FINAL REPORT

Project Name: CMP 18 – Maximizing the ecological value of coastal wetland restoration: comparisons among restoration techniques

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Co-principal Investigators: Dr. Antonietta Quigg, Dr. Susan Knock, TAMUG

GLO Contract No.: 14-084-000-7952 (TAMUG 480841)

Reporting Period: 1 October 2013 through 30 June 2015

A REPORT FUNDED BY A TEXAS COASTAL MANAGEMENT PROGRAM GRANT APPROVED BY THE TEXAS LAND COMMISSIONER PURSUANT TO NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION AWARD NO. NA13NOS4190113.

Task 1: Wetland Comparisons

Status of the task during this reporting period: ☐ in progress ☒ completed

Major accomplishments and findings:

Our overarching project objective was to identify restoration techniques that maximize wetland restoration success. Our analyses sought to identify the influences of construction techniques and the surrounding landscape on ecosystem restoration success.

Approaches to wetland restoration vary in construction technique and placement within a larger landscape matrix of wetland habitat. Engineered marshes are often constructed by placing soil in terrace or mound formations, whereas a beneficial uses (BU) approach deposits dredge material to fill continuous areas to emergent marsh elevation. Either construction approach can be planted with native species, or colonization can occur naturally. Likewise, either type of wetland can be isolated in a degraded area, or be situated within a network of relict and restored marshes. We investigated how restoration success was influenced by the localized configuration of individual restoration sites and by the placement of each site within a wetland matrix.

Our study areas included *engineered* sites, multiple *beneficial use* sites, and additional unmanaged (*reference*) sites, in the Lower Neches and J.D. Murphree Wildlife Management Areas (Fig. 1). *Engineered marshes* contained mound or terrace formations that form a mixture of aquatic habitat, emergent marsh habitat, and "edge" habitat at the vegetation-water interface. *Beneficial uses marshes* (BUDM) were created by depositing dredge material to fill continuous areas to emergent marsh elevation, creating areas with expansive emergent marsh habitat. Subsets of both areas were actively planted with emergent marsh vegetation, and others were left unplanted. *Reference marshes* were adjacent unmanaged areas with comparable elevation and tidal influence.

In October 2013 and 2014, we surveyed emergent plant characteristics in planted engineered and BUDM sites that varied in size, isolation, and proximity to urban developments near Sabine Lake, TX. Plant biomass, cover, and species richness in BUDM marshes were similar to reference conditions (Figs. 2-4). In contrast, emergent plant biomass and cover were frequently over 70% lower in engineered marshes than in BUDM and reference marshes. Restoration failure (emergent plant cover < 10 % and biomass < 0.5 kg/m^2) occurred only in small (< 0.5 km^2) sites, though not all small sites failed (Fig. 5). Plant species richness was up to 2x higher in more altered sites that were close (< 1 km) to roads or urban development (Fig. 6). Individual restoration sites were highly dissimilar to each other, and some were failures in terms of emergent plant cover. However, when the failed sites were within a relatively large surrounding matrix of successful restored and reference sites, the ecosystem effects of that failure were minimized. Our analysis shows that construction method is less important than the placement of restoration projects within a fairly large wetland matrix in ensuring restoration success.

