Final Project Memorandum
Southeast Climate Science Center Project

1. ADMINISTRATIVE

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Project Title:
Ecological implications of mangrove forest migration in the southeastern U.S.

Project Number:
011

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12 November, 2014

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September 2012 - September 2014

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$272,076

2. PUBLIC SUMMARY

Winter climate change has the potential to have a large impact on coastal wetlands in the southeastern United States. Warmer winter temperatures and reductions in the intensity of freeze events would likely lead to mangrove forest range expansion and salt marsh displacement in parts of the U.S. Gulf of Mexico and Atlantic coast. The objective of this research was to better evaluate the ecological implications of mangrove forest migration and salt marsh displacement. The potential ecological impacts of mangrove migration are diverse, ranging from important biotic impacts (e.g., coastal fisheries, land bird migration; colonial-nesting wading birds) to ecosystem stability (e.g., response to sea-level rise and drought; habitat loss; coastal protection) to biogeochemical processes (e.g., carbon storage; water quality). This research specifically investigated the impact of mangrove forest migration on coastal wetland soil processes and the consequent implications for coastal wetland responses to sea-level rise and carbon storage.

3. TECHNICAL SUMMARY

In tidal saline wetlands, climate change is expected to result in the poleward migration of mangrove forests at the expense of salt marshes. To better understand some of the ecological effects of mangrove forest encroachment in different climatic settings, we compared plant-soil interactions across mangrove forest structural gradients in three locations in the northern Gulf of Mexico (Florida, Louisiana, and Texas). These locations are affected by distinct climate-mediated abiotic factors. At each location, we sampled three salt marsh sites and nine mangrove forest sites that spanned the respective mangrove forest structural gradient. Our study specifically addressed the following questions: (1) How do ecological processes and ecosystem properties differ between salt marshes and mangrove forests; (2) As mangrove forests develop, how do their ecosystem properties change and how do these properties compare to salt marshes; (3) How do plant-soil interactions across mangrove forest structural gradients differ among three distinct locations that span the northern Gulf of Mexico; and (4) What are the ecological implications of mangrove forest encroachment and development into salt marsh in terms of soil development, carbon and nitrogen storage, and soil strength? We quantified relationships between plant community composition and structure, soil and porewater physicochemical properties, hydroperiod, and climatic conditions. The suite of measurements that we collected provide initial insights into how different geographic areas of an ecotone, with different environmental conditions, may be impacted by mangrove forest expansion and development, and how these changes may alter the supply of specific ecosystem goods and services. Marsh species composition and mangrove forest structural complexity varied greatly across these locations. At all locations, aboveground carbon stocks were higher in mangrove forests than in salt marshes; however, mangrove forest belowground carbon stocks were only higher than salt marshes in the driest location (Texas), which is where mangrove forest structural development exerted the largest impact on properties related to soil peat development and carbon storage (i.e., bulk density and the accumulation of soil organic matter, carbon, and nitrogen). In the wetter locations (Louisiana and Florida), the linkages between mangrove forest development and soil properties were not significant or minimal. At all three locations, soil shear strength was higher in mangrove forests than in salt marshes. Collectively, our results indicate that interactions between winter temperatures and rainfall influence the above- and belowground ecological implications of poleward mangrove forest expansion and development in the northern Gulf of Mexico. Looking more broadly, these findings reinforce the importance of considering interactions between multiple climatic drivers when attempting to predict the ecological implications of climate-induced ecological transitions, especially those that involve woody plants encroaching into grass-dominated ecosystems. The data and publications from our work can help environmental managers and decision makers plan and prepare for future change in coastal wetland ecosystems.

