Final Project Memorandum
South Central Climate Science Center Project

1. ADMINISTRATIVE

Principal Investigator:
Michael J. Osland
U.S. Geological Survey, Wetland and Aquatic Research Center
700 Cajundome Blvd.
Lafayette, LA 70506
Phone: 337-266-8664; email: mosland@usgs.gov

Co- Investigators:
- Sinéad M. Borchert, Nicholas M. Enwright (U.S. Geological Survey, Wetland and Aquatic Research Center)

Project Title:
Landscape conservation design for enhancing the adaptive capacity of coastal wetlands in the face of sea-level rise and coastal development

Date of Report:
April 12, 2018

Period of Performance:
October 2016 – April 2018

Total Cost:
$65,000 total ($35,000 from the South Central CSC, and $30,000 from the Southeast CSC; FY2016 funds)

2. PUBLIC SUMMARY

Coastal wetlands provide many valuable benefits to people and wildlife, including critical habitat, improved water quality, reduced flooding impacts, and protected coastlines. However, in the 21st century, accelerated sea-level rise and coastal development are expected to greatly alter coastal landscapes across the globe. The future of coastal wetlands is uncertain, challenging coastal environmental managers to develop conservation strategies that will increase the resilience of these valuable ecosystems to change and preserve the benefits they provide. One strategy for preparing for the effects of sea-level rise is to ensure that there is space available for coastal wetlands to migrate inland. In a recent study, we identified areas where coastal wetlands may move inland along the northern Gulf of Mexico coast, one of the most wetland-rich and sea-level rise sensitive regions of the world. Building on these findings, this project produced customized landscape conservation-design products focused on identifying landward migration routes for coastal wetlands. The resulting products provide environmental managers with information to make decisions to enhance the capacity of coastal wetlands to adapt to sea-level

rise and coastal development, protecting these ecosystems and the critical economic and ecological benefits that they provide.

3. TECHNICAL SUMMARY

The primary products from this project were: (1) a series of workshops and customized analyses focused on wetland landward migration; and (2) a manuscript that compares the 39 estuaries along the U.S. Gulf of Mexico coast according to their potential for wetland migration and coastal squeeze due to low-lying urban lands that might prevent migration. The workshops and customized analyses are described in more detail in the outreach section of this report. The abstract from the manuscript is pasted below in quotations and italicized.

From: Borchert, S. M., M. J. Osland, N. M. Enwright, and K. T. Griffith, *In press*. Coastal wetland adaptation to sea-level rise: quantifying potential for landward migration and coastal squeeze. Accepted to *Journal of Applied Ecology*.

Abstract:

1. *"Coastal wetland ecosystems are expected to migrate landward in response to rising seas. However, due to differences in topography and coastal urbanization, estuaries vary in their ability to accommodate migration. Low-lying urban areas can constrain migration and lead to wetland loss (i.e., coastal squeeze), especially where existing wetlands cannot keep pace with rising seas via vertical adjustments. In many estuaries, there is a pressing need to identify landward migration corridors and better quantify the potential for landward migration and coastal squeeze."*
2. *"We quantified and compared the area available for landward migration of tidal saline wetlands and the area where urban development is expected to prevent migration for 39 estuaries along the wetland-rich USA Gulf of Mexico coast. We did so under three sea level rise scenarios (0.5-, 1.0-, and 1.5-m by 2100)."*
3. *"Within the region, the potential for wetland migration is highest within certain estuaries in Louisiana and southern Florida (e.g., Atchafalaya/Vermilion Bays, Mermentau River, Barataria Bay, and the North and South Ten Thousand Islands estuaries)."*
4. *"The potential for coastal squeeze is highest in estuaries containing major metropolitan areas that extend into low-lying lands. The Charlotte Harbor, Tampa Bay, and Crystal-Pithlachascotee estuaries (Florida) have the highest amounts of urban land expected to constrain wetland migration. Urban barriers to migration are also high in the Galveston Bay (Texas) and Atchafalaya/Vermilion Bays (Louisiana) estuaries."*
5. *"Synthesis and applications. Coastal wetlands provide many ecosystem services that benefit human health and well-being, including shoreline protection and fish and wildlife habitat. As the rate of sea level rise accelerates in response to climate change, coastal wetland resources could be lost in areas that lack space for landward migration. Migration corridors are particularly important in highly urbanized estuaries where, due to low-lying coastal development, there is not space for wetlands to move and adapt to sea level rise. Future-focused landscape conservation plans that incorporate the protection of wetland migration corridors can increase the adaptive capacity of these valuable ecosystems and simultaneously decrease the vulnerability of coastal human communities to the harmful effects of rising seas."*

4. PURPOSE AND OBJECTIVES

The purpose and objectives associated with the workshops and customized analyses are described in more detail in the outreach section of this report. The purpose and objectives of the manuscript are included in the subsequent paragraphs (in quotations and italicized) from Borchert et al. (*In press*).

From: Borchert, S. M., M. J. Osland, N. M. Enwright, and K. T. Griffith, *In press*. Coastal wetland adaptation to sea-level rise: quantifying potential for landward migration and coastal squeeze. Accepted to *Journal of Applied Ecology*.

"Natural resource management has been undergoing a paradigm shift in recent decades as decision makers are increasingly challenged to prepare for and respond to the ecological effects of climate change (Hulme, 2005; Heller & Zavaleta, 2009; Lawler, 2009; Mawdsley et al., 2009; Stein et al., 2014). Climate change adaptation efforts are particularly important in low-lying coastal regions that are threatened by rising seas (Nicholls et al., 1999; Titus et al., 2009; Hinkel et al., 2014). As global temperatures continue to increase, warming oceans coupled with melting ice sheets and glaciers are expected to accelerate the rate of sea-level rise (Church et al., 2013; Sweet et al., 2017). Coastal and estuarine ecosystems are particularly vulnerable to accelerated sea-level rise (Scavia et al., 2002; Nicholls & Cazenave, 2010; Kirwan & Megonigal, 2013; Ellison, 2015). Climate-smart conservation efforts along the coast can increase the adaptive capacity of valuable coastal ecosystems and also protect coastal communities from the harmful impacts of sea-level rise (Arkema et al., 2013; Duarte et al., 2013; Spalding et al., 2014; Stein et al., 2014)."

"Sea-level rise is expected to transform many coastal wetlands and negatively affect some of the goods and services that these ecosystems support (Craft et al., 2009; Kirwan et al., 2010; Runting et al., 2017; Yoskowitz et al., 2017). Coastal wetlands are highly productive ecosystems that provide many benefits to society, including erosion control, coastal protection during storms, water filtration, flood reduction, carbon sequestration, recreational opportunities, and productive coastal fisheries (Morgan et al., 2009; Barbier et al., 2011; Costanza et al., 2014; Sutton-Grier et al., 2015). Given the threat of wetland loss in response to sea-level rise, coastal managers are increasingly challenged to maximize the adaptive capacity of coastal wetlands. Despite their high sensitivity to sea-level rise, many coastal wetlands are resilient ecosystems, which have the capacity to adjust to sea-level rise through two primary adaptation mechanisms (Kirwan & Megonigal, 2013; Rogers et al., 2016; Woodroffe et al., 2016). The first adaptation mechanism involves vertical adjustments due to feedbacks between plant growth, inundation, and sediment deposition (Morris et al., 2002; Nyman et al., 2006; McKee, 2011; Krauss et al., 2014). The second adaption mechanism involves the landward migration of wetlands into, and at the expense of, adjacent upslope or upriver ecosystems (Williams et al., 1999a; Doyle et al., 2010; Enwright et al., 2016; Langston et al., 2017). If the rate of sea-level rise surpasses the ability of coastal wetlands to keep pace via vertical adjustments, certain wetland ecosystems may be submerged and converted to subtidal ecosystems (Couvillion et al., 2017; Jankowski et al., 2017). Hence, under higher rates of sea-level rise, local wetland loss rates are expected to be high and landward migration is expected to become the primary mechanism for coastal wetland adaptation to sea-level rise."

"To maximize the adaptive capacity of coastal wetlands, there is a pressing need in many estuaries to better identify, manage, and protect low-lying, undeveloped lands that could

facilitate the landward migration of these ecosystems (Rogers et al., 2014; Ellison, 2015; Lester & Matella, 2016; Wigand et al., 2017). Estuaries differ in their ability to accommodate wetland migration due to variability in physiographic setting and the historical extent of wetland and anthropogenic development. High gradients in slope and other topographic barriers along an estuary's coastline can limit the surface area available for wetland migration (Doyle et al., 2010; Stralberg et al., 2011; Enwright et al., 2016). Low-lying infrastructure and anthropogenic shoreline protection features can also function as barriers to landward migration, as coastal wetlands are squeezed between the encroaching ocean and the human-built environment (i.e., coastal squeeze) (Doody, 2013; Pontee, 2013; Torio & Chmura, 2013; Woodroffe et al., 2016). For climate-smart conservation planning purposes that target the most vulnerable estuaries, there is a need for regional analyses that quantify and compare the potential for estuaries to accommodate landward migration and/or prevent migration via coastal squeeze."

"More than half of the contiguous USA's coastal wetlands are located along the northern Gulf of Mexico coast (Field et al., 1991) and these wetlands benefit the region's growing coastal communities (Engle, 2011; Yoskowitz et al., 2017). Despite valuable county-level assessments of the potential for landward migration (Doyle et al., 2010; Enwright et al., 2016) and widespread recognition that wetlands in this region are highly vulnerable to sea-level rise (Williams et al., 1999b; Kirwan & Guntenspergen, 2010; Day et al., 2013; Jankowski et al., 2017), the relative ability of the region's estuaries to accommodate landward migration has not been assessed. In this study, we investigated the following questions for estuaries along the northern Gulf of Mexico coast (USA, including which estuaries have: (1) the largest amount of land available for the landward migration of tidal saline wetlands (i.e., mangrove forests, salt marshes, and salt flats); and (2) the largest amount of low-lying, urban lands that are expected to prevent landward migration of tidal saline wetlands (i.e., a high potential for coastal squeeze)? For 39 estuaries, we quantified and compared the potential for landward migration and coastal squeeze, under three alternative future sea-level rise scenarios (0.5-, 1.0-, and 1.5-m by 2100)."

5. ORGANIZATION AND APPROACH

The organization and approach associated with the workshops and customized analyses are described in more detail in the outreach section of this report. The organization and approach of the manuscript are included in the subsequent paragraphs (in quotations and italicized) from Borchert et al. (*In press*).

From: Borchert, S. M., M. J. Osland, N. M. Enwright, and K. T. Griffith, *In press*. Coastal wetland adaptation to sea-level rise: quantifying potential for landward migration and coastal squeeze. Accepted to *Journal of Applied Ecology*.