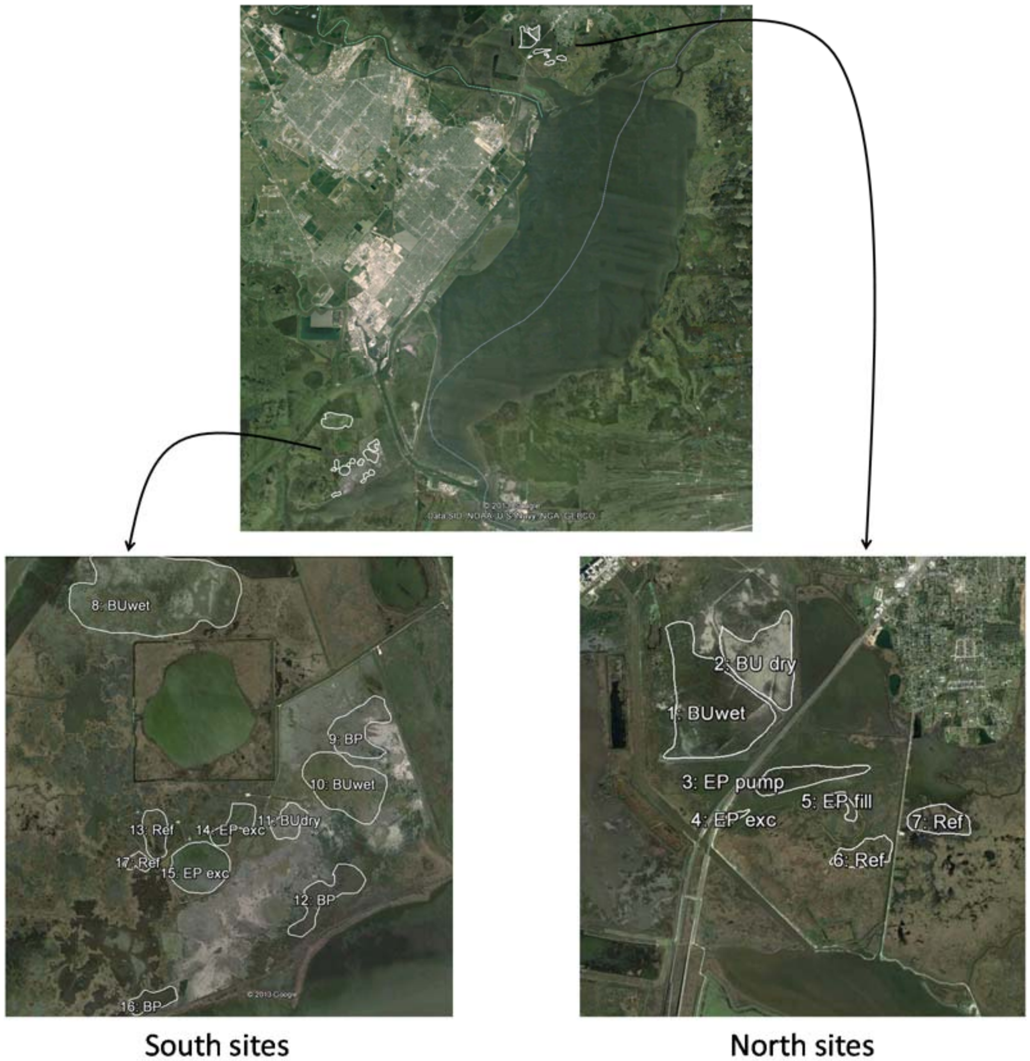

Figure 1: Study sites relative to Sabine Lake (top panel). Close-up views of site groups (lower panels). EP = Engineered, planted; BP = Beneficial uses, planted; BU dry = Beneficial uses, unplanted, high elevation; BU wet = Beneficial uses, unplanted, low elevation; Ref = Reference sites. EP areas are subdivided into different structural configurations: exc = dedicated on-site excavation into terrace or mound formations; pump = addition of off-site dredge material, creating mound formations; filled = excavations to create mounds followed by the addition of dredge material.

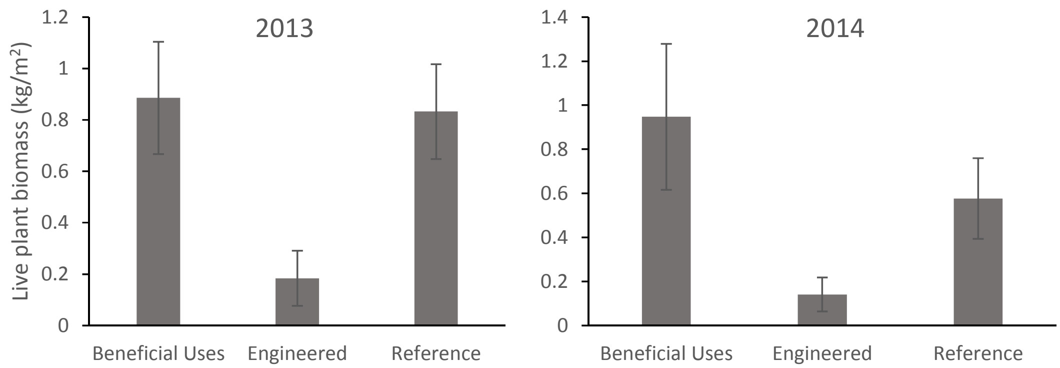

Figure 2: Average live plant biomass cover in planted beneficial uses sites, planted engineered sites, and reference sites, in October 2013 and October 2014. Error bars represent standard error.

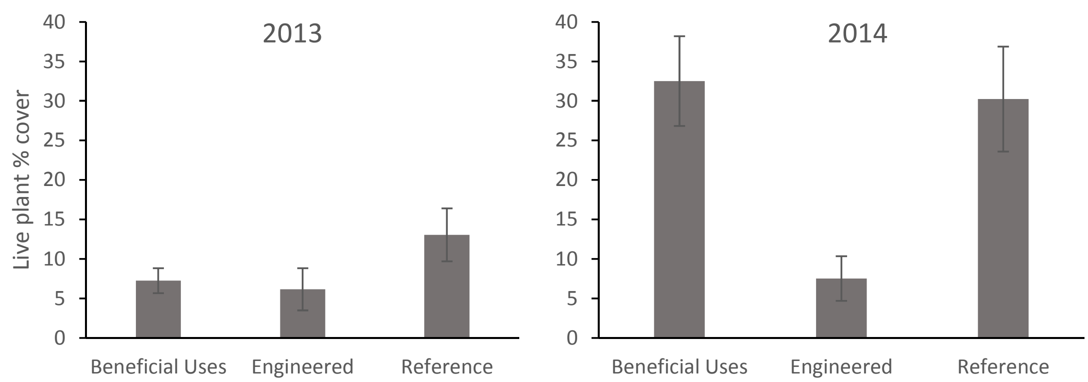

Figure 3: Average live plant percent cover in planted beneficial uses sites, planted engineered sites, and reference sites, in October 2013 and October 2014. Error bars represent standard error.