The data and metadata from this project have been archived on Science Base and are available via this link: https://nccwsc.usgs.gov/display-project/5006f8dee4b0abf7ce733fc5/5016c89be4b06fb5ce8b736a

In addition to Science Base, the GIS shapefiles from the Osland et al. 2013 analyses have been posted to the Landscape Conservation Cooperative's Conservation Planning Atlas and are available via this link:
http://databasin.org/datasets/6ec804f5250a483abd9bdb200939247f

4. PURPOSE AND OBJECTIVES

In parts of the southeastern U.S., winter climate change has the potential to cause relatively dramatic landscape-scale structural transformations as mangrove trees replace salt marsh grasses in tidal saline wetlands (Osland et al. 2013, Cavanaugh et al. 2014, Saintilan et al. 2014). The objective of the proposed research was to investigate some of the ecological implications of mangrove forest migration and salt marsh displacement. Our research investigated the impact of mangrove forest migration on coastal wetland soil processes and the consequent implications for coastal wetland responses to sea-level rise and carbon storage. We specifically addressed the following questions: (1) How do ecological processes and ecosystem properties differ between salt marshes and mangrove forests; (2) As mangrove forests develop, how do their ecosystem properties change and how do these properties compare to salt marshes; (3) How do plant-soil interactions across mangrove forest structural gradients differ among three distinct locations that span the northern Gulf of Mexico; and (4) What are the ecological implications of mangrove forest encroachment and development into salt marsh in terms of soil development, carbon and nitrogen storage, and soil strength?

5. ORGANIZATION AND APPROACH

This work was conducted by a team of scientists from the U.S. Geological Survey National Wetlands Research Center and the University of Louisiana at Lafayette. The paragraphs below identify the research methods utilized and activities performed.

Study Area

We selected three distinct locations within the salt marsh-mangrove ecotone in the northern Gulf of Mexico where *A. germinans* individuals exist at their latitudinal limit. The three locations were at Port Aransas (hereafter Texas; 27.854 º-27.912 º N, 97.055º-97.072º W), Port Fourchon (hereafter Louisiana; 29.100º-29.110º N, 90.193º -90.201º W), and Cedar Key (hereafter Florida; 29.141º-29.143º N, 83.021º-83.032º W). These three locations are the most well-studied northern Gulf of Mexico salt marsh-mangrove ecotones in their respective states. The Texas location is a relatively dry area (mean annual precipitation: 941 mm) compared to the Louisiana and Florida locations (mean annual precipitation: 1592 and 1360 mm, respectively). All three locations are micro-tidal environments; Louisiana and Texas have mean tidal ranges of 0.37 m and 0.27 m, respectively, and Florida has a slightly larger mean tidal range of 0.86 m. *Avicennia germinans* is the dominant mangrove species in all three locations, and herbaceous vegetation at the sites includes a mixture of halophytic graminoids and succulent forbs.

Experimental Design

At each of the three locations, three salt marsh and nine mangrove sites were identified (i.e., 12 sites per location; three locations; 36 total sites). The nine mangrove sites spanned the natural *A. germinans* structural gradient present within each location and captured varying stages of forest development. Mangrove sites were selected to represent uniform size classes that were defined primarily by height in order to capture the mangrove structural gradient. The three salt marsh sites within each location were dominated by salt marsh species, although some sites did have a limited number of small mangrove shrubs or seedlings in the greater area. At each site, we established one 100-m^2 circular plot (radius: 5.65 m), and all measurements were collected from within this 100-m^2 plot. Sampling in ecosystems with high structural diversity and multiple morphologies of mangrove trees, shrubs, and salt marshes can be challenging; therefore, in this study we used a sampling design that included multiple strata and a series of nested subplots (sensu Osland et al. 2012). Within the 100-m^2 circular plot, we randomly established three nested 1-m^2 subplots and three 0.25-m^2 subplots for determination of small-scale properties (e.g., herbaceous layer, soil, and porewater properties) using a randomly assigned compass direction and distance from the center of the plot. Larger subplots (e.g., 2 m^2, 25 m^2) were also established on a density-dependent basis to adequately characterize some mangrove forest structural properties (e.g., short tree strata), which occurred at variable densities.