"STUDY AREA

Our study area includes 39 estuaries along the USA's northern Gulf of Mexico coast (Table 1). These estuaries are located in the following five states: Texas, Louisiana, Mississippi, Alabama, and Florida (Fig. 1). To identify estuary boundaries, we used the estuarine drainage area (EDA), coastal drainage area (CDA), and fluvial drainage area (FDA) data contained within the National Oceanic and Atmospheric Administration's (NOAA) Coastal Assessment Framework (CAF). All drainage areas of the same name and CDAs entirely adjacent to an EDA were merged. Two CDAs (G025 and G033) were merged with the EDA with which they shared the most coastline (i.e., North Ten Thousand Islands). The Everglades CDA spanned two EDAs

(North Ten Thousand Islands and South Ten Thousand Islands); hence, it was split perpendicularly where the EDAs met and the two resulting polygons were merged with their respective EDAs. We excluded two estuaries, Withlacoochee (Florida) and Rio Grande (Texas), because they include very small sections of the coastline that represent the mouths of the Withlacoochee and Rio Grande Rivers, respectively."

"ELEVATION AND TIDAL DATUM DATA
For more details regarding the data and methodology used in this study, see Enwright et al. (2015; 2016). For elevation data, we utilized digital elevation models (DEMs) that were created using airborne topographic light detection and ranging (lidar) elevation data. The vertical datum for these lidar-based DEMs was the North American Vertical Datum of 1988 (NAVD88). We used NOAA's VDatum software tool version 3.1 (Parker, 2003) to transform the vertical datum of the DEMs from NAVD88 to a tidal datum, mean higher high water (MHHW) (Schmid et al., 2014). Whereas the EDAs identify estuarine drainage areas, the VDatum data is provided within VDatum regions, which are NOAA tidal datum modeling regions. Our study area includes 39 estuaries and 9 VDatum regions; hence, each VDatum region includes multiple estuaries."

"WETLAND AND URBAN DEVELOPMENT DATA
Tidal saline wetlands in the northern Gulf of Mexico include graminoid salt marshes, succulent salt marshes, salt flats, and mangrove forests (West, 1977; Odum et al., 1982; Withers, 2002). Climatic drivers greatly influence the distribution, abundance, and diversity of tidal saline wetlands in this region (Osland et al., 2016; Feher et al., 2017; Gabler et al., 2017). In recognition of this diversity and due to a lack of consistency in thematic resolution of wetland ecosystems in land cover datasets, we combined these different wetland plant communities into a single tidal saline wetland class. We created a current tidal saline wetland surface using the best available data from the U.S. Fish and Wildlife Service's (USFWS's) National Wetlands Inventory (NWI). Information from the NWI was used to determine the presence or absence of tidal saline wetlands in each cell. Cells with tidal saline wetlands were defined as those that contained estuarine intertidal wetland NWI classes. We used two data sources to identify current urban areas, including data contained within SLEUTH (Slope, Land use, Excluded, Urban, Transportation and Hillshade) output produced by Terando et al. (2014) and the developed land-cover classes (i.e., developed high intensity, developed medium intensity, developed low intensity, and developed open space) contained within the 2011 U.S. Geological Survey (USGS) National Land Cover Database (Homer et al., 2015). See Enwright et al. (2015; 2016) for more details regarding the wetland and developed land cover."

"IDENTIFYING THE TIDAL SALINE WETLAND BOUNDARY
Prior to considering how sea-level rise scenarios would influence the future location of tidal saline wetlands, we determined the current tidal saline wetland boundary. Within each VDatum region, we used the elevation data relative to MHHW data for the most recent tidal epoch, the tidal saline wetland presence/absence data, and a recursive partitioning approach to determine the elevation threshold for the tidal saline wetland boundary (Enwright et al., 2015; Enwright et al., 2016). Elevation uncertainty in densely vegetated coastal wetlands is a common problem that affects coastal habitat modeling efforts. Prior studies have shown that the aerial topographic lidar data used to create DEMs can overpredict elevation by as much as 60 cm in coastal wetlands (Medeiros et al., 2015; Buffington et al., 2016; Enwright et al., 2018). Several

techniques have been developed to deal with elevation uncertainty; for example, simple lidar processing techniques like the minimum bin approach (Schmid et al., 2011) or the incorporation of error estimates into probabilistic models (Enwright et al., 2018) to more advanced techniques that determine lidar corrections that are based upon relationships between lidar error and biomass (Medeiros et al., 2015; Buffington et al., 2016). These approaches offer exciting advancements and are leading to better elevation products that can be incorporated into wetland habitat change studies. In this study, we expect that our use of a data-driven approach (i.e., the use of habitat data in combination with elevation data to develop an elevation threshold per VDatum region) may have helped to reduce some of the issues related to elevation uncertainty, particularly in comparison with efforts that use an elevation threshold based solely on a tidal datum (i.e., without the use of habitat data)."

"IDENTIFYING FUTURE TIDAL SALINE WETLANDS
To identify future tidal saline wetlands, we used the identified tidal saline wetland threshold elevation and the sea-level rise increment for each of three sea-level rise scenarios (0.5-, 1.0-, and 1.5-m by 2100) (Enwright et al., 2015; Enwright et al., 2016). The 0.5-m "Intermediate-Low", 1.0-m "Intermediate", and 1.5-m "Intermediate-High" sea-level rise scenarios were selected from a recent report on sea-level rise scenarios for the United States (Sweet et al., 2017). We assumed that the regional elevation thresholds identified using contemporary data would remain constant into the future."

"ESTUARY-LEVEL ANALYSES OF MIGRATION AND COASTAL SQUEEZE
To identify spatial variation in the potential for wetland migration across northern Gulf of Mexico estuaries, we quantified the following information for each of the 39 estuaries including the area: (1) available for the landward migration of tidal saline wetlands; and (2) of current urban development that may act as barrier to future migration (i.e., coastal squeeze). For comparative purposes, we scaled these two variables from 0 to 1 by dividing the estuary-level results by the maximum value for all estuaries. We assumed that current urban lands would be protected from inundation in the future and become barriers to wetland landward migration; hence, the urban barrier to future migration designation consisted of cells that were classified as currently urban and low enough in the landscape that they would have been available for wetland migration if they were not urban. For these cells, we assume the future anthropogenic activities (e.g., levee construction) will prevent future wetland migration. In contrast, lands that were classified as being available for future wetland landward migration consisted of cells that were not urban and also not constrained by adjacent levees or natural topographic barriers as described in Enwright et al. (2015; 2016)."

"For the 1-m sea-level rise scenario, we created bivariate plots that illustrate the relative potential for wetland migration as well as the relative potential for urban barriers to prevent wetland migration for each estuary. To elucidate and compare the amount of area affected, we produced similar bivariate plots with area-based axes. For these latter analyses, we grouped estuaries by state (Texas, Florida, and one category for Louisiana, Mississippi, and Alabama) and compared three sea-level rise scenarios (0.5-, 1.0-, and 1.5-m SLR by 2100) for each group. We also used the area-based results to create maps that depict the potential for landward migration and coastal squeeze. Esri ArcGIS 10.4.1 (Environmental Systems Research Institute, Redlands, California, USA) was used to create maps and conduct all spatial analyses. Bivariate plots were created in R (R Core Team 2016)."

6. PROJECT RESULTS

The results associated with the workshops and customized analyses are described in more detail in the outreach section of this report. The results from the manuscript analyses are included in the subsequent paragraphs (in quotations and italicized) from Borchert et al. (*In press*). The figures and tables from the manuscript and mentioned in the text are included at the end of the document.

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"Our analyses illustrate differences in the potential for landward wetland migration and coastal squeeze across northern Gulf of Mexico estuaries (Figs. 2-3). Under the 1.0-m sea-level rise scenario, the potential for landward wetland migration is highest in estuaries in low-sloping, coastal Louisiana and southern Florida (Fig. 2a; Fig. 3; Table 1). For landward migration potential, the Atchafalaya/Vermilion Bays (AVB) (3,676 km²; 20% of study area total), Mermentau River (MER) (2,184 km²; 12% of study are total), and Barataria Bay (BB) (1,664 km²; 9% of study area total) estuaries are the highest-ranking and account for 42% of the total landward migration expected in the study area (Fig. 3; Table 1). The West Mississippi Sound (WMS), South Ten Thousand Islands (STTI), and North Ten Thousand Islands (NTTI) estuaries ranked fourth, fifth, and sixth, respectively (Fig. 3; Table 1). The relative rankings of estuaries by wetland migration potential under the 0.5- and 1.5-m sea-level rise scenarios are similar to the 1.0-m sea-level rise scenario; however, the amount of area affected is lower and higher, respectively (Figs. 4-6)."

"Across the Gulf of Mexico, there is high variation in the amount of low-lying urban lands that are expected to impede future wetland migration (Fig. 2b; Fig. 3; Table 1). The estuaries along Florida's south-central coast, from Homosassa Springs to Naples, are highly developed and contain a large amount of low-lying urban land that is expected to limit landward migration of wetlands (Fig. 2b). In terms of area, the Charlotte Harbor (CH), Tampa Bay (TB), and Crystal-Pithlachascotee (CP) estuaries contain the highest potential barriers to wetland migration (160 km² [13% of study area total], 106 km² [9% of study area total], and 93 km² [8% of study area total], respectively, under the 1.0-m sea-level rise scenario) (Fig. 3; Table 1). Outside of Florida, urban barriers to migration are high in the Galveston Bay (GB) estuary due to urban sprawl of the greater Houston area into low-lying areas (80 km²; 6%) (Fig. 3; Table 1). The Atchafalaya/Vermilion Bays (AVB) and West Mississippi Sound (WMS) estuaries ranked fifth and sixth, respectively, in terms of urban barriers to migration (70 and 68 km^2, and 6 and 5%, respectively) (Fig. 3; Table 1). Altogether, these six estuaries account for 46% of the total amount of land in the study area where urban barriers are expected to constrain wetland migration (Table 1). For coastal squeeze, the relative rankings of estuaries under the 0.5- and 1.5-m sea-level rise scenarios are generally similar to the 1.0-m sea-level rise scenario; the amount of landward migration that is expected to be prevented by urban barriers is lower and higher, respectively (Figs. 4-6). However, under the higher sea-level rise scenario, these results reveal certain estuaries where the urban barriers to migration will greatly increase [e.g., see Atchafalaya/Vermilion Bays (AVB) and West Mississippi Sound (WMS) in Fig. 3, Galveston Bay (GB) in Fig. 4, and Charlotte Harbor (CH) in Fig. 6]."

7. ANALYSIS AND FINDINGS

The analyses and findings associated with the workshops and customized analyses are described in more detail in the outreach section of this report. The discussion of results of the manuscript are included in the subsequent paragraphs (in quotations and italicized) from Borchert et al. (*In press*).

