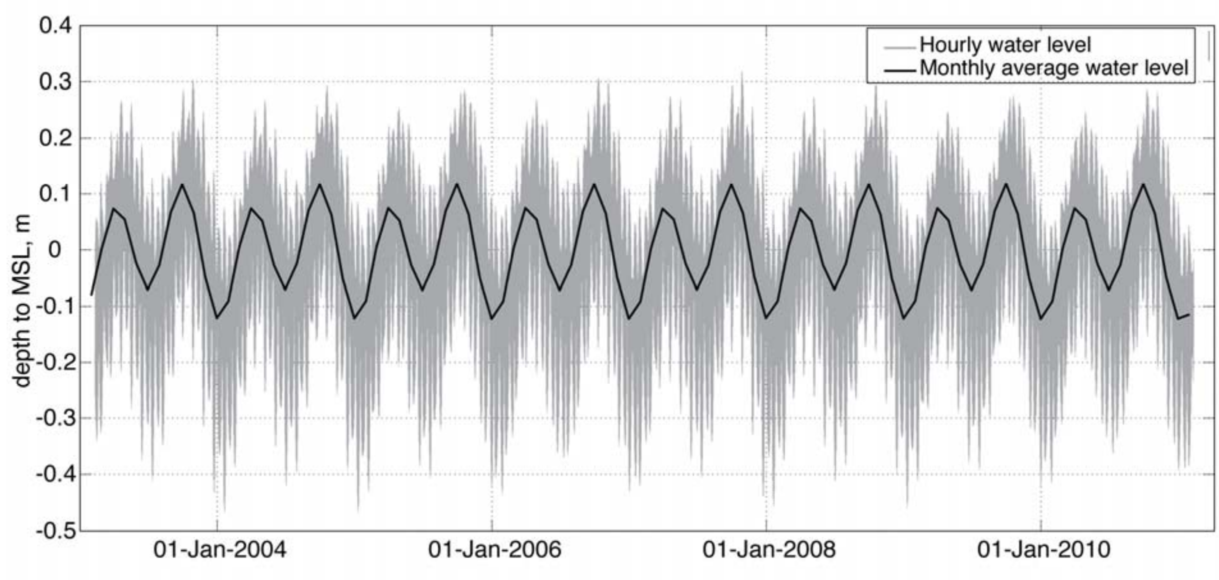

Figure 8. Hourly and monthly mean of sea level at NOAA Port Aransas Tide Station. Sea level in the study area peaks in the spring and fall.

Second, we have four strategies for sustaining the life of the field experiment beyond this single Sea Grant proposal, assuming strong preliminary results. 1) We will submit a second Sea Grant proposal to continue the experiment for another two years. 2) Using data generated by Sea Grant funding, we will submit an NSF proposal to continue the experiment. 3) We will pursue funding from the Environmental Institute of Houston to support research within the experimental plots. EIH funding was instrumental in gathering some of the preliminary data for this proposal (Figure 4). Although EIH grants are limited to modest support for materials and graduate students, this level of funding would be sufficient to allow the experimental treatments to be maintained and some additional data collected. 4) The University of Houston Coastal Center (Pennings is director) will support annual maintenance of the experimental treatments for at least 3 years if other funding is not forthcoming. Thus, if there is a gap in Sea Grant or NSF funding, the treatments will be maintained, allowing data collection to resume at a later date.

Detailed Methodology. *Edaphic characteristics.* We will collect 5 soil cores at the beginning of the study across an elevational gradient within each sampling and experimental plot to determine soil organic content (by combustion) and particle size distributions. We will collect an additional 6 cores from each plot monthly (June-August) or quarterly (October, January, April) to measure soil water content (gravimetrically) and salinity (because porewater cannot be squeezed from relatively dry, mineral soils, we will rehydrate dried soils in a known volume of distilled water, measure salinity of the supernatant, and back-calculate to the original porewater volume (Pennings and Richards 1998)). Soil redox potential (10 cm depth) will be measured with a platinum electrode and an Orion meter adjacent to salinity cores on the same schedule as salinity. Measuring redox potential in wetland soils is challenging, but this approach is sufficient to determine if large differences in redox potential exist between elevations, sampling plots or experimental treatments. All cores will be collected from locations of known elevation and processed individually.