Hydrology

We calculated hydroperiod by determining site elevations and relating these to local hydrologic regimes (i.e., tidal data). Elevation was determined for the center of each site via real time kinematic survey (RTK) (Trimble R8 Receiver & Trimble TSC3 Controller, Trimble Navigation, Ltd., Sunnydale, California), and expressed in North American Vertical Datum of 1988 (NAVD88) Geoid 12A. Local tide gauges were utilized to determine hourly water level data from five years prior to March 2013 for each location (Cedar Key, Florida- NOAA [National Oceanic and Atmospheric Administration] Tides and Currents-Station ID: 8727520; Port Fourchon, Louisiana- CRMS [Coastal Reference Monitoring System]-Station ID: CRMS0292; Port Aransas, Texas-TCOON [Texas Coastal Ocean Observation Network]-Station ID: DNR-009). All water levels were either collected in, or converted to, NAVD88-Geoid 12A to be directly comparable with survey measurements to determine percentage of time flooded. For all locations, we subtracted the elevation for each site from the local tide gauge hourly water level data which provided us with the flooding status for each site for every hour over the past five years. Total number of hours flooded was divided by total number of hours recorded giving us the percentage of time flooded at each site (percent exceedance).

Soil

Within each 100-m^2 plot, two soil cores were collected to a depth of 30 cm from a 1-m buffer surrounding each of the three 1-m^2 subplots. These six cores were collected to form two sets of composite soil samples, one set of composite samples for physicochemical analyses and one set of composite samples for the determination of bulk density and soil moisture. For each composite sample set, three cores (i.e., one from each subplot buffer) were partitioned into depth increments of 0-5 cm, 5-15 cm, and 15-30 cm from the soil surface and then composited by depth increment in the field. The coring device used to collect soil samples was a custom-made stainless-steel split corer (4.7 cm diameter, split cylinder with a piano hinge). After collection, cores were stored in a cooler with ice packs. Upon return to the laboratory, cores were stored at 4 ºC until processing. Soil cores for physicochemical analyses were dried at 60 ºC, hand ground with a mortar and pestle, and sieved through a 2-mm screen prior to all analyses. Subsamples for elemental analyses were homogenized using a planetary mill (Frisch Pulviresette USA, New York, New York). Physicochemical analyses included total nitrogen (TN), total carbon (TC), soil organic matter (SOM), and particle size. An elemental analyzer (Flash EA 1112, NC Soils, Thermo Quest, Thermo Fisher Scientific, Waltham, MA) was used to measure TN and TC via dry combustion (McGill and Figueiredo 1993, Tiessen and Moir 1993, respectively). TN and TC were converted from percentages to grams per cm^3 and megagrams (Mg) per hectare using the bulk density measurements. These volumetric conversions were performed to facilitate comparisons among sites and locations with differing soil properties. SOM was determined via loss on ignition in a muffle furnace at 475 ºC for 16 hours (Wang et al. 2011). Bulk density samples were dried at 105 ºC to a constant mass and simple dry weight to volume ratios were used to calculate bulk density (Blake and Hartge 1986). Percent soil moisture was determined via the weight difference after drying. Soil shear strength was determined in the field using a handheld geovane (Geovane Model 49, Geotechnics, Auckland, New Zealand) with a 33-mm vane blade. Triplicate determinations of soil shear strength were taken within each 1-m^2 subplot at 2.5 cm, 10 cm, and 22.5 cm depths below the soil surface and determined as torque was applied to the geovane measuring pressure needed to shear the present soil and converted to kilopascals (kPa). The three measurements were averaged for each depth. The three depths represent the midpoints of the three segments in each of the 30-cm soil cores; 2.5 cm for the 0-5 cm segment, 10 cm for the 5-15 cm segment, and 22.5 cm for the 15-30 cm segment.

Porewater

Porewater samples were collected with a sipper tube apparatus (McKee et al. 1988) from each of the three 1-m^2 subplots at a depth of 15 cm below the soil surface. One aliquot was immediately preserved with antioxidant buffer and analyzed for sulfides within 12 hours of collection (Orion 9616 BN silver/sulfide electrode, Thermo Scientific, Waltham, MA). A second aliquot was used for *in situ* determination of temperature and salinity (YSI 30, YSI Inc., Yellow Springs, OH) as well as pH (Oakton WD 35801-00, Oakton Instruments, Vernon Hills, IL). The third aliquot was maintained on ice, filtered, and preserved with trace-metal grade nitric acid and thereafter submitted to the Louisiana State University Soil Testing and Plant Analysis Lab for Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) analyses of trace elements (Al, Fe, S, P, Na).