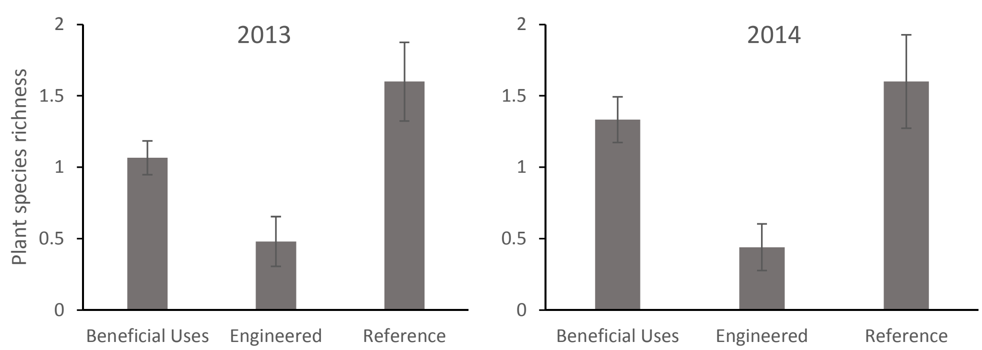

Figure 4: Average plant species richness in planted beneficial uses sites, planted engineered sites, and reference sites, in October 2013 and October 2014. Error bars represent standard error.

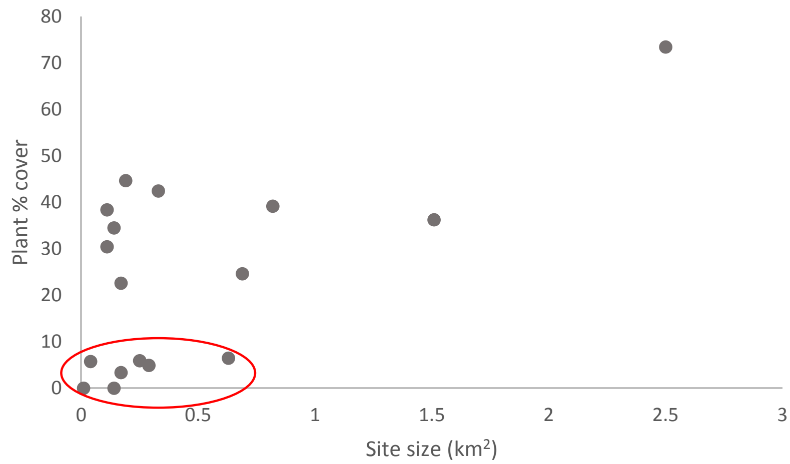

Figure 5: The relationship between live plant percent cover and site size in October 2014. The red circle highlights failed restoration sites, defined as < 10% emergent plant cover.

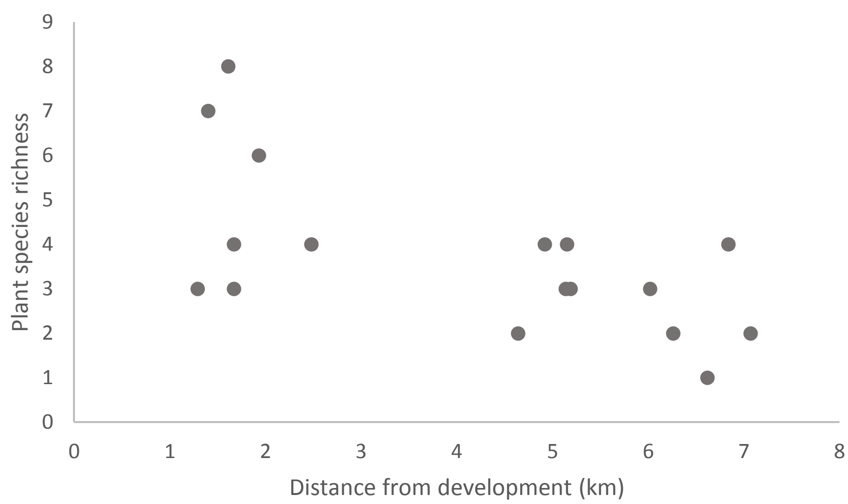

Figure 6: The relationship between plant species richness and distance from urban development in October 2014.

Deliverables completed during this reporting period:

The final report for this project was posted on the PI's webpage (http://www.tamug.edu/armitage/Current_Projects.html).

The following oral and poster presentations related to this project were or will be given at local, national, and international scientific conferences. The abstracts are included as documentation of deliverable completion.

(* indicates graduate student; ◊ indicates postdoc)

Quigg A., ◊Kinney E.L., Bowers K., Ho C.-K., Madrid E.N., Bell M.T., Armitage A.R. November 2013. Did acute drought affect ecosystem development in a restored brackish marsh? Coastal and Estuarine Research Federation 22nd Biennial Conference.