Elevations. We will construct a Digital Elevation Map of each sampling and experimental plot using LIDAR (if available) or standard surveying equipment (owned by Pennings and Armitage labs). If plots are surveyed, we will install permanent markers in each plot and rent RTK-GPS equipment to measure the absolute elevations of the markers so that elevations of all sampling and experimental plots can be directly compared.

Wind and waves. Wetlands, by creating increased friction, reduce the power of winds, waves and storm surges hitting coastlines, and therefore protect valuable coastal infrastructure (Farber 1987, Costanza et al. 2008). Although completely addressing the effects of vegetation on coastal protection in Texas is beyond the scope of this proposal, we will collect data that will 1) provide information on the frictional effect of different mangrove-salt marsh vegetation combinations on wind and waves, and 2) provide an abiotic context for other measurements made in this study. Temperature, humidity and wind speed will be recorded continuously using data loggers (2 sensors/variable/plot, deployed above and within the canopy). Data loggers will be deployed for 1 month in the experimental plots before mangrove vegetation is thinned to assess initial similarity of the plots, then placed in sampling plots for a 1-month deployment, and then permanently deployed in experimental plots. Wind data will be censored to only examine periods when wind is blowing directly into plots from the channel (Fig. 7). When possible, we will seek additional funding from other sources to more extensively instrument the sampling and experimental plots. Directional wave dampening will be measured with a cross-shore transect of three high frequency (>4Hz) high-resolution Aquadopp current meters (available through Boston University) rotated among the sampling and experimental plots. This will allow us to compare wave height and direction at each location moving shoreward. Measurements will be scheduled during the annual peaks in water level to ensure plots will be submerged (Fig. 8). If field time becomes limiting, we will make this aspect of the project a lower priority, but we believe that preliminary data in this area will be valuable for a follow-on NSF proposal for this project.

Plant community structure. Mangrove abundance and size structure will be documented by individually measuring the size (height, canopy width and depth) of all mangroves in permanent 4 x 4 m sub-plots (5 sub-plots per sampling or experimental plot). We will document the community structure of understory plants by sampling ten 0.5 × 0.5 m quadrats (nested with 4 x 4 m plots). In each quadrat, we will score the percent cover of each plant species (including mangrove seedlings < 25 cm tall), count pneumatophores, and measure the height of the understory vegetation at each corner of the quadrat. To document light interception by vegetation, we will measure a vertical PAR profile at each quadrat using a 1 m light wand. Measurements will be taken at 25 cm vertical intervals from the soil surface to above the top of the canopy. These measurements will be repeated annually in mid-summer (July-August).

Invertebrate community structure. We will count benthic macroinvertebrates (mostly *Littoraria irrorata* snails) and crab burrows in 0.5 x 0.5 m vegetation sampling quadrats. We will also collect insect and spider community samples using a D-Vac suction sampler (twenty, 10-second collections from each sampling and experimental plot) in mid-summer (July-August). The taxa will be counted under a stereomicroscope, identified to the lowest taxonomic level possible, and body sizes of the most abundant and widespread taxa will be measured. Taxa will be assigned to feeding guilds (herbivore, predator, detritivore) based on the literature and mouthpart structure.

Nekton. Quantifying nekton density within complexes of aerial mangrove roots is logistically challenging, but in pilot field trials, we have developed two techniques that will quantify (a) relative and (b) absolute nekton abundances in stands of marsh and mangrove vegetation. (a) To assess relative abundance rapidly and simultaneously in multiple locations, we will deploy light traps from dusk to dawn. Light traps will be constructed from fine mesh (0.5 mm) minnow traps with a submersible light source inside. (b) The structural complexity of aerial roots in mangrove stands makes the quantitative sampling of associated fauna challenging, but stake nets are generally considered to be the most effective technique (Vance et al. 1996, Rönnbäck et al. 1999). Stake nets have been successfully used to sample relatively small areas (Rönnbäck et al. 2002), so we will deploy stake nets enclosing 4-m^2 of habitat. The top and the bottom of the net will be open, and the upper and lower rims of the net will be secured to the benthos (Rönnbäck et al. 2002, Huxham et al. 2004). The stakes securing the top of the net will be connected with a line to a marker on shore. After a one-hour acclimation period, the top of the net will be released by a technician on shore, and the buoyant top of the net will rapidly rise to the surface of the water. Stake nets often rely on ebbing tides to force fauna into a cod end, but in areas with limited tidal exchange (such as the Gulf of Mexico), hand collection from the nets is an alternative approach (Rönnbäck et al. 2002). Therefore, dip nets will be used to remove all organisms trapped within the nets. Collected animals from both sampling techniques will be enumerated and identified to species, and diversity calculated using standard indices.