Vegetation

A variety of vegetation measurements at multiple strata were performed to capture differences in vegetation structure. Within the 100-m^2 plots, three broad categories were utilized for all measurements: tall tree mangroves (>1.4 m in height), short tree mangroves (0.3-1.4 m in height), and salt marsh species. Percent cover was determined for each of three strata, as well as an integrated total. The integrated total was an estimate of percent cover for the entire plot regardless of strata and did not exceed 100%. Measurements of mangrove individuals were divided into the two different strata (i.e., tall trees and short trees). For the short tree stratum, we measured total height, basal diameter (stem diameter at 0.3 m above the soil surface), and crown diameter in two perpendicular directions (i.e., one measurement across the widest extent of the canopy and another measurement across the widest extent that was perpendicular to the first) (sensu Osland et al. 2014). Since our sites were selected to capture structural gradients, the structural complexity and diversity of the vegetation at our sites was high (i.e., sites that ranged from marsh to dense shrubs to tall forests). As a result, the density of short trees and tall trees was highly variable. Depending upon the density of the short tree stratum, measurements were performed in either the whole plot or an appropriate subdivision that enabled approximately 20 individuals to be included. Most often the short tree measurements were recorded within two nested and randomly located 2-m^2 subplots. Similarly, height and diameter at breast height (DBH: defined as at 1.4 m above the soil surface) of tall trees was determined in the whole plot or a subplot that enabled approximately 20 individuals to be included. In total (i.e., including all sites and locations), we measured the structural attributes of 583 and 907 individuals in the tall and short tree stratums, respectively. Aboveground biomass for the short tree stratum was estimated via an allometric equation for freeze-affected *A. germinans* individuals that utilizes plant volume measurements (i.e., a combination of crown diameter and plant height measurements) (Osland et al. 2014). Aboveground biomass for tall trees was estimated using a species-specific allometric equation that utilizes DBH (Smith III and Whelan 2006). Total estimated aboveground mangrove biomass was used to estimate grams (g) of carbon per m^2 and also megagrams (Mg) of carbon per hectare by utilizing a 41.5% conversion (Bouillon et al. 2008).

Salt marsh plant cover and canopy height was estimated within all 1-m^2 subplots, and species-specific stem density, shoot height, pneumatophore density, and pneumatophore height were determined within each of the nested 0.25-m^2 subplots. Clip plots from all three of the 0.25-m^2 subplots were harvested during the growing season and combined into a composite sample for each site in order to determine biomass and estimate aboveground carbon stocks. Upon returning to the lab, clip plot samples were sorted by species into live and dead components and weighed after drying at 60º C. Total estimated aboveground salt marsh biomass was converted to an estimate of Mg of aboveground carbon per hectare by utilizing a 44.0% conversion (McKee and Rooth 2008).

6. PROJECT RESULTS

The primary project results are summarized below. These text sections come from: (1) a manuscript that is in preparation (Yando et al. *In prep*); and (2) a manuscript that has been published (Osland et al. 2013). The publication portion of this memorandum provides links to additional project results and products.

Abstract from: Yando, E. S., M. J. Osland, J. A. Willis, R. H. Day, K. W. Krauss, and M. W. Hester. *In prep*. Mangrove forests vs. salt marshes: the implications of climate-induced woody plant encroachment on plant-soil interactions in tidal saline wetlands. For submission to Global Change Biology.