Abstract: Extreme events like droughts can dramatically alter ecosystem functions – the effects may be most profound in transitional (e.g., brackish) habitats or in the early-successional stages in developing ecosystems, such as recently restored habitats. As part of a long-term wetland restoration monitoring program, we were able to document the effects of the 2011 exceptional drought in Texas and to follow near-term recovery of ecosystem functions in restored brackish marshes in the NW Gulf of Mexico. As a result of the year-long drought, salinities increased to three-times greater than normal for several months, but then returned to normal (< 10 ppt) in 2012. Immediate effects on emergent plants were minimal, but lower plant biomass in 2012 suggested long-term drought effects. Drought and the corresponding high salinity had dramatic and long-term effects on submerged aquatic vegetation (SAV). The invasive Eurasian milfoil (*Myriophyllum spicatum*) was essentially eradicated during the drought and remained rare throughout 2012. Drought effects were less dramatic for native *Ruppia maritima*, which slightly increased in biomass in 2011 and 2012, possibly due to a release from competition from *Myriophyllum*. Drought may have caused a long-term loss of total SAV biomass and a possibly beneficial shift in species composition by disproportionately impacting the invasive species. Effects on phytoplankton were immediate during the drought, with a shift in community composition from diatom- to cyanobacteria-dominated. Many aquatic fauna, including snails, grass shrimp, and fish, declined dramatically during the drought. This may have been a direct response to salinity, as well as a trophic response to the substantial changes in the producers at the base of the food web. The findings from this study, which include pre-, during-, and post-drought surveys, provide insight into how acute drought affects ecosystem development in restored brackish marshes.

Armitage A.R., Bowers K., Bergren, R., Quigg A. 2015. Maximizing wetland restoration success: the influences of construction techniques and the surrounding landscape. Coastal and Estuarine Research Federation 23rd Biennial Conference.

Abstract: Approaches to wetland restoration vary in construction technique, planting strategy, and placement within a larger landscape matrix of wetland habitat. Engineered marshes are often constructed by placing soil in terrace or mound formations, whereas a beneficial uses (BU) approach deposits dredge material to fill continuous areas to emergent marsh elevation. Either construction approach can be planted with native species, or colonization can occur naturally. Likewise, either type of wetland can be isolated in a degraded area, or be situated within a network of relict and restored marshes. We investigated how restoration success was influenced by the localized configuration of individual restoration sites and by the placement of that site within a wetland matrix. In October 2014, we surveyed emergent plant characteristics in planted engineered and BU sites along with unplanted BU tidal brackish marshes that varied in size, isolation, and proximity to urban developments near Sabine Lake, TX (USA). Plant biomass, cover, and species richness in BU marshes were similar to reference conditions, regardless of planting technique. In contrast, emergent plant biomass and cover were over 70% lower in engineered marshes than in BU and reference marshes. Restoration failure (emergent plant cover < 10 % and biomass < 0.5 kg/m^2) occurred only in small (< 0.5 km^2) sites, though not all small sites failed. Plant species richness was up to 2x higher in more altered sites that were close (< 1 km) to roads or urban development. Individual restoration sites were highly dissimilar from each other, and some were failures in terms of emergent plant cover. However, when the failed sites were within a relatively large surrounding matrix of successful restored and reference sites, the ecosystem effects of that failure were minimized. Our analysis shows that construction method is less important than the placement of restoration projects within a fairly large wetland matrix in ensuring restoration success.

Bowers K., Armitage A.R., Bergren, R., ◊Kinney E.L., ◊Ho C.-K., ◊Madrid E.N., *Bell M.T., Quigg A. 2015. Resilience versus vulnerability: Prolonged consequences of an exceptional drought in a brackish marsh. Coastal and Estuarine Research Federation 23rd Biennial Conference.

Abstract: Extreme events like droughts can substantially alter ecosystem functions, and the effects may be particularly dramatic in transitional habitats such as brackish marshes. As part of a six-year restoration monitoring program, we documented the ecosystem effects of an exceptional drought in Texas in 2011. We measured emergent and aquatic habitat characteristics over two years before the drought, during the drought, and over a three-year recovery period. The emergent plant community was resilient to drought conditions; plant cover, biomass, and productivity did not significantly differ among years. In contrast, characteristics of the aquatic community, including water quality, submerged aquatic vegetation (SAV) biomass, and total fish and invertebrate densities were markedly different among pre-, during-, and post-drought periods. Prior to the drought, salinities were low (< 10 ppt), invasive Eurasian milfoil (*Myriophyllum spicatum*) dominated the SAV, and faunal densities frequently exceeded 25/m^2. During the 2011 drought, salinity was > 25 ppt, leading to an eradication of milfoil and a drop in fish and invertebrate densities to less than 5/m^2. By 2012, one year after the drought, salinity returned to brackish levels. However, milfoil remained absent and was replaced by native widgeongrass (*Ruppia maritima*) and filamentous green algae. The fish and invertebrate communities were relatively resilient, and recovered to comparable pre-drought density and composition, though with high interannual variation. Overall, the brackish marsh exhibited complex responses to an exceptional drought, with high resilience within the emergent plant assemblage. Aquatic plants did not return to pre-drought conditions, but drought effects on aquatic fauna were temporary. These findings highlight the prolonged consequences for brackish ecosystems as a result of an exceptional drought.