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"Although coastal scientists have long recognized that landward migration corridors are an important strategy for maximizing the adaptive capacity of coastal wetlands in response to sea level rise (Titus, 1986; Titus, 1998; Williams et al., 1999b; Scavia et al., 2002; Woodroffe et al., 2016), data limitations in many estuaries have hindered efforts to quantify the potential for landward migration and coastal squeeze. In the past decade, the quality and availability of relevant elevation, tidal datum, coastal wetland, and land use data have been rapidly improving (Medeiros et al., 2015; Passeri et al., 2015; Buffington et al., 2016; Enwright et al., 2018). As a result, there has been a large increase in the number of studies that have quantified landward migration and/or coastal squeeze. Most of these studies have been conducted in Australia and the United States, but the potential for landward migration has also been examined along the coasts of Martinique, the United Kingdom, Germany, Kenya, and Canada (Table 2). Some of these studies have focused upon the effects of sea level rise on habitat for fish and wildlife species (e.g., Traill et al., 2011; Torio & Chmura, 2015), while others have examined the implications for certain ecosystem services (e.g., Craft et al., 2009; Feagin et al., 2010; Runting et al., 2017; Yoskowitz et al., 2017)."

"Most studies have focused on landward migration within a particular estuary, but several studies have included assessments conducted at regional scales (Doyle et al., 2010; Geselbracht et al., 2015; Enwright et al., 2016). For example, in a comparison of 14 estuaries along the Pacific coast of the continental United States, Thorne et al. (2018) identified estuaries where future wetland losses are expected to be large. These regional assessments play an important role because they enable resource managers to identify priority areas following comparison of the potential for wetland landward migration and coastal squeeze across cities, counties, estuaries, and/or states. Ideally, regional analyses should be followed by customized models developed to address a specific local decision. Due to local hydrologic, geomorphic, and biotic variation, the utility of wetland landward migration models is often improved when the spatial extent is limited to smaller areas where high-resolution and locally-relevant data are available (Doyle et al., 2015; Passeri et al., 2015)."

"One of our primary objectives in this study was to compare the capacity of the estuaries along the northern Gulf of Mexico coast to accommodate landward migration. Our regional-scale comparison identifies certain estuaries where the potential for landward migration and coastal squeeze are high (see color intensity of estuaries in Fig. 2, see isolated estuaries in Figs. 3-6, and see low estuary ranks in Table 1). Those analyses indicate that the potential for landward migration of wetlands is very high in the following six estuaries: (1) Atchafalaya/Vermilion Bays (AVB) (Louisiana); (2) Mermentau River (MER) (Louisiana); (3) Barataria Bay (BB) (Louisiana); (4) West Mississippi Sound (WMS) (Louisiana/Mississippi); (5)

South Ten Thousand Islands (STTI) (south Florida); and (6) North Ten Thousand Islands (NTTI) (south Florida). These are estuaries where ecological impacts and transformations due to sea level rise are expected to be very large. Within each of these six estuaries, large areas of land will be affected by sea level rise as tidal saline wetlands migrate landward and replace upslope and upriver ecosystems (Williams et al., 1999b; Doyle et al., 2010; Krauss et al., 2011; Flower et al., 2017; Howard et al., 2017; Langston et al., 2017). Hence, these are estuaries where there is much value in future-focused and climate-smart conservation planning efforts that promote landward migration and also manage habitats at risk of conversion to tidal saline wetlands."

"In addition to identifying estuaries with high potential to accommodate landward migration, we also sought to identify estuaries where the potential for coastal squeeze is high. In these estuaries, low-lying urban lands are expected to prevent the landward migration of coastal wetlands, which could result in wetland loss if the existing wetlands are not able to adjust to sea level rise via vertical elevation change. We assumed that shoreline-protection infrastructure would be used to protect these low-lying urban communities (Gittman et al., 2015; Hill, 2015; Sutton-Grier et al., 2015). Our analyses identified the following six estuaries as having a large amount of urban land that is expected to impede wetland migration: (1) Charlotte Harbor (CH) (Florida); (2) Tampa Bay (TB) (Florida); (3) Crystal-Pithlachascotee (CP) (Florida); (4) Galveston Bay (GB) (Texas); (5) Atchafalaya/Vermilion Bays (AVB) (Louisiana); and (6) West Mississippi Sound (WMS) (Louisiana/Mississippi). Note that the latter three estuaries are estuaries that have both a large amount of land available for wetland migration and a large amount of land where urban barriers are expected to prevent migration. The first three estuaries in Florida are highly urbanized (Terando et al., 2014), and have very little land available for landward migration. Hence, under higher rates of sea level rise where existing wetlands are not able to keep pace with sea level rise via vertical adjustments, the potential for coastal wetland loss (i.e., coastal squeeze) in these estuaries is very high. Urban lands that are expected to serve as barriers to migration are highly vulnerable to sea level rise. Within the identified highly urbanized estuaries, we expect that efforts to protect these low-lying, urban lands and/or respond to sea level rise related flooding events will be expensive. Climate-smart conservation efforts in these urban estuaries, including the facilitation of landward migration through land protection or the removal of existing infrastructure, will require a greater upfront cost because property values are often high (Feagin et al., 2010; Runting et al., 2017). However, the indirect cost of failing to preserve landward migration corridors may be much higher. Conservation efforts that protect landward migration corridors today and maximize the future ability of coastal wetlands to adapt to sea level rise will enable future generations to benefit from the many ecosystem goods and services they provide."

"In the face of accelerated sea level rise and rapid coastal urbanization, coastal managers and conservation planners are increasingly challenged to develop strategies that will increase the adaptive capacity of coastal ecosystems and maintain important ecosystem goods and services for future generations. Regional-scale comparisons of the potential for wetland landward migration and coastal squeeze can help coastal decision-makers identify estuaries where climate change adaptation efforts are likely to be most important. Coastal wetland ecosystems can protect shorelines, sequester carbon, reduce flooding, provide seafood, create recreational opportunities, and support valuable fish and wildlife habitat. Climate-smart conservation practices, including the identification, protection, and management of landward migration corridors can minimize future wetland loss, protect ecosystem services for future generations, and reduce harmful sea level rise related impacts to coastal communities."

8. CONCLUSIONS AND RECOMMENDATIONS

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"Coastal wetlands provide many ecosystem services that benefit human health and well-being, including shoreline protection, carbon sequestration, flood mitigation, seafood, recreational opportunities, and fish and wildlife habitat. As the rate of sea-level rise accelerates in response to climate change, coastal wetland resources could be lost in areas that lack space for landward migration. Migration corridors are particularly important in highly-urbanized estuaries where, due to low-lying coastal development, there is not space for wetlands to move and adapt to sea-level rise. Future-focused landscape conservation plans that incorporate the protection of wetland migration corridors can increase the adaptive capacity of these valuable ecosystems and simultaneously decrease the vulnerability of coastal human communities to the harmful effects of rising seas."

9. OUTREACH

The outreach products included below are separated into the following four categories: publications, presentations, attendees by estuary, and partner product requests. The presentations category includes workshop presentations, webinars, conference presentations, and meetings.

<u>Publications</u>

Borchert, S. M., M. J. Osland, N. M. Enwright, and K. T. Griffith, *In press*. Coastal wetland adaptation to sea-level rise: quantifying potential for landward migration and coastal squeeze. Accepted to *Journal of Applied Ecology*.

<u>Presentations</u>

Workshops:

1. **Aransas Bay Estuary/Corpus Christi Bay Estuary:** "Coastal wetland migration: Landscape conservation design for enhancing the adaptive capacity of coastal wetlands in the face of sea-level rise and coastal development". Workshop (host: Sinéad Borchert). University of Texas Marine Science Institute, Port Aransas, TX, USA. March 2nd, 2017. **16 attendees.**

2. **East Mississippi Sound Estuary:** "Coastal wetland migration: Landscape conservation design for enhancing the adaptive capacity of coastal wetlands in the face of sea-level rise and coastal development". Workshop (host: Sinéad Borchert). Grand Bay National Estuarine Research Reserve, Moss Point, MS, USA. April 20th, 2017. **18 attendees.**

3. **Charlotte Harbor Estuary:** "Building resilience through actionable science: New products to inform how and where land protection can increase coastal resiliency". Workshop jointly hosted with The Nature Conservancy (hosts: Sinéad Borchert/USGS and Dr. Christine

Shepard/TNC). Charlotte Community Foundation, Punta Gorda, FL, USA. May 23rd, 2017. **26 attendees.**

4. **Calcasieu Lake Estuary:** “Building resilience through actionable science: New products to inform how and where land protection can increase coastal resiliency”. Workshop jointly hosted with The Nature Conservancy’s Gulf of Mexico Program (hosts: Sinéad Borchert/USGS and Dr. Christine Shepard/TNC). Southwest Louisiana Entrepreneurial and Economic Development Center, Lake Charles, LA, USA. June 6th, 2017. **28 attendees.**

5. **West Mississippi Sound Estuary:** “Building resilience through actionable science: New products to inform how and where land protection can increase coastal resiliency”. Workshop jointly hosted with The Nature Conservancy’s Gulf of Mexico Program (hosts: Sinéad Borchert/USGS and Dr. Christine Shepard/TNC). Biloxi Visitor’s Center Ballroom, Biloxi, MS, USA. June 7th, 2017. **31 attendees.**

6. **Mobile Bay Estuary:** “Building resilience through actionable science: New products to inform how and where land protection can increase coastal resiliency”. Mini-workshop (appended to the Mobile Bay Estuary Program’s monthly Project Implementation Committee meeting) jointly hosted with The Nature Conservancy’s Gulf of Mexico Program (hosts: Sinéad Borchert/USGS and Dr. Christine Shepard/TNC). Five Rivers Delta Center, Spanish Fort, AL, USA. June 8th, 2017. **Approximately 35 attendees.**

7. **Pensacola Bay Estuary:** “Building resilience through actionable science: New products to inform how and where land protection can increase coastal resiliency”. Workshop jointly hosted with The Nature Conservancy’s Gulf of Mexico Program (hosts: Sinéad Borchert/USGS and Dr. Christine Shepard/TNC). UF/IFAS Santa Rosa Extension Office, Milton, FL, USA. June 9th, 2017. **22 attendees.**

We attempted to spread the workshop locations across estuaries and Landscape Conservation Cooperatives in the northern Gulf of Mexico (Fig. 7). The initial two USGS-only workshops (2-3 hours long) at the Mission-Aransas and Grand Bay National Estuarine Research Reserves were hosted by Sinéad Borchert. She shared the results from the Tidal Saline Wetland Migration study at the northern Gulf of Mexico scale. To highlight potential areas for conservation, she transitioned to locally-relevant scales by showing maps of wetland migration corridors in areas of interest for attendees. Following the workshops, Sinéad asked the group a series of questions (developed by Marie-Blanche Roudaut of the University of Arizona Center for Climate Adaptation Science and Solutions) related to sea-level rise, climate change, tidal saline wetland migration, and custom products that attendees could use for landscape conservation planning. After the workshops, Sinéad followed-up with all attendees and created products for the City of Port Aransas, Grand Bay National Estuarine Research Reserve, Mission-Aransas National Estuarine Research Reserve, and the USFWS Gulf Coast Refuge Complex. These workshops served as a proving ground for the question list, which was later narrowed to the three questions that most improved our understanding of meeting attendees and their needs.