In tidal saline wetlands, climate change is expected to result in the poleward migration of mangrove forests at the expense of salt marshes. To better understand some of the ecological effects of mangrove forest encroachment in different climatic settings, we compared plant-soil interactions across mangrove forest structural gradients in three locations in the northern Gulf of Mexico (Florida, Louisiana, and Texas). These locations are affected by distinct climate-mediated abiotic factors. At each location, we sampled three salt marsh sites and nine mangrove forest sites that spanned the respective mangrove forest structural gradient. Marsh species composition and mangrove forest structural complexity varied greatly across these locations. At all locations, aboveground carbon stocks were higher in mangrove forests than in salt marshes; however, mangrove forest belowground carbon stocks were only higher than salt marshes in the driest location (Texas), which is where mangrove forest structural development exerted the largest impact on properties related to soil peat development and carbon storage (i.e., bulk density and the accumulation of soil organic matter, carbon, and nitrogen). In the wetter locations (Louisiana and Florida), the linkages between mangrove forest development and soil properties were not significant or minimal. Collectively, our results indicate that interactions between winter temperatures and rainfall influence the above- and belowground ecological implications of poleward mangrove forest expansion and development in the northern Gulf of Mexico. Looking more broadly, these findings reinforce the importance of considering interactions between multiple climatic drivers when attempting to predict the ecological implications of climate-induced ecological transitions, especially those that involve woody plants encroaching into grass-dominated ecosystems.

Abstract from: Osland, M. J., N. Enwright, R. H. Day, and T. W. Doyle. 2013. Winter climate change and coastal wetland foundation species: salt marshes versus mangrove forests in the southeastern U.S. Global Change Biology **19**:1482-1494.

We live in an era of unprecedented ecological change in which ecologists and natural resource managers are increasingly challenged to anticipate and prepare for the ecological effects of future global change. In this study, we investigated the potential effect of winter climate change upon salt marsh and mangrove forest foundation species in the southeastern U.S. Our research addresses the following three questions: (1) What is the relationship between winter climate and the presence and abundance of mangrove forests relative to salt marshes; (2) How vulnerable are salt marshes to winter climate change-induced mangrove forest range expansion; and (3) What is the potential future distribution and relative abundance of mangrove forests under alternative winter climate change scenarios? We developed simple winter climate-based models to predict mangrove forest distribution and relative abundance using observed winter temperature data (1970-2000) and mangrove forest and salt marsh habitat data. Our results identify winter climate thresholds for salt marsh-mangrove forest interactions and highlight coastal areas in the southeastern U.S. (e.g., Texas, Louisiana, and parts of Florida) where relatively small changes in the intensity and frequency of extreme winter events could cause relatively dramatic landscape-scale ecosystem structural and functional change in the form of poleward mangrove forest migration and salt marsh displacement. The ecological implications of these marsh-to-mangrove forest conversions are poorly understood but would likely include changes for associated fish and wildlife populations and for the supply of some ecosystem goods and services.

7. ANALYSIS AND FINDINGS

The primary project analyses and findings are summarized below. These text sections come from: (1) a manuscript that is in preparation (Yando et al. *In prep*); and (2) a manuscript that has been published (Osland et al. 2013). The publication portion of this memorandum provides links to additional project results and products.

Abstract from: Yando, E. S., M. J. Osland, J. A. Willis, R. H. Day, K. W. Krauss, and M. W. Hester. *In prep*. Mangrove forests vs. salt marshes: the implications of climate-induced woody plant encroachment on plant-soil interactions in tidal saline wetlands. For submission to Global Change Biology.

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8. CONCLUSIONS AND RECOMMENDATIONS

Primary Conclusions:

- Our results identify winter climate thresholds for salt marsh-mangrove forest interactions and highlight coastal areas in the southeastern U.S. (e.g., Texas, Louisiana, and parts of Florida) where relatively small changes in the intensity and frequency of extreme winter events could cause relatively dramatic landscape-scale ecosystem structural and functional change in the form of poleward mangrove forest migration and salt marsh displacement. The ecological

implications of these marsh-to-mangrove forest conversions are poorly understood but would likely include changes for associated fish and wildlife populations and for the supply of some ecosystem goods and services.
- Marsh species composition and mangrove forest structural complexity varied greatly across the three northern Gulf of Mexico study locations. At all locations, aboveground carbon stocks were higher in mangrove forests than in salt marshes; however, mangrove forest belowground carbon stocks were only higher than salt marshes in the driest location (Texas), which is where mangrove forest structural development exerted the largest impact on properties related to soil peat development and carbon storage (i.e., bulk density and the accumulation of soil organic matter, carbon, and nitrogen). In the wetter locations (Louisiana and Florida), the linkages between mangrove forest development and soil properties were not significant or minimal. Collectively, our results indicate that interactions between winter temperatures and rainfall influence the above- and belowground ecological implications of poleward mangrove forest expansion and development in the northern Gulf of Mexico. Looking more broadly, these findings reinforce the importance of considering interactions between multiple climatic drivers when attempting to predict the ecological implications of climate-induced ecological transitions, especially those that involve woody plants encroaching into grass-dominated ecosystems.