Armitage A.R., Bowers K., Bergren, R., Quigg A. January 2016. Maximizing wetland restoration success in Galveston Bay: lessons on the influences of construction techniques and the surrounding landscape. 10th State of the Bay Symposium.

Abstract: Approaches to wetland restoration vary in construction technique, planting strategy, and placement within a larger landscape matrix of wetland habitat. Engineered marshes are often constructed by placing soil in terrace or mound formations; this approach is common in Galveston Bay. In contrast, the relatively less widespread beneficial uses (BU) approach deposits dredge material to fill continuous areas to emergent marsh elevation. Either construction approach can be planted with native species, or colonization can occur naturally. Likewise, either type of wetland can be isolated in a degraded area, or be situated within a network of relict and restored marshes. We investigated how restoration success was influenced by the localized configuration of individual restoration sites and by the placement of that site within a wetland matrix. In October 2014, we surveyed emergent plant characteristics in planted engineered and BU sites along with unplanted BU tidal brackish marshes that varied in size, isolation, and proximity to urban developments near Sabine Lake, TX (USA). Plant biomass, cover, and species richness in BU marshes were similar to reference conditions, regardless of planting technique. In contrast, site-level emergent plant biomass and cover were over 70% lower in engineered marshes than in BU and reference marshes. Restoration failure (defined as emergent plant cover < 10 % and biomass < 0.5 kg/m^2) occurred only in small (< 0.5 km^2) sites, though not all small sites failed. Plant species richness was up to 2x higher in more altered sites that were close (< 1 km) to roads or urban development. Individual restoration sites were highly dissimilar from each other, and some were failures in terms of emergent plant cover. However, when the failed sites were within a relatively large surrounding matrix of successful restored and reference sites, the ecosystem effects of that failure were minimized. Our analysis shows that construction method is less important than the placement of restoration projects within a fairly large wetland matrix in ensuring restoration success. These lessons are directly applicable to the design and implementation of future wetland restoration projects in Galveston Bay.

Were there any problems or obstacles encountered during this reporting period (e.g., delays, remedial action taken, schedule revision). ☒ Yes ☐ No If yes, please explain:

A three-month no-cost extension was granted to extend the project end date to 6/30/15. All tasks were completed by that end date.

Task 2: Planting Technique Comparisons

Status of the task during this reporting period: ☐in progress ☒completed

Major accomplishments and findings:

As part of the monitoring performed for Task 1, we compared a subset of the sites by focusing on beneficial uses sites with and without plants added during the initial restoration effort. We measured plant biomass and cover at these sites.

Plant biomass was lower in unplanted marshes than in planted marshes and reference sites, particularly in 2013 (Fig. 7). The difference between unplanted and reference conditions was relatively small in 2014. Plant biomass in planted and unplanted marshes was similar to reference conditions in 2013 and 2014 (Fig. 8).

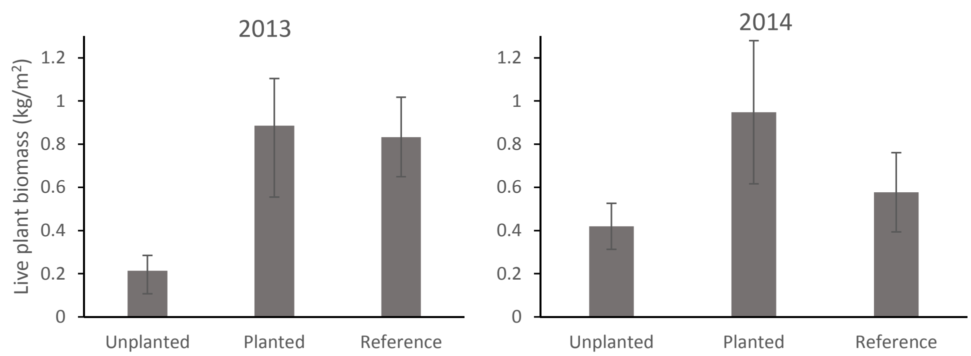

Figure 7: Average live plant biomass in planted and unplanted beneficial uses restored sites and reference sites in October 2013 and October 2014. Error bars represent standard error.

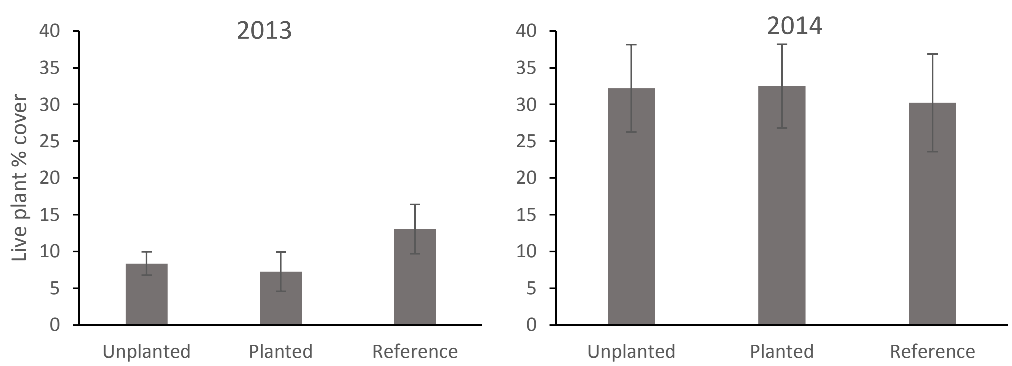

Figure 8: Average live plant percent cover in planted and unplanted beneficial uses restored sites and reference sites in October 2013 and October 2014. Error bars represent standard error.