The following five half-day workshops were jointly hosted with Dr. Christine Shepard, Director of Science for The Nature Conservancy’s Gulf of Mexico Program. We identified overlapping themes between our study and TNC’s Open Space Study and merged our efforts for all subsequent workshops. The Open Space Study identified watersheds across the northern Gulf of Mexico with a high probability of flooding and high conservation value. Their goal was to highlight open space protection as a flood risk reduction and conservation strategy. As flood mitigation is an ecosystem service provided by wetlands, our Tidal Saline Wetland Migration data represented one tool a planner could potentially use to identify open spaces that will be important for wetland migration with rising seas.

The format for these workshops consisted of: 1) an overview presentation of TNC's Open Space Study (Dr. Christine Shepard); 2) an overview presentation of the USGS Tidal Saline Wetland Migration Study, followed by a discussion of mapped wetland migration corridors in local areas of interest (Sinéad Borchert); 3) a presentation by a local guest speaker on a relevant land conservation project or scientific study; 4) a demonstration of the Open Space and Tidal Saline Wetland Migration datasets on The Nature Conservancy's Coastal Resilience 2.0 website; and 5) a facilitated discussion of strategic land conservation in the context of these studies, including map, flip-chart, and index card activities. For the Biloxi, MS, Spanish Fort, AL, and Milton, FL workshops, we partnered with Renee Collini of the Mississippi-Alabama Sea Grant's Northern Gulf of Mexico Sentinel Site Cooperative. Renee assisted in identifying invitees and facilitating discussions.

Our objectives for these workshops included:

- Share the Open Space and Tidal Saline Wetland Migration findings with a diverse group of end users and facilitate a discussion about how outputs can be used to increase coastal resilience.
- Review both datasets on Coastal Resilience 2.0 to facilitate discussion of local use of land protection for flood risk reduction and how wetland migration data could affect decision making.
- Solicit input from attendees on what planning processes or decisions could be impacted by the open space and wetland migration projects and what next steps or custom data would be most useful to support these efforts.

Our desired outputs included:

- Contact info for stakeholders interested in receiving custom data products from us in order to follow-up (USGS and TNC).
- List of land protection efforts underway that have flood risk reduction goals or would benefit from including flood risk reduction as a goal (TNC).
- Notes on requested data products including format and intended use, planning process or decision context (USGS and TNC).

After lunch, we asked attendees to split into small groups (2-3 groups depending on the size of the workshop). At each station, we had a map of the area and a flip chart. For the mapping activity, a facilitator asked each group the following question: Question 1) Are there specific resources (e.g., a body of water, ecosystem or ecological community, a specific species, or infrastructure), future projects (e.g., planned development, restoration), or future land acquisition endeavors that are particularly important for us to know about? Attendees were invited to place color-coded sticky dots on the maps (green = general land protection [including areas potentially important for wetland migration], blue = land protection for flood reduction, yellow = nature-based shoreline protection or living shorelines, and red = other important areas and/or resource locations). The purpose of this activity was to determine the resources that were important to them, the projects they were working on, and whether they were currently considering flood risk reduction or wetland migration in their work (see Fig. 8 for the attendee composition by workshop). Following the mapping activity, we switched to the flip-charts. Each facilitator recorded answers to the next two questions: Question 2) What are the options you think your organization has to conserve open space and/or facilitate the landward migration of coastal wetlands in response to sea-level rise (i.e., what are the opportunities and barriers?); and Question 3) What information do you want from the open space and wetland migration projects? In what format would custom products be useful to you? For the third question, we passed out index cards and asked participants to record their responses, which we used to identify participants for targeted follow-up e-mails. Once the flip chart activity was complete, each facilitator summarized their group's responses for the other workshop attendees (Table 3).

Other presentations:

8. "Outreach progress report: Barriers and opportunities for the landward migration of tidal saline wetlands with sea-level rise and urbanization". Webinar (Sinéad Borchert) for the four Gulf Coast Landscape Conservation Cooperatives. May 12th, 2017.

Reviewed the findings of the Tidal Saline Wetland Migration study and described the outreach component for representatives of the four Gulf Coast Landscape Conservation Cooperatives. Solicited suggestions for potential invitees and LCC-related products.

9. "Barriers and opportunities for the landward migration of tidal saline wetlands with sea-level rise and urbanization". Panel discussion and live tool demonstration (Sinéad Borchert). Climate and Resilience Community of Practice Meeting. Covington, LA, USA. May 16th, 2017.

We were invited to participate in the Climate and Resilience Community of Practice Meeting alongside the Mission-Aransas National Estuarine Research Reserve. Sinéad Borchert joined Dana Sjostrom and others for a 45-minute live panel discussion of the products she created for the Mission-Aransas NERR. The panel format consisted of a community representative and a tool developer discussing a problem facing the community and why the community selected the developer's tool to help solve it. The Mission-Aransas NERR was interested in identifying future tidal saline wetland migration corridors adjacent to their boundary and other protected areas in order to communicate the importance of these areas for conservation in extension and outreach efforts. Following the panel discussion, Borchert gave a live demonstration of how to use the tool while Sjostrom provided context.

10. "Outreach progress report: Barriers and opportunities for the landward migration of tidal saline wetlands with sea-level rise and urbanization". Oral presentation (Sinéad Borchert). Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative Spring Retreat. Panama City, FL. May 17th, 2017.

We were invited to present a progress report on the outreach component of the Tidal Saline Wetland Migration study for the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative's Spring Retreat. Borchert presented the findings of the study, described the ongoing workshops, and mapped future tidal saline wetland migration corridors around Panama City, FL to demonstrate how communities might use these data for planning.

11. "Barriers and opportunities for the landward migration of tidal saline wetlands with sea-level rise and urbanization". Oral presentation and group discussion (Sinéad Borchert). Tampa Bay Estuary Program Office, St. Petersburg, FL, USA. May 24th, 2017.

The Tampa Bay Estuary Program was interested in leveraging our data for a comparison with their own Habitat Evolution Model for Tampa Bay. Borchert traveled to the TBEP office to present the findings of the study, demonstrate future tidal saline wetland corridors in areas around Tampa Bay, and discuss how they could use our dataset.

12. "Barriers and opportunities for the landward migration of tidal saline wetlands with sea-level rise and urbanization". Webinar (Sinéad Borchert) for the Rookery Bay National Estuarine Research Reserve. July 14th, 2017.

Sinéad Borchert presented the study, discussed wetland migration in Collier County, and demonstrated how to work with the datasets in ArcMap. Afterwards the group discussed the potential products that could be created to assist with outreach and planning in their region.

Attendees by Estuary

Aransas Bay Estuary/Corpus Christi Bay Estuary (Port Aransas, TX workshop): Aransas National Wildlife Refuge, Aransas County, City of Port Aransas, City of Rockport, Coastal Bend Bays and Estuaries Program, Mission-Aransas National Estuarine Research Reserve, Mott MacDonald Consultants, and the University of Texas Marine Science Institute.

East Mississippi Sound Estuary (Moss Point, MS workshop): Dauphin Island Sea Lab, Grand Bay National Estuarine Research Reserve, Mississippi-Alabama Sea Grant, Mississippi Department of Marine Resources, Mississippi State University Northern Gulf Institute, Office of the Mississippi Secretary of State, USFWS Gulf Coast Refuge Complex, U.S. Forest Service De Soto Ranger District, and the Weeks Bay National Estuarine Research Reserve.

Charlotte Harbor Estuary (Punta Gorda, FL workshop): Audubon of the Western Everglades, Charlotte County, Charlotte Harbor National Estuary Program, City of Punta Gorda, Collier County, Conservation Foundation of the Gulf Coast, Ecological Laboratories, Inc., Eco-Voice, Inc., ESA Scheda, Florida Gulf Coast University Center for Environmental and Sustainability Education, Florida Fish and Wildlife Commission, Responsible Growth Management Coalition, Rookery Bay National Estuarine Research Reserve, Sarasota County, Sanibel-Captiva Conservation Foundation, Southwest Florida Regional Planning Council, Tampa Bay Regional Planning Council, The Nature Conservancy Florida Chapter, and the University of Tampa.

Calcasieu Lake Estuary (Lake Charles, LA workshop): Calcasieu Parish Police Jury, Chevron, CITGO Petroleum Corp., Ducks Unlimited, Empire of the SEED, Gulf Coast Prairie Landscape Conservation Cooperative, Hoover-Slovacek Law Firm, Louisiana Department of Wildlife and Fisheries, S&ME, Inc., The Nature Conservancy Louisiana Chapter, The Nature Conservancy

Texas Chapter, The Water Institute of the Gulf, U.S. Army Corps of Engineers New Orleans District, USDA Natural Resources Conservation Service, U.S. Fish and Wildlife Service, and the U.S. Geological Survey Wetland and Aquatic Research Center.

West Mississippi Sound Estuary (Biloxi, MS workshop): BMI Environmental Services, City of Biloxi, City of D'Iberville, Coastal Environments Inc., Covington Civil and Environmental on behalf of the Everglades Foundation, Gulf of Mexico Alliance, Harrison County Board of Supervisors, Harrison County Zoning, Jackson County, Land Trust for the Mississippi Coastal Plain, Mississippi Department of Marine Resources, Mississippi Secretary of State's Office, Mississippi Urban Forest Council, National Oceans and Applications Research Center, National Wildlife Federation, Neel-Schaffer, Mississippi State University Northern Gulf Institute, Partnership for Gulf Coast Land Conservation, The Conservation Fund, The Nature Conservancy Mississippi Chapter, unabridged Architecture, and Waggoner Engineering.

Mobile Bay Estuary (Spanish Fort, AL mini-workshop): Mini-workshop appended onto the Tampa Bay Estuary Program's monthly Project Implementation Committee meeting. Attendees that requested follow-ups included the Alabama Department of Environmental Management, Ecology and Environment, Inc., Environmental Science Associates, Pelican Coast Conservancy, The Nature Conservancy Alabama Chapter, and Thompson Engineering.

Pensacola Bay Estuary (Milton, FL workshop): CH2M, Escambia County (Engineering, Environmental Services, and Natural Resources Departments), Florida Sea Grant, Santa Rosa County, Sustainable Town Concepts, The Nature Conservancy Florida Chapter, and the University of Florida.

<u>Partner Product Requests</u>
These are estuary partners that requested follow-up products (e.g., customized maps from published datasets) regarding wetland migration.