Primary Recommendations
- Along the Gulf of Mexico coast, macroclimatic drivers greatly influence coastal wetland ecosystem structure, function, and the provision of ecosystem goods and services. The effects of changing macroclimatic conditions should be incorporated into future-focused models and conservation planning efforts. The Gulf of Mexico coastal region has multiple "zones of instability." These are zones where small changes in climate can result in landscape-scale changes in coastal wetland ecosystem structure and function. Within these "zones of instability", additional research and monitoring is needed to improve of our understanding of the potential implications of climate change-induced ecological regime shifts for important ecosystem goods and services.
- One of the primary challenges facing coastal wetland scientists today is the improved understanding and prediction of the response of coastal wetlands to sea-level rise and other aspects of global change. Much of the research to date within this arena has focused on salt marsh grasses and has not incorporated the effects of macroclimatic drivers. There is a need for longer-term experimentation and research that will contribute to our understanding and ability to predict the implications of changes in foundation species structure and composition upon ecological processes that will enable coastal wetlands to keep pace with sea-level rise, migrate inland, and continue to provide important ecosystem goods and services in the future.

9. MANAGEMENT APPLICATIONS AND PRODUCTS

The transition from salt marsh to mangrove forests is relatively dramatic to even the casual observer (i.e., an ecosystem that has been historically grass-dominated transitions to a woody plant-dominated system). In some locales, stakeholders and resource managers are likely to resist these transformations to the extent possible, and, potentially, manage for the historical wetland condition (e.g., via the use of prescribed fire or other management tools to limit mangrove migration into salt marsh at local scales as in Ten Thousand Islands NWR). In other locales, managers may promote mangrove expansion in order to capitalize on positive ecosystem impacts (e.g., in Louisiana where there has been discussion of planting mangroves in order to increase carbon sequestration rates, reduce storm surge, and reduce wetland land loss). In both instances, resource managers will benefit from having resources that can be used to better evaluate the ecosystem impacts of mangrove migration. Our results elucidate some of the ecological implications of mangrove forest expansion and development at the expense of salt marsh. Our results also identify ecological thresholds and coastal zones that are especially vulnerable to mangrove expansion into salt marsh habitat.

To complete this research, we worked with the following landowners/land managers: (1) Mission Aransas National Estuarine Research Reserve and the Texas General Land Office (Texas); (2) Conoco-Phillips and the Louisiana Land Exploration (Louisiana); (3) Wisner Family Foundation (Louisiana); and (4) The Cedar Key National Wildlife Refuge (Florida). We also worked with various partners to share and distribute our findings including Landscape Conservation Cooperatives (LCC). The Gulf Coastal Plains and Ozarks LCC and Gulf Coast Prairie LCCs were especially helpful in sharing our research products.

10. OUTREACH

The outreach products included below are separated into the following two categories: (1) Publications; and (2) Presentations. The presentations category includes webinars, conference presentations, workshop presentations, and seminars.

Publications

Baustian, J. J., I. A. Mendelssohn, and M. W. Hester. 2012. Vegetation's importance in regulating surface elevation in a coastal salt marsh facing elevated rates of sea level rise. Global Change Biology **18**:3377-3382.

Krauss, K. W., K. L. McKee, and M. W. Hester. 2014a. Water use characteristics of black mangrove (*Avicennia germinans*) communities along an ecotone with marsh at a northern geographical limit. Ecohydrology **7**:354-365.

Krauss, K. W., K. L. McKee, C. E. Lovelock, D. R. Cahoon, N. Saintilan, R. Reef, and L. Chen. 2014b. How mangrove forests adjust to rising sea level. New Phytologist **202**:19-34.