Deliverables completed during this reporting period: See Task 1.

Were there any problems or obstacles encountered during this reporting period (e.g., delays, remedial action taken, schedule revision). ☒Yes ☐No If yes, please explain:

A three-month no-cost extension was granted to extend the project end date to 6/30/15. All tasks were completed by that end date.

Task 3: Secondary production: Aquatic fauna and shorebirds

Status of the task during this reporting period: ☐in progress ☒completed

Major accomplishments and findings:

Many wetland bird species forage in unvegetated areas called mudflats, yet these mudflats are rarely included in wetland restoration design. The beneficial uses (BUDM) restoration method uses dredge material to create a continuous area of wetlands. This approach can yield small variations in elevation, soil moisture, and the amount of vegetation. These variations may increase the number and diversity of birds using the restored area. We compared populations of birds, and the small, mud-dwelling animals (infauna) that they eat, among planted, unplanted + high elevation (dry), and unplanted + low elevation (wet) areas of a restored coastal marsh near Port Arthur, TX. We hypothesized that unplanted, wet areas would have the most infauna, and would therefore support more birds. Replicate cores were taken from each habitat type, sieved, and infauna were identified to the lowest taxonomic group possible. To monitor bird use, time-lapse wildlife cameras were deployed in each habitat type during the overwintering and spring and fall migration periods in 2013 and 2014. The pictures were later analyzed and birds were identified to species. Infaunal density in unplanted areas was 109 times higher than in planted areas (Fig. 9). Infaunal density was 68 times higher in wet unplanted areas than in dry unplanted areas. Likewise, birds were most frequently observed in wet, unplanted areas (Fig. 9). Snails (Class Gastropoda) were the most common type of fauna found, followed by bivalves (Class Pelecypoda) and worms (Class Oligochaeta) (Fig. 10). Oligochaetes were only found in wet, unplanted areas. The most common birds in wet areas were ibis, herons, egrets, and ducks (Fig. 11). In conclusion, when restoring wetlands, including areas that are wet and unplanted is important for providing habitat for the infauna that will support residential and migratory bird populations.

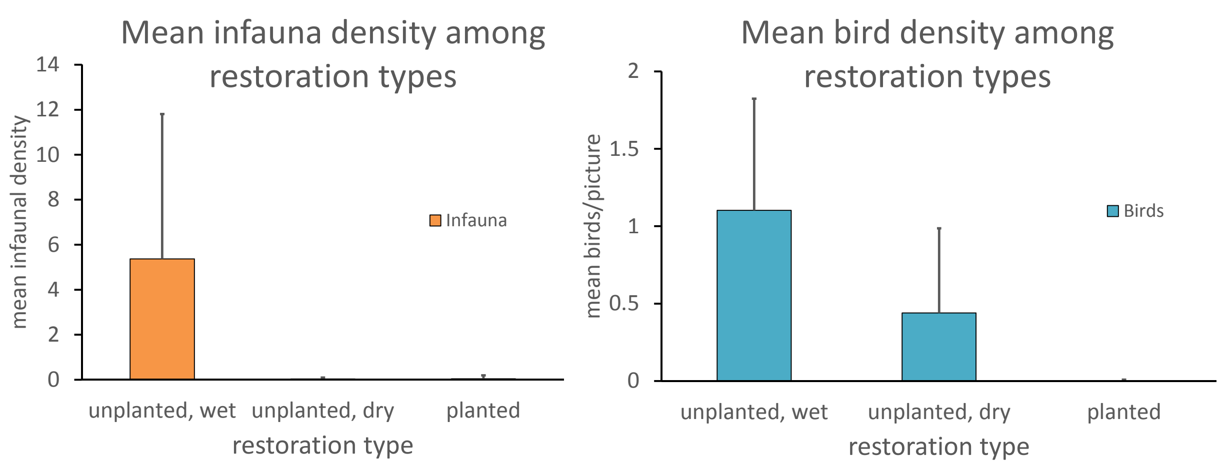

Figure 9: Average infaunal and bird densities in wet (low elevation) and dry (high elevation) unplanted beneficial uses restored sites, and in planted restored sites, in spring 2014. Error bars represent standard error.