- Mission-Aransas National Estuarine Research Reserve, TX (Aransas Bay and San Antonio Bay Estuaries, TX)
- City of Port Aransas, TX (Corpus Christi Bay and Aransas Bay Estuaries, TX)
- USFWS Gulf Coast Refuge Complex (West Mississippi Sound Estuary, LA/MS, East Mississippi Sound Estuary, MS/AL, and Mobile Bay Estuary, AL)
- Grand Bay National Estuarine Research Reserve, MS (East Mississippi Sound Estuary, MS/AL)
- South Atlantic Landscape Conservation Cooperative, Big Bend Landscape Conservation Design (Apalachee Bay, Econfina-Steinhatchee, Suwannee River, and Waccasassa Estuaries, FL)
- The Nature Conservancy, Louisiana Chapter (Calcasieu Lake, Mermentau River, and Barataria Bay Estuaries, LA)
- Conservation Foundation of the Gulf Coast, FL (Crystal-Pithlachascotee, Tampa Bay, Sarasota Bay, Charlotte Harbor, and Big Cypress Swamp Estuaries, FL)
- Southwest Florida Regional Planning Council (Sarasota Bay, Charlotte Harbor, Big Cypress Swamp, Rookery Bay, and North Ten Thousand Islands Estuaries, FL)

- Rookery Bay National Estuarine Research Reserve, FL (Big Cypress Swamp, Rookery Bay, and North Ten Thousand Islands Estuaries, FL)

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LITERATURE CITED

Alizad K, Hagen SC, Morris JT, Bacopoulos P, Bilskie MV, Weishampel JF, Medeiros SC (2016a) A coupled, two-dimensional hydrodynamic-marsh model with biological feedback. *Ecological Modelling,* **327**, 29-43.

Alizad K, Hagen SC, Morris JT, Medeiros SC, Bilskie MV, Weishampel JF (2016b) Coastal wetland response to sea-level rise in a fluvial estuarine system. *Earth's Future,* **4**, 483-497.

Arkema KK, Guannel G, Verutes G*, et al.* (2013) Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change*, **3**, 913-918.

Barbier EB, Hacker SD, Kennedy C, Koch EW, Stier AC, Silliman BR (2011) The value of estuarine and coastal ecosystem services. *Ecological Monographs,* **81**, 169-193.

Borchert SM, Osland MJ, Enwright NM, Griffith KT (*In press*) Coastal wetland adaptation to sea-level rise: quantifying the potential for landward migration and coastal squeeze in northern Gulf of Mexico estuaries. *Accepted to Journal of Applied Ecology*.

Buffington KJ, Dugger BD, Thorne KM, Takekawa JY (2016) Statistical correction of lidar-derived digital elevation models with multispectral airborne imagery in tidal marshes. *Remote Sensing of Environment*, **186**, 616-625.

Church JA, Clark PU, Cazenave A*, et al.* (2013) Sea level change. In: *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Stocker TF, Qin D, Plattner GK*, et al.*), pp. 1137-1216, Cambridge University Press, Cambridge, United Kingdom.

Costanza R, de Groot R, Sutton P*, et al.* (2014) Changes in the global value of ecosystem services. *Global Environmental Change*, **26**, 152-158.

Couvillion BR, Beck H, Schoolmaster D, Fischer M (2017) *Land area change in coastal Louisiana 1932 to 2016: U.S. Geological Survey Scientific Investigations Map 3381, 16 p. pamphlet,* https://doi.org/10.3133/sim3381.

Craft C, Clough J, Ehman J*, et al.* (2009) Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment*, **7**, 73-78.

Day JW, Yáñez-Arancibia A, Cowan JH, Day RH, Twilley RR, Rybczyk JR (2013) Global climate change impacts on coastal ecosystems in the Gulf of Mexico: considerations for integrated coastal management. In: *Gulf of Mexico Origin, Waters, and Biota Volume 4: Ecosystem-based Management* (eds Day JW, Yáñez-Arancibia A), pp. 253-271, Texas A&M University Press, College Station.

Di Nitto D, Neukermans G, Koedam N, Defever H, Pattyn F, Kairo JG, Dahdouh-Guebas F (2014) Mangroves facing climate change: landward migration potential in response to projected scenarios of sea level rise. *Biogeosciences,* **11**, 857-871.

Doody JP (2013) Coastal squeeze and managed realignment in southeast England, does it tell us anything about the future? *Ocean & Coastal Management,* **79**, 34-41.

Doyle TW, Krauss KW, Conner WH, From AS (2010) Predicting the retreat and migration of tidal forests along the northern Gulf of Mexico under sea-level rise. *Forest Ecology and Management,* **259**, 770-777.

Doyle TW, Chivoiu B, Enwright NM (2015) *Sea-level rise modeling handbook: Resource guide for coastal land managers, engineers, and scientists,* U.S. Geological Survey Professional Paper 1815.

Duarte CM, Losada IJ, Hendriks IE, Mazarrasa I, Marbà N (2013) The role of coastal plant communities for climate change mitigation and adaptation. *Nature Climate Change,* **3**, 961-968.

Ellison JC (2015) Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetlands Ecology and Management*, **23**, 115-137.

Engle VD (2011) Estimating the provision of ecosystem services by Gulf of Mexico coastal wetlands. *Wetlands,* **31**, 179-193.

Enwright NM, Griffith KT, Osland MJ (2015) *Incorporating future change into current conservation planning—Evaluating tidal saline wetland migration along the U.S. Gulf of Mexico coast under alternative sea-level rise and urbanization scenarios,* U.S. Geological Survey Data Series 969, http://dx.doi.org/10.3133/ds969.

Enwright NM, Griffith KT, Osland MJ (2016) Barriers to and opportunities for landward migration of coastal wetlands with sea-level rise. *Frontiers in Ecology and the Environment,* **14**, 307-316.

Enwright NM, Wang L, Borchert SM, Day RH, Feher LC, Osland MJ (2018) The impact of lidar elevation uncertainty on mapping intertidal habitats on barrier islands. *Remote Sensing,* **10**, article 5.

Feagin RA, Martinez ML, Mendoza-Gonzalez G, Costanza R (2010) Salt marsh zonal migration and ecosystem service change in response to global sea level rise: a case study from an urban region. *Ecology and Society,* **15**, article 14.

Feher LC, Osland MJ, Griffith KT, *et al.* (2017) Linear and nonlinear effects of temperature and precipitation on ecosystem properties in tidal saline wetlands. *Ecosphere,* **8**, article e01956.

Field DW, Reyer AJ, Genovese PV, Shearer BD (1991) *Coastal Wetlands of the United States: An Accounting of a Valuable National Resource*, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA.

Flower H, Rains M, Fitz C (2017) Visioning the future: scenarios modeling of the Florida coastal everglades. *Environmental Management,* **60**, 989-1009.

Gabler CA, Osland MJ, Grace JB, *et al.* (2017) Macroclimatic change expected to transform coastal wetland ecosystems this century. *Nature Climate Change,* **7**, 142-147.

Geselbracht L, Freeman K, Kelly E, Gordon DR, Putz FE (2011) Retrospective and prospective model simulations of sea level rise impacts on Gulf of Mexico coastal marshes and forests in Waccasassa Bay, Florida. *Climatic Change,* **107**, 35-57.

Geselbracht LL, Freeman K, Birch AP, Brenner J, Gordon DR (2015) Modeled sea level rise impacts on coastal ecosystems at six major estuaries on Florida's Gulf Coast: implications for adaptation planning. *PLOS ONE,* **10**, e0132079.

Gittman RK, Fodrie FJ, Popowich AM, *et al.* (2015) Engineering away our natural defenses: an analysis of shoreline hardening in the US. *Frontiers in Ecology and the Environment,* **13**, 301-307.

Heller NE, Zavaleta ES (2009) Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation,* **142**, 14-32.

Hill K (2015) Coastal infrastructure: a typology for the next century of adaptation to sea-level rise. *Frontiers in Ecology and the Environment,* **13**, 468-476.

Hinkel J, Lincke D, Vafeidis AT, *et al.* (2014) Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences,* **111**, 3292-3297.

Homer CG, Dewitz JA, Yang L, *et al.* (2015) Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, **81**, 345-354.

Howard RJ, Day RH, Krauss KW, From AS, Allain L, Cormier N (2017) Hydrologic restoration in a dynamic subtropical mangrove-to-marsh ecotone. *Restoration Ecology,* **25**, 471-482.

Hulme PE (2005) Adapting to climate change: is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology,* **42**, 784-794.

Jankowski KL, Törnqvist TE, Fernandes AM (2017) Vulnerability of Louisiana's coastal wetlands to present-day rates of relative sea-level rise. *Nature Communications,* **8**, 14792.

Kirwan ML, Guntenspergen GR (2010) Influence of tidal range on the stability of coastal marshland. *Journal of Geophysical Research: Earth Surface,* **115**, F02009.

Kirwan ML, Guntenspergen GR, D'Alpaos A, Morris JT, Mudd SM, Temmerman S (2010) Limits on the adaptability of coastal marshes to rising sea level. *Geophysical Research Letters*, **37**, L23401.

Kirwan ML, Megonigal JP (2013) Tidal wetland stability in the face of human impacts and sea-level rise. *Nature,* **504**, 53-60.

Krauss KW, From AS, Doyle TW, Doyle TJ, Barry MJ (2011) Sea-level rise and landscape change influence mangrove encroachment onto marsh in the Ten Thousand Islands region of Florida, USA. *Journal of Coastal Conservation,* **15**, 629-638.

Krauss KW, McKee KL, Lovelock CE, Cahoon DR, Saintilan N, Reef R, Chen L (2014) How mangrove forests adjust to rising sea level. *New Phytologist,* **202**, 19-34.

Krolik-Root C, Stansbury DL, Burnside NG (2015) Effective LiDAR-based modelling and visualisation of managed retreat scenarios for coastal planning: An example from the southern UK. *Ocean & Coastal Management,* **114**, 164-174.

Langston AK, Kaplan DA, Putz FE (2017) A casualty of climate change? Loss of freshwater forest islands on Florida's Gulf Coast. *Global Change Biology,* **23**, 5383-5397.

Lawler JJ (2009) Climate change adaptation strategies for resource management and conservation planning. *Annals of the New York Academy of Sciences,* **1162**, 79-98.

Lester C, Matella M (2016) Managing the coastal squeeze: resilience planning for shoreline residential development. *Stanford Environmental Law Journal*, **36**, 23.

Linhoss AC, Kiker G, Shirley M, Frank K (2014) Sea-level rise, inundation, and marsh migration: simulating impacts on developed lands and environmental systems. *Journal of Coastal Research,* **31**, 36-46.

Mawdsley JR, O'malley R, Ojima DS (2009) A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. *Conservation Biology,* **23**, 1080-1089.

McKee KL (2011) Biophysical controls on accretion and elevation change in Caribbean mangrove ecosystems. *Estuarine, Coastal and Shelf Science,* **91**, 475-483.

Medeiros S, Hagen S, Weishampel J, Angelo J (2015) Adjusting lidar-derived digital terrain models in coastal marshes based on estimated aboveground biomass density. *Remote Sensing,* **7**, 3507-3525.

Mills M, Leon JX, Saunders MI, *et al.* (2016) Reconciling development and conservation under coastal squeeze from rising sea level. *Conservation Letters,* **9**, 361-368.

Morgan PA, Burdick DM, Short FT (2009) The functions and values of fringing salt marshes in northern New England, USA. *Estuaries and Coasts,* **32**, 483-495.

Morris JT, Sundareshwar PV, Nietch CT, Kjerfve B, Cahoon DR (2002) Responses of coastal wetlands to rising sea level. *Ecology*, **83**, 2869-2877.