Lovelock, C. E., K. W. Krauss, M. J. Osland, R. Reef, and M. C. Ball. *In prep*. The physiology of mangrove trees with changing climate.*in* G. H. Goldstein and L. S. Santiago, editors. Tropical Tree Physiology: adaptation and responsed in a chaning environment. Springer.

Osland, M. J., R. H. Day, J. C. Larriviere, and A. S. From. 2014a. Aboveground allometric models for freeze-affected black mangroves (*Avicennia germinans*): equations for a climate sensitive mangrove-marsh ecotone. PLoS ONE **9(6)**:e99604.

Osland, M. J., N. Enwright, R. H. Day, and T. W. Doyle. 2013. Winter climate change and coastal wetland foundation species: salt marshes versus mangrove forests in the southeastern U.S. Global Change Biology **19**:1482-1494.

Osland, M. J., N. Enwright, and C. L. Stagg. 2014b. Freshwater availability and coastal wetland foundation species: ecological transitions along a rainfall gradient. Ecology **95**:2789-2802.

Saintilan, N., N. C. Wilson, K. Rogers, A. Rajkaran, and K. W. Krauss. 2014. Mangrove expansion and salt marsh decline at mangrove poleward limits. Global Change Biology **20**:147-157.

Yando, E. S., M. J. Osland, J. A. Willis, R. H. Day, K. W. Krauss, and M. W. Hester. *In prep*. Mangrove forests vs. salt marshes: the implications of climate-induced woody plant encroachment on plant-soil interactions in tidal saline wetlands. For submission to Global Change Biology.

Presentations

Osland M.J., Enwright N., Ellison M.S., Day R.H., Doyle T.W. 2012. Projected climate-induced mangrove forest range expansion in the southeastern U.S.: the role of winter temperatures. International Wetlands Conference: Society of Wetland Scientists and the International Association for Ecology.

Osland M.J. 2013. Regional climate variability and coastal wetland foundation species. Webinar for the Gulf Coast Vulnerability Assessment.

Yando E.S., M.W. Hester, K.W. Krauss, R.H. Day, M.J. Osland. 2013. The belowground implications of mangrove forest migration: plant-soil variability across forest structural gradients in TX, LA, and FL. Texas Mangrove Research Symposium, Mission Aransas National Estuarine Reserve.

Osland M.J., N. Enwright, R.H. Day, T.W. Doyle. 2013. Winter climate change and coastal wetland foundation species: salt marshes vs. mangrove forests. Texas Mangrove Research Symposium, Mission Aransas National Estuarine Reserve.

Osland M.J., E.S. Yando, R.H. Day, J. Larriviere, A.S. From, M. Dupuis, K.W. Krauss, J.W. Willis, M.W. Hester. 2013. A comparison of salt marsh-mangrove ecotones in the northern Gulf of Mexico: above and belowground variability across structural gradients. Society of Wetland Scientists [Withdrew presentation due to federal travel restrictions]

Yando E.S., M.J. Osland, J.W. Willis, R.H. Day, K.W. Krauss, M.W. Hester. 2013. Mangrove structural gradients: A comparison of plant-soil interactions across saltmarsh-mangrove ecotones. Society of Wetland Scientists, South Central Chapter.

Osland M.J., Enwright N., R.H. Day, C.L. Stagg. 2013. Macroclimatic drivers of tidal wetland ecosystems along the Gulf of Mexico coast. Grand Bay National Estuarine Research Reserve Research Symposium.

Yando E.S., M.J. Osland, J.W. Willis, R.H. Day, K.W. Krauss, M.W. Hester. 2013. Salt marsh-mangrove ecotones in the Northern Gulf of Mexico: a comparison of plant-soil variability across structural gradients. Coastal and Estuarine Research Federation.

Osland M.J., Day R.H., Enwright N., Doyle T.W., Stagg C.L. 2013. Climate change and tidal wetland foundation species: thresholds, resilience, and alternative stable states in the northern Gulf of Mexico. Coastal and Estuarine Research Federation.

Day R.H., M.J. Osland, J. Larriviere, A.S. From. 2013. An allometric equation for estimating aboveground biomass of black mangrove (*Avicennia germinans* (L.) L.) shrubs in the northern Gulf of Mexico. Coastal and Estuarine Research Federation.

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