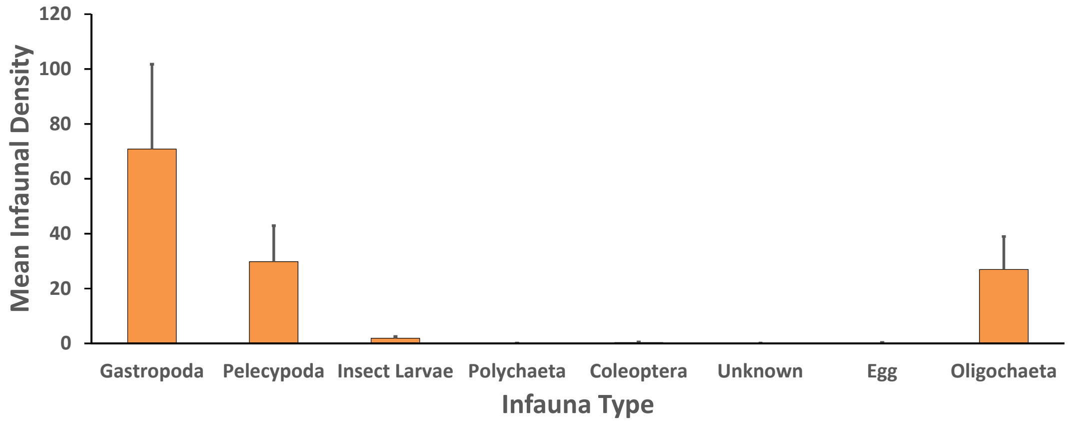

Figure 10: Average densities of infaunal groups, pooled across all restored wetland types, in spring 2014. Error bars represent standard error.

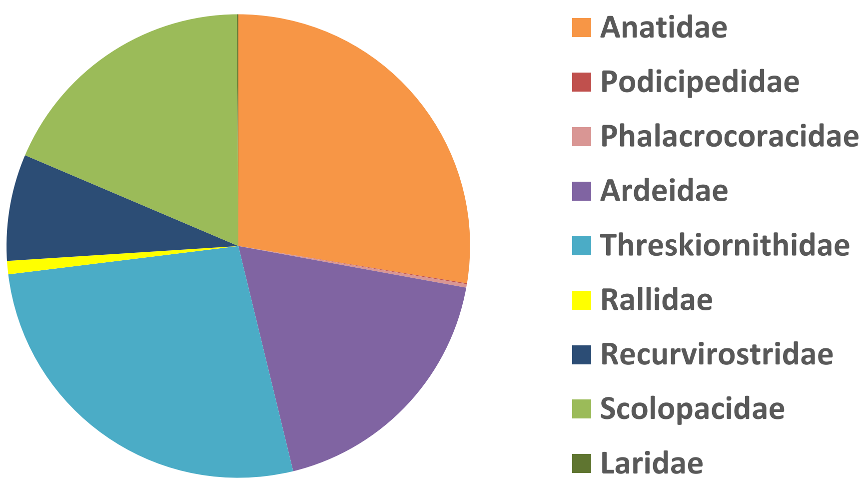

Figure 11: Relative family composition of bird assemblages, pooled across all restored wetland types, in spring 2014.

Deliverables completed during this reporting period:

The following poster presentations related to this project were given at local, national, and international scientific conferences. The abstracts are included as documentation of deliverable completion.

(* indicates graduate student; # indicates undergraduate student)

#Morrison R.V., *Whitt A.A., *Weaver C.A., Armitage A.R. April 2014. Bird density and family composition in restored brackish marshes. Texas A&M University at Galveston Student Research Symposium.

Abstract: Coastal wetlands provide critical foraging and roosting habitat for many species of migratory and resident birds. Wetland restoration usually focuses on emergent vegetation, and seldom includes the mudflat or subtidal habitat that is essential for these species, but an innovative restoration project near Port Arthur, TX

included some unvegetated mudflat habitat. We compared bird density and species richness between engineered marshes (EM) surrounded by extensive aquatic habitat and beneficial uses marshes (BUDM) with extensive mudflat. Data were recorded using time lapse digital cameras that took two pictures every 30 minutes from dawn to dusk, for five day periods in October and December 2013. Families Anatidae (ducks), Areidae (herons, egrets), Podicipedidae (grebes), Recurvirostridae (black-necked stilts), Scolopacidae (sandpipers), and Threskiornithidae (ibis and roseate spoonbills) were more abundant in the BUDM area, whereas families Pelecanidae (pelicans) and Phalacrocoracidae (cormorants) were more abundant in the EM area. The data are consistent with the feeding behavior of the birds observed; herons, egrets, and ibises forage in shallowly flooded mudflats, like those at the BUDM sites, for gastropods, bivalves, and crustaceans. Other birds, like cormorants and pelicans, prefer to eat fish and will dive for them in deeper waters like those at the EM site. These findings demonstrate the ecological benefit of including a variety of subtidal and mudflat habitats into coastal wetland restoration.

*Whitt A., #Morrison R., Rathjen M., #Norris A., Armitage A.R. July 2014. Migrating bird use of brackish marshes: Does restoration technique matter? 2014 Conference on Ecological and Ecosystem Restoration.

Abstract: An important goal of coastal wetland restoration, particularly from the public perspective, is to rehabilitate impacted wildlife populations, including migratory and resident birds. If successful, such restoration projects will revitalize migratory flyways for waterfowl (ducks) and shorebirds by providing trophic support and roosting habitat. There are many different approaches to wetland restoration, including variations in construction technique and planting strategy. *Engineered* marshes are often constructed by placing soil in terrace or mound formations, creating aquatic habitat that can be used by waterfowl. In contrast, *beneficial uses (BUDM)* marshes are created by depositing dredge material to fill continuous areas to emergent marsh elevation. Neither the *engineering* nor the *BUDM* approaches explicitly incorporates mudflat habitat, despite its importance for the charismatic shorebirds that are iconic coastal wetland species. Mudflat habitat may be created in *BUDM* areas by reducing or delaying marsh planting.