Nicholls RJ, Hoozemans FM, Marchand M (1999) Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change,* **9**, S69-S87.

Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. *Science,* **328**, 1517-1520.

Nyman JA, Walters RJ, Delaune RD, Patrick WH (2006) Marsh vertical accretion via vegetative growth. *Estuarine, Coastal and Shelf Science,* **69**, 370-380.

Odum WE, McIvor CC, Smith III TJ (1982) *The ecology of mangroves of south Florida: a community profile,* U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., USA FWS/OBS-81/24.

Osland MJ, Enwright NM, Day RH, Gabler CA, Stagg CL, Grace JB (2016) Beyond just sea-level rise: considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change. *Global Change Biology,* **22**, 1-11.

Parker BB (2003) The difficulties in measuring a consistently defined shoreline- the problem of vertical referencing. *Journal of Coastal Research,* **38**, 44-56.

Passeri DL, Hagen SC, Medeiros SC, Bilskie MV, Alizad K, Wang D (2015) The dynamic effects of sea level rise on low-gradient coastal landscapes: A review. *Earth's Future,* **3**, 159-181.

Pontee N (2013) Defining coastal squeeze: A discussion. *Ocean & Coastal Management,* **84**, 204-207.

Rogers K, Saintilan N, Copeland C (2014) Managed retreat of saline coastal wetlands: challenges and opportunities identified from the Hunter River Estuary, Australia. *Estuaries and Coasts,* **37**, 67-78.

Rogers K, Boon PI, Branigan S, *et al.* (2016) The state of legislation and policy protecting Australia's mangrove and salt marsh and their ecosystem services. *Marine Policy,* **72**, 139-155.

Runting RK, Lovelock CE, Beyer HL, Rhodes JR (2017) Costs and opportunities for preserving coastal wetlands under sea level rise. *Conservation Letters,* **10**, 49-57.

Scavia D, Field JC, Boesch DF, *et al.* (2002) Climate change impacts on U.S. coastal and marine ecosystems. *Estuaries*, **25**, 149-164.

Schile LM, Callaway JC, Morris JT, Stralberg D, Parker VT, Kelly M (2014) Modeling tidal marsh distribution with sea-level rise: Evaluating the role of vegetation, sediment, and upland habitat in marsh resiliency. *PLOS ONE,* **9**, e88760.

Schleupner C (2008) Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean & Coastal Management,* **51**, 383-390.

Schmid K, Hadley B, Waters K (2014) Mapping and portraying inundation uncertainty of bathtub-type models. *Journal of Coastal Research*, **30**, 548-561.

Schmid KA, Hadley BC, Wijekoon N (2011) Vertical Accuracy and Use of Topographic LIDAR Data in Coastal Marshes. *Journal of Coastal Research,* **27**, 116-132.

Spalding MD, Ruffo S, Lacambra C, Meliane I, Hale LZ, Shepard CC, Beck MW (2014) The role of ecosystems in coastal protection: adapting to climate change and coastal hazards. *Ocean & Coastal Management,* **90**, 50-57.

Stein BA, Glick P, Edelson N, Staudt A (2014) *Climate-smart conservation: putting adaptation principles into practice,* National Wildlife Federation, Washington, D.C., USA.

Sterr H (2008) Assessment of vulnerability and adaptation to sea-level rise for the coastal zone of Germany. *Journal of Coastal Research,* **24**, 380-393.
Stralberg D, Brennan M, Callaway JC, *et al.* (2011) Evaluating tidal marsh sustainability in the face of sea-level rise: a hybrid modeling approach applied to San Francisco Bay. *PLOS ONE,* **6**, e27388.
Sutton-Grier AE, Wowk K, Bamford H (2015) Future of our coasts: the potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environmental Science & Policy,* **51**, 137-148.
Sweet WV, Kopp RE, Weaver CP, Obeysekera J, Horton RM, Thieler ER, Zervas C (2017) *Global and regional sea level rise scenarios for the United States. NOAA Technical Report NOS CO-OPS 083,* NOAA, Silver Spring, Maryland, USA.
Terando AJ, Costanza J, Belyea C, Dunn RR, McKerrow A, Collazo JA (2014) The southern megalopolis: Using the past to predict the future of urban sprawl in the southeast U.S. *PLOS ONE*, **9**, e102261.
Thorne K, MacDonald G, Guntenspergen G, *et al.* (2018) U.S. Pacific coastal wetland resilience and vulnerability to sea-level rise. *Science Advances,* **4**, eaao3270.
Titus JG (1986) Greenhouse effect, sea level rise, and coastal zone management. *Coastal Zone Management Journal,* **14**, 147-171.
Titus JG (1998) Rising seas, coastal erosion, and the takings clause: how to save wetlands and beaches without hurting property owners. *Maryland Law Review,* **57**, 1279-1399.
Titus JG, Hudgens DE, Trescott DL, *et al.* (2009) State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic coast. *Environmental Research Letters,* **4**, 044008.
Torio DD, Chmura GL (2013) Assessing coastal squeeze of tidal wetlands. *Journal of Coastal Research,* **29**, 1049-1061.
Torio DD, Chmura GL (2015) Impacts of sea level rise on marsh as fish habitat. *Estuaries and Coasts,* **38**, 1288-1303.
Traill LW, Perhans K, Lovelock CE, Prohaska A, McFallan S, Rhodes JR, Wilson KA (2011) Managing for change: wetland transitions under sea-level rise and outcomes for threatened species. *Diversity and Distributions,* **17**, 1225-1233.
West RC (1977) Tidal salt-marsh and mangal formations of Middle and South America. In: *Ecosystems of the World. 1. Wet coastal ecosystems* (ed Chapman VJ), pp. 193-213, Elsevier, Amsterdam, Netherlands.
Wigand C, Ardito T, Chaffee C, *et al.* (2017) A climate change adaptation strategy for management of coastal marsh systems. *Estuaries and Coasts,* **40**, 682-693.
Williams K, Ewel KC, Stumpf RP, Putz FE, Workman TW (1999a) Sea-level rise and coastal forest retreat on the west coast of Florida, USA. *Ecology,* **80**, 2045-2063.
Williams K, Pinzon ZS, Stumpf RP, Raabe EA (1999b) *Sea-level rise and coastal forests on the Gulf of Mexico,* US Geological Survey, Open-File Report 99-441.
Withers K (2002) Wind-tidal flats. In: *The Laguna Madre of Texas and Tamaulipas* (eds Tunnell JW, Judd FW), pp. 114-126, Texas A&M University Press, College Station, Texas, USA.
Woodroffe CD, Rogers K, McKee KL, Lovelock CE, Mendelssohn I, Saintilan N (2016) Mangrove sedimentation and response to relative sea-level rise. *Annual Review of Marine Science,* **8**, 243-266.

Yoskowitz D, Carollo C, Pollack JB, Santos C, Welder K (2017) Integrated ecosystem services assessment: Valuation of changes due to sea level rise in Galveston Bay, Texas, USA. *Integrated Environmental Assessment and Management*, **13**, 431-443.

Tables and Figures

Tables 1-2 and Figs. 1-6 are associated with the following manuscript; Figs. 7-8 are focused on outreach and are not from the manuscript.

From: Borchert, S. M., M. J. Osland, N. M. Enwright, and K. T. Griffith, *In press*. Coastal wetland adaptation to sea-level rise: quantifying potential for landward migration and coastal squeeze. Accepted to *Journal of Applied Ecology*.

Table 1. For a 1-m sea-level rise scenario by the Year 2100, the estuary-specific area available for landward migration of tidal saline wetlands and the area where low-lying urban lands are expected to prevent tidal saline wetland migration. Numbers in parentheses are descending order ranks.

Estuary code	Estuary name	State	Area available for wetland migration (km²) (rank)	Area with urban barriers to wetland migration (km²) (rank)
AEB	Apalachee Bay	FL	337 (14)	13 (25)
AAB	Apalachicola Bay	FL	427 (11)	11 (30)
AB	Aransas Bay	TX	159 (20)	22 (16)
AVB	Atchafalaya/Vermilion Bays	LA	3676 (1)	70 (5)
AO	Austin-Oyster	TX	19 (36)	7 (32)
BB	Barataria Bay	LA	1664 (3)	38 (13)
BCS	Big Cypress Swamp	FL	17 (38)	54 (7)
BR	Brazos River	TX	127 (23)	4 (35)
BRC	Breton/Chandeleur Sound	LA	76 (30)	2 (39)
CL	Calcasieu Lake	LA	547 (9)	38 (12)
CH	Charlotte Harbor	FL	111 (26)	160 (1)
CB	Choctawhatchee Bay	FL	101 (28)	14 (22)
CCB	Corpus Christi Bay	TX	69 (31)	17 (20)
CP	Crystal-Pithlachascotee	FL	201 (18)	93 (3)
EMS	East Mississippi Sound	MS/AL	129 (22)	13 (26)
ES	Econfina-Steinhatchee	FL	57 (32)	6 (34)
FB	Florida Bay	FL	420 (12)	9 (31)
FK	Florida Keys	FL	7 (39)	50 (10)
GB	Galveston Bay	TX	625 (7)	80 (4)
LLM	Lower Laguna Madre	TX	270 (15)	14 (23)
MB	Matagorda Bay	TX	189 (19)	13 (24)
MER	Mermentau River	LA	2184 (2)	53 (8)
MR	Mississippi River	LA	108 (27)	3 (37)
MO	Mobile Bay	AL	465 (10)	22 (17)
NTTI	North Ten Thousand Islands	FL	1102 (6)	21 (18)
PAB	Pensacola Bay	FL	115 (25)	20 (19)

POB	Perdido Bay	AL/FL	53 (33)	11 (29)
RB	Rookery Bay	FL	38 (35)	33 (15)
SL	Sabine Lake	TX/LA	565 (8)	39 (11)
SAB	San Antonio Bay	TX	120 (24)	7 (33)
SB	Sarasota Bay	FL	18 (37)	51 (9)
STTI	South Ten Thousand Islands	FL	1190 (5)	3 (38)
STB	St. Andrew Bay	FL	92 (29)	16 (21)
SR	Suwannee River	FL	249 (16)	12 (27)
TB	Tampa Bay	FL	50 (34)	106 (2)
TTB	Terrebonne/Timbalier Bays	LA	406 (13)	36 (14)
ULM	Upper Laguna Madre	TX	245 (17)	12 (28)
W	Waccasassa	FL	152 (21)	3 (36)
WMS	West Mississippi Sound	LA/MS	1417 (4)	68 (6)

Table 2. Studies that have investigated the potential for wetland landward migration and/or coastal squeeze. For each study, we show the country, spatial scale, and a subtopic that was emphasized.