Birds. To assess bird use of marsh and mangrove habitats, we will enlist the assistance of stakeholder groups of bird watchers. With the assistance of Sea Grant Marine Information Service (MIS) staff under the direction of Jim Hiney, we will develop a website describing the project and for bird watchers to report bird species and abundance at a subset of the sampling plots with easy road access. This website will developed in cooperation with MIS programmer Eric Graham using available software and will be hosted on the Texas Sea Grant server. Extension Specialist Russ Miget will help direct us to local bird watching groups that can identify ideal study sites. MIS staff will also assist us with the development of signage and pamphlets to explain the project objectives and direct birdwatchers to the website. Incorporation of the general public in data acquisition may introduce some statistical uncertainty in terms of identification or density estimates, but these can be minimized by filtering the data based on the level of expertise of the volunteer (repeat volunteers are likely to be known by leaders of birding groups). In addition, using data from volunteers will enable us to collect information on bird use of the sites over a much larger temporal scale than we could feasibly accomplish on our own. If we observe bird use of experimental plots, we will solicit volunteers from our bird-watcher volunteer corps to conduct extended focal-individual observations of bird activity within the experimental plots.

Table 1. Predictions about responses of variables to mangrove cover.

Variables	Nature of relationship with mangrove density	Rationale
Nekton density and diversity	Linear (Figure 3A)	In the shallow water column, access by nekton will depend on the abundance of marsh plants and pneumatophores
Plant diversity, insect/spider diversity,	Hump-shaped (Figure 3B)	Plant diversity will be highest in mixtures. Insects/spider diversity will parallel plant diversity because taxa are associated with particular plants.
Light interception by vegetation, humidity, wind interception, moderation of waves, above-ground biomass (C storage),	Accelerating/threshold (Figure 3C)	These variables are affected by mangrove biomass, which will increase faster than mangrove cover because plants will grow taller in addition to expanding their canopy area.
Temperature, soil porewater salinity, Bird density and diversity	Decelerating/threshold	Shade and boundary layer will increase with mangrove biomass. Wetland birds will avoid plots as soon as moderate mangrove densities make it difficult to watch for predators and to walk through the vegetation

Food webs. In order to determine the contribution of different producers to the food web and compare trophic relationships between *Spartina* and *Avicennia* habitats, we will characterize food web structure by drying and homogenizing plant and animal tissues for stable isotope analyses. We will quantify the relative abundance of ^{13}C and ^{15}N isotopes in producers and consumers and use IsoSource v.1.3.1 software to calculate diet contributions with a linear mixing model modified for multiple sources. Funding for these measurements will be obtained elsewhere as part of the PhD work of Carolyn Weaver, a graduate student in the Armitage lab.

We will work with Sea Grant MIS staff to develop products that will inform Texas residents about our research, particularly by disseminating breaking news in local newspapers. The project website and brochures will provide a more permanent outreach opportunity, as they will be available to the public beyond the timeline of this project. We have dedicated a portion of our budget to these outreach materials and for travel to facilitate working meetings with Sea Grant staff, especially in the early development of the project website.

Table 2. Major project milestones.

Activity	Spring 2012	Summer 2012	Fall 2012	Winter 2012	Spring 2013	Summer 2013	Fall 2013	Winter 2013
Develop project website	X	X						
Select locations for sampling plots	X	X						
Micrometeorological data in sampling plots		X						
Collect data from sampling plots		X	X			X	X	
Bird data collection		X	X	X	X	X	X	X
Select locations for experimental plots, preliminary data	X	X						
Mangrove thinning		X		X				X
Collect data in experimental plots		X	X	X	X	X	X	X

Products. This project will directly support one PhD student and two postdoctoral research associates. Graduate students funded from other sources will expand the scope of the project. The project will support two undergraduates in year 1. Additional undergraduates will be involved in the project as volunteers and as part of directed studies, honors, and REU programs available at UH and TAMUG. The PIs, postdocs, graduate students and undergraduates will all work closely together in the field, and participate in quarterly meetings between the two research groups, supplemented by Skype video calls as needed. All group members will interact with Sea Grant personnel and birding groups to improve training in outreach and exposure of the project.