We investigated how these varied restoration techniques altered migratory and wintering bird usage of restored brackish marshes in the J. D. Murphree Wildlife Management Area near Port Arthur, TX (USA). Our research addressed two questions: (1) What is the value of restored brackish marshes to migrating birds? (2) Does bird density and species composition differ among marsh restoration techniques? We deployed time-lapse game cameras for two-week periods in fall 2013 and winter 2014 in a native undisturbed marsh and two constructed marshes, one with engineered mounds and the other an unplanted poured dredge slurry. We assessed bird utilization of the restored brackish marshes by comparing the frequency of bird presence and bird species richness among habitat types. Shorebirds and waterfowl preferred the less vegetated restored marshes, relative to the heavily vegetated native marsh. Of the two constructed marsh types, there was a higher abundance of birds in the *BUDM* marsh than in the marsh with engineered mounds. However, there were different species of waterfowl, wading and shorebirds utilizing each restored marsh type. For instance, *Eudocimus albus* (white ibis) and *Limnodromus* sp. (dowitcher) were more commonly seen along the edges of the engineered mounds, whereas *Himantopus mexicanus* (black-necked stilts) and *Anas discors* (blue-winged teal) utilized the *BUDM* marsh. These data will inform management decisions by showing that an ideal restoration design incorporates both aquatic and mudflat habitats which can be utilized by various species of waterfowl and shorebirds.

#Norris, A.E., Armitage, A.R. March 2015. Identifying coastal wetland restoration techniques to maximize benefits to bird populations. Texas Undergraduate Research Day at the Capitol.

Abstract: Many wetland bird species forage in unvegetated areas called mudflats, yet these mudflats are rarely included in wetland restoration design. Therefore, wetland restoration projects that include small variations in elevation, soil moisture, and the amount of vegetation may increase the number and diversity of birds using the restored area. Our objective was to compare populations of birds, and the small, mud-dwelling animals (infauna) that they eat, among high elevation (dry), low elevation (wet), planted, and unplanted areas of a restored coastal marsh near Port Arthur, TX. We hypothesized that unplanted, wet areas would have the most infauna, and would

therefore support more birds. Infauna were collected from soil cores, and game cameras captured bird pictures every 30 minutes and were also triggered by motion. Unplanted areas had 109 times more infauna than planted areas. Wet areas had 68 times more infauna than dry areas. There was a positive correlation between the number of infauna and number of birds within an area. The most common birds in wet areas were ibis, herons, egrets, and ducks. When restoring wetlands, including areas that are wet and unplanted is important for providing habitat for the infauna that will support residential and migratory bird populations.

#Norris, A.E., Armitage, A.R. April 2015. Identifying coastal wetland restoration techniques to maximize benefits to bird populations. 2015 Texas Bays and Estuaries Meeting.
See above.

#Norris, A.E., Armitage, A.R. April 2015. Identifying coastal wetland restoration techniques to maximize benefits to bird populations. TAMUG Research Symposium.
See above.

Were there any problems or obstacles encountered during this reporting period (e.g., delays, remedial action taken, schedule revision). ☒Yes ☐No If yes, please explain:

A three-month no-cost extension was granted to extend the project end date to 6/30/15. All tasks were completed by that end date.

Task 4: Education and Outreach

Status of the task during this reporting period: ☐in progress ☒completed

Major accomplishments and findings:

Over the course of the project, we partially supported one graduate student (Whitt) who is conducting thesis work related to this project. We supported two undergraduate research interns (Norris, Morrison) to assist with bird image processing and analysis, and employed two undergraduate student workers to assist with sample processing.

Deliverables completed during this reporting period:

See Task 3.

Were there any problems or obstacles encountered during this reporting period (e.g., delays, remedial action taken, schedule revision). ☒Yes ☐No If yes, please explain:

A three-month no-cost extension was granted to extend the project end date to 6/30/15. All tasks were completed by that end date.

Task 5: Project Reporting and Data Transfer

Status of the task during this reporting period: ☐in progress ☒completed

Major accomplishments and findings:

Progress reports have been filed on schedule.

Deliverables completed during this reporting period:

Quarterly progress reports have been filed on schedule.

Were there any problems or obstacles encountered during this reporting period (e.g., delays, remedial action taken, schedule revision). ☒Yes ☐No If yes, please explain:

A three-month no-cost extension was granted to extend the project end date to 6/30/15. All tasks were completed by that end date.

Acknowledgements: Logistical support, access to the study site (Old River Unit of the Lower Neches Wildlife Management Area), and additional support was provided by the Wildlife Division of the Texas Parks and Wildlife Department, under Wildlife Division Director Clayton Wolf. In particular, Jim Sutherlin and Mike Rezsutek from TPWD provided extensive logistical support.