Study	Country	Spatial scale	Emphasized subtopic
(Alizad *et al.*, 2016a)	USA	Portion of estuary	Dynamic modeling
(Alizad *et al.*, 2016b)	USA	Single estuary	Dynamic modeling
(Craft *et al.*, 2009)	USA	Multiple estuaries	Ecosystem services
(Di Nitto *et al.*, 2014)	Kenya	Portion of estuary	Adaptation strategies
(Doyle *et al.*, 2010)	USA	Regional	Ecosystem responses
(Enwright *et al.*, 2016)	USA	Regional	Barriers & opportunities
(Feagin *et al.*, 2010)	USA	Portion of estuary	Economic tradeoffs
(Flower *et al.*, 2017)	USA	Multiple estuaries	Everglades National Park
(Geselbracht *et al.*, 2011)	USA	Single estuary	Conservation planning
(Geselbracht *et al.*, 2015)	USA	Multiple estuaries	Adaptation planning
(Krolik-Root *et al.*, 2015)	UK	Single estuary	Coastal zone
(Linhoss *et al.*, 2014)	USA	Portion of estuary	Conservation planning
(Mills *et al.*, 2016)	Australia	Portion of estuary	Conservation planning
(Rogers *et al.*, 2014)	Australia	Single estuary	Ecosystem responses
(Runting *et al.*, 2017)	Australia	Portion of estuary	Conservation planning
(Schile *et al.*, 2014)	USA	Portion of estuary	Conservation planning
(Schleupner, 2008)	Martinique	National	Coastal zone
(Sterr, 2008)	Germany	National	Coastal zone
(Stralberg *et al.*, 2011)	USA	Single estuary	Conservation planning
Thorne et al. 2018	USA	Regional	Ecosystem responses
(Titus *et al.*, 2009)	USA	Regional	Shoreline protection
(Torio & Chmura, 2013)	USA/Canada	Multiple marshes	Conservation planning
(Torio & Chmura, 2015)	USA	Multiple marshes	Fish habitat conservation
(Traill *et al.*, 2011)	Australia	Portion of estuary	Threatened native rodent
(Yoskowitz *et al.*, 2017)	USA	Single estuary	Ecosystem services

Fig. 1. Study extent showing the 39 focal estuaries along the northern Gulf of Mexico coast (USA). See Table 1 for estuary codes. Whereas the darker grey lines indicate estuary boundaries, the lighter grey lines within estuaries represent the coastline and state boundaries.

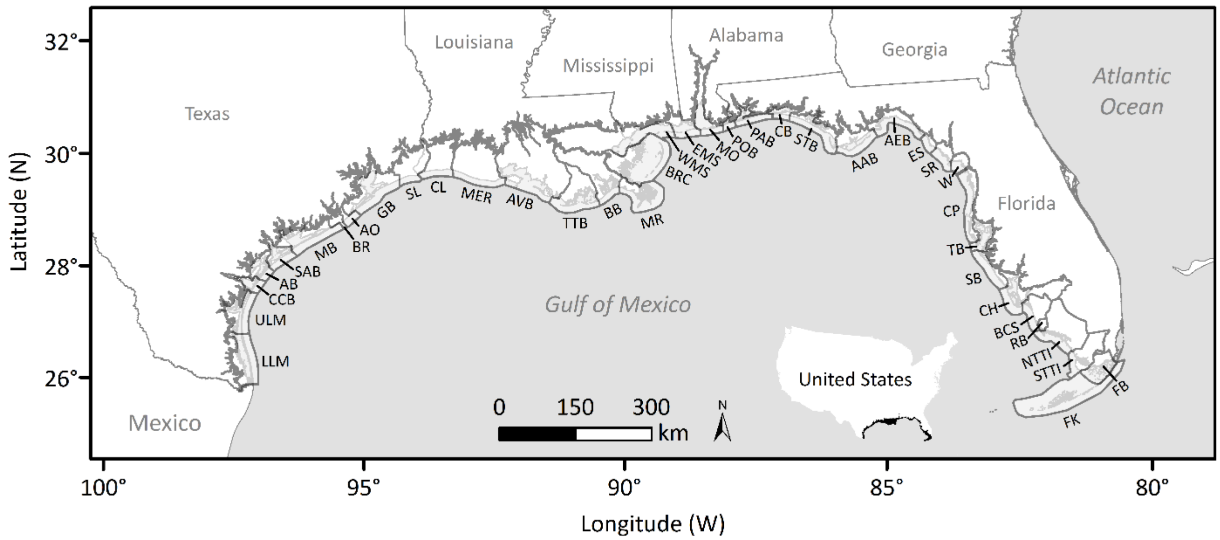

Fig. 2. For a 1-m sea-level rise scenario, the estuary-specific: (a) area available for landward migration of tidal saline wetlands; and (b) area of low-lying urban lands that are expected to prevent landward migration of tidal saline wetlands. Note that some estuaries have both a large amount of land available for wetland migration and a large amount of land where urban barriers are expected to prevent migration.

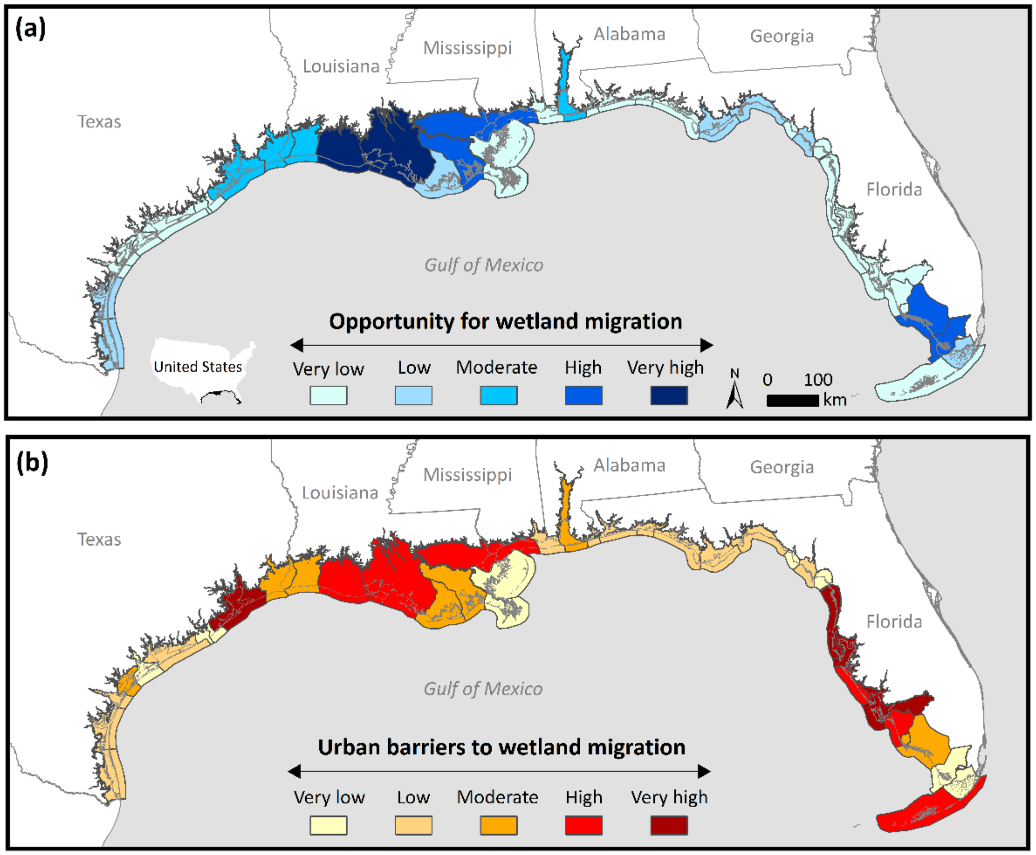

Fig. 3. For a 1-m sea-level rise scenario, the estuary-specific relative area available for landward migration of tidal saline wetlands versus the relative area of low-lying urban lands that are expected to prevent landward migration of tidal saline wetlands. Estuary codes are in Table 1.

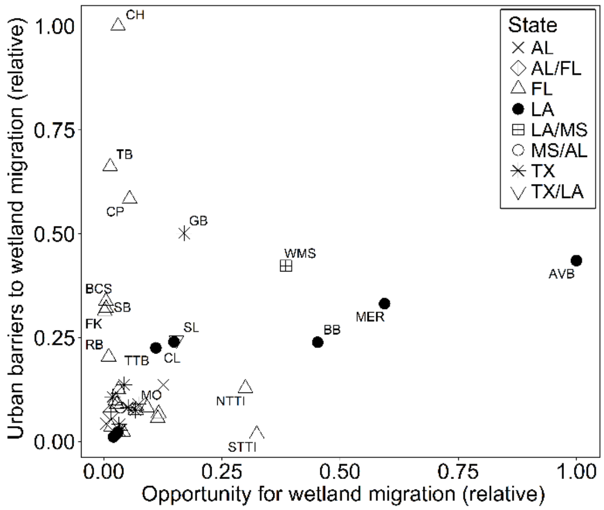

Fig. 4. For estuaries within and bordering the states of Louisiana, Mississippi, and Alabama (USA), the estuary-specific area available for landward migration of tidal saline wetlands versus the area of low-lying urban lands that are expected to prevent landward migration of tidal saline wetlands, for 0.5-, 1.0-, and 1.5-m sea-level rise scenarios. Estuary codes are in Table 1.

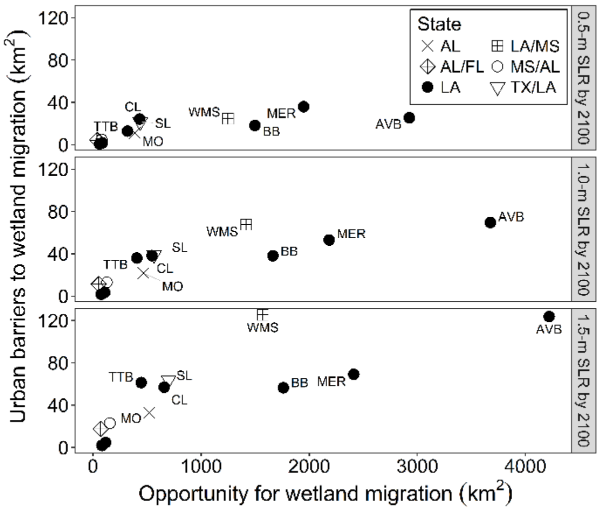

Fig. 5. For estuaries within and bordering the state of Texas (USA), the estuary-specific area available for landward migration of tidal saline wetlands versus the area of low-lying urban lands that are expected to prevent landward migration of tidal saline wetlands, for 0.5-, 1.0-, and 1.5-m sea level rise scenarios. Estuary codes are in Table 1.