Results from the proposed work will be presented as seminars at interested agencies such as GBEP and TPWD. The PIs regularly attend state and national meetings where results will be presented, including the State of the Bay meetings and conferences held by the American Society for Limnologists and Oceanographers, Ecological Society of America, and Coastal and Estuarine Research Federation. In addition, the project will produce publications in the scientific literature, with both PIs having strong publication records.

The PIs have websites (Pennings: www.bchs.uh.edu/~steve/; Armitage: http://www.tamug.edu/marb/armitage/) describing their currently-funded wetland ecology and restoration projects. A new, dedicated web page will be developed for this project, with reciprocal links from PI sites, birding group web sites, and other related sites. This web site will serve as the nexus for interactions with birding groups and for presenting project results to the general public. PIs will take responsibility for quality control of the data presented.

Project Management. This project is a collaboration between the University of Houston (Pennings) and Texas A&M Galveston (Armitage). Pennings is a professor at the University of Houston. He has studied coastal wetlands for over 20 years, and has an extensive record of publishing in the best ecological journals. He received the Merit Award for outstanding research from the Society of Wetland Scientists in 2010. His laboratory is currently studying the ecological interactions between mangrove seedlings and salt marsh vegetation that are mediating the success of mangroves in different habitats along the Texas coast. Hongyu Guo, who coordinated these studies of mangrove-salt marsh interactions, and gathered much of the preliminary data for this proposal, is receiving his PhD in May 2011, and will work on the current project as a postdoc. Hughes is a visiting scholar in the Pennings lab who will provide oceanographic expertise to support assessments of vegetation effects on waves. Armitage is an assistant professor at Texas A&M University at Galveston. As a community ecologist with over 10 years of experience working in coastal ecosystems, her research has focused on the restoration and management of wetlands. Her current research projects address how nutrient enrichment alters ecological interactions and processes in the mangrove-marsh ecotone and other coastal wetland habitats. Armitage has an adjunct position in Pennings' department at UH and has served on the committees of several of his students. Carolyn Weaver, a PhD candidate in Armitage's lab, will be partially supported on this project.

Personnel from the two institutions will work together synergistically to complete the project. Pennings will take ultimate supervisory responsibility for the project and timeline (Table 2). The UH team will take primary responsibility for measuring edaphic, micrometeorological, wave dampening, and plant, macroinvertebrate and insect/spider community structure. The TAMUG team will take primary responsibility for sampling nekton and birds, and coordinating outreach activities with Sea Grant personnel.

Data Management. Data sheets will be photocopied daily. Electronic data files will be backed up to multiple external locations daily. Synthetic data sets will be archived in tabular form with complete metadata in EML (Ecological Metadata Language) using the Morpho software tool (available from NCEAS at http://knb.ecoinformatics.org/morphoportal.jsp). Instrument logs will be archived in both their native format and tabular formats, with associated metadata describing the deployment location and methodology. Data files will be openly and freely available at the Knowledge Network for Biocomplexity data repository (http://knb.ecoinformatics.org/index.jsp) or Dryad (http://datadryad.org/) as papers are published. Data sets will be versioned to indicate changes since initial release.

Performance Outcomes. Although it is difficult to quantify the absolute monetary value of coastal wetlands, the importance of the support provided by coastal marshes to local and state economies communities cannot be overstated. Many fisheries depend on coastal marshes for nursery habitat and food web support; commercial fisheries provide $1.6 trillion in gross state product annually, and recreational anglers add another $2.6 billion to the state economy each year (NMFS 2010). In addition, birdwatchers spend more per capita in Texas than in any other Gulf state: each of the seven million birdwatchers that visit the Texas coast each year will spend, on average, over $1,100 at local hotels, restaurants, boating operations, and stores (NRDC 2010). Thus, the transition from salt marshes to mangroves has the potential to affect coastal industries in Texas with a value of nearly $1.7 trillion per year. Similarly, an average 100 km swath of coastal wetland in Texas protects an annual Gross Domestic Product of over $63 billion dollars per year (Costanza et al. 2008); how the transition from salt marshes to mangroves will affect coastal protection is poorly understood. Appropriate management of coastal habitats in support of these commercial and recreational stakeholder communities will not only provide tangible economic income to local and state economies, but will also improve job retention and hiring in these industries. Furthermore, we expect to provide direct employment support for two postdoctoral research associates and one graduate student, as well as essential job training for other graduate and undergraduate students, better preparing them to enter the work force.

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