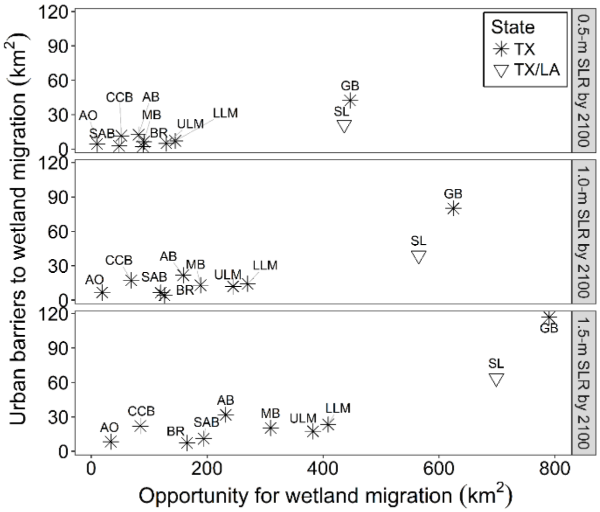

Fig. 6. For estuaries within and bordering the state of Florida (USA), the estuary-specific area available for landward migration of tidal saline wetlands versus the area of low-lying urban lands that are expected to prevent landward migration of tidal saline wetlands, for 0.5-, 1.0-, and 1.5-m sea level rise scenarios. Estuary codes are in Table 1.

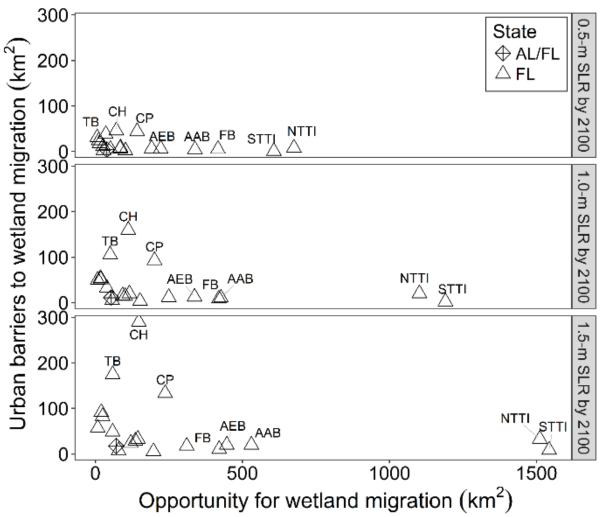

Fig. 7. Locations of the workshops and meetings in the northern Gulf of Mexico. All dates are in 2017.

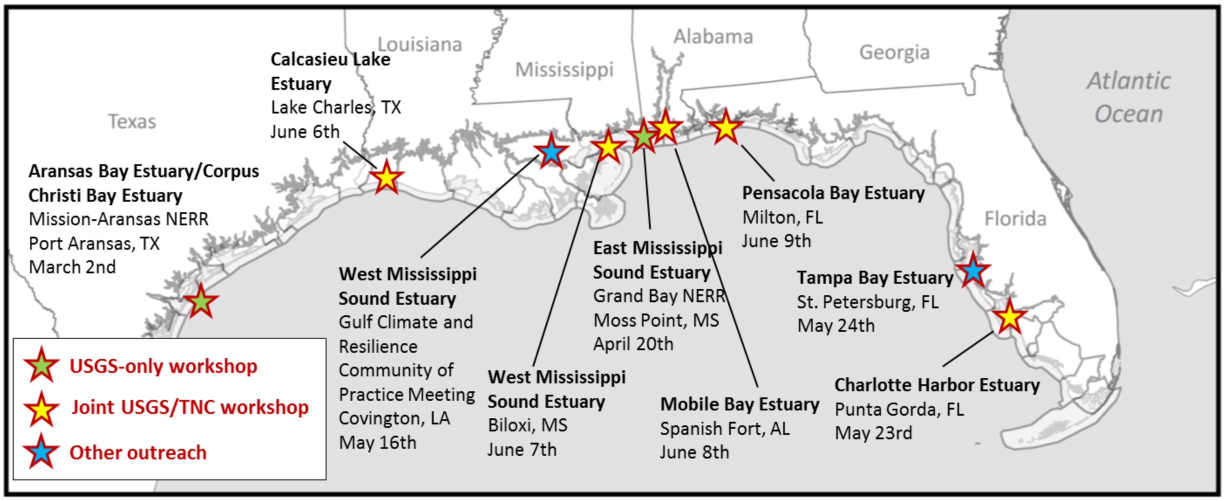

Fig. 8. Attendee composition by workshop for four of the jointly hosted USGS/TNC workshops. Acronyms: GIS = Geographic Information System; CRS = Community Rating System.

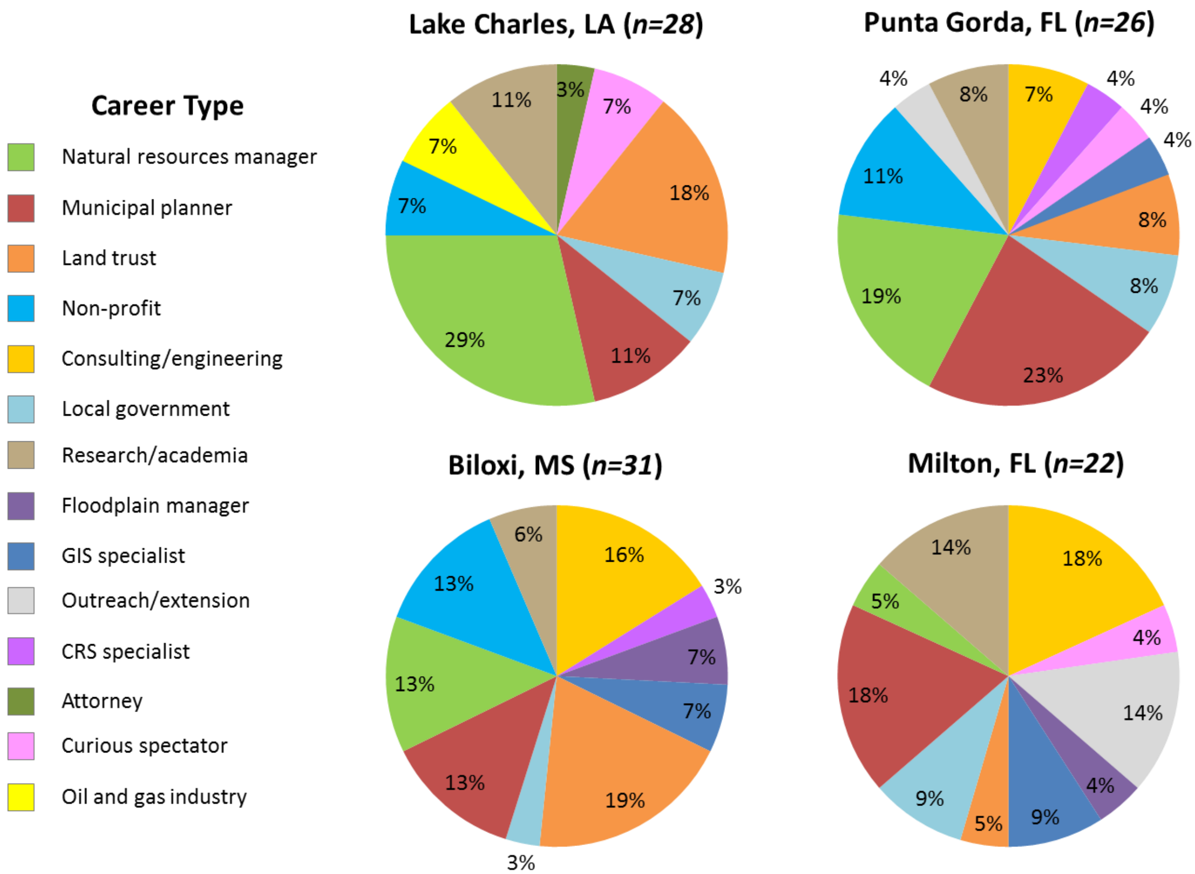

Table 3. Facilitated discussion questions and responses.

Question	Specific Examples
1) Are there specific resources, future projects, or future land acquisition endeavors that are particularly important for us to know about?	Infrastructure: erosion of roads as a public safety issue, protecting city utilities, and how sea-level rise affects infrastructure Species: Whooping Cranes, Piping Plovers, fish (sport fishing as an ecotourism draw), oysters, Mississippi Sandhill Cranes, beach mice, and gopher tortoises. Habitats: marshes, bogs, longleaf pine savanna, dunes, and barrier island habitats. Land protection: participants identified repetitive loss areas (including FEMA buy-outs), communities at high risk for flooding, many living shoreline projects, wetland land acquisitions, locations of vulnerable species, and general land protection acquisitions. Restoration projects: prescribed burning of adjacent uplands to facilitate migration, barrier island restoration, wetland creation projects, beach nourishment, and marsh grass plantings for shoreline protection.
2) What are the options you think your organization has to conserve open space and/or facilitate the landward migration of coastal wetlands in response to sea-level rise (i.e., what are the opportunities and barriers?)	Opportunities: land acquisition; easements; emphasizing the synergy between conservation and economic development (making money from ecotourism); using these datasets for public communication on sea-level rise risk before they purchase property; FEMA buyouts (repetitive loss properties); FEMA's Community Rating System; RESTORE funds; NRDA funds; Florida Forever funds; Tidelands Trust Fund in Mississippi; USDA conservation funds (however, often working lands cannot be taken out of production); hazard mitigation grants; local options sales tax (LA); stormwater utility fee (LA); identifying high flood risk areas that will be uninsurable; wetland setbacks and setbacks from the dune line; stream buffers for wetland migration; open space credits are rarely maxed out; Department of Defense land acquisitions near their properties; developers are allowed to cluster homes if they conserve wetlands (FL); Florida state law requires you to address sea-level rise in planning; land trust properties can be counted for open space credits as long as they allow for public use. Barriers: political will; planning efforts are often focused on preservation of existing resources (not future ones, e.g., wetland migration corridors); managing development within cities for

	open space protection is not a priority; conversion of freshwater systems to tidal saline wetlands is not viewed as a positive in Louisiana (freshwater wetlands valued); fund matching requirements; cost-benefit analysis requirements of various projects in order to receive funding; high cost of coastal land makes land acquisitions for conservation difficult (lack of return on investment); existing infrastructure is unlikely to be removed or moved; attitudes to wetland conservation (the public does not understand the benefits and prefers to fill wetlands in); lack of funds for long-term management once properties are acquired; the liability associated with having a piece of land that is not developed; isolated repetitive loss properties are generally not purchased; acquiring land without the mineral rights could affect its conservation value (LA)
3) What information do you want from the open space and wetland migration projects? What form would custom products take to be useful to you?	<u>Graphics:</u> maps and figures of wetland migration corridors overlaid with protected areas, land parcels, the Open Space study watersheds, county boundaries, and other areas of interest. <u>Communication materials:</u> non-technical presentations for laypeople or elected officials, short written descriptions of the studies, brochures, and 1-2 page fact sheets. <u>Spatial analyses:</u> areal calculations of future wetland migration by scenario and time-step, areal calculations of the conversion of other habitats to tidal saline wetland as the sea-level rises, comparisons of the various sea-level rise related models (e.g., Sea Level Affecting Marshes and Ecological Effects of Sea Level Rise), and identifying areas in overlap between habitat models.