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An Assessment of Long-Term, Multipurpose Ecosystem Functions and Engineering Benefits Derived from Historical Dredged Sediment Beneficial Use Projects

Jacob F. Berkowitz, Nathan R. Beane, Kevin D. Philley
Nia R. Hurst, and Jake F. Jung

July 2021



Environmental Laboratory

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Environmental Laboratory
US Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Abstract

The beneficial use of dredged materials improves environmental outcomes while maximizing navigation benefits and minimizing costs, in accordance with the principles of the Engineering With Nature® (EWN) initiative. Yet, few studies document the long-term benefits of innovative dredged material management strategies or conduct comprehensive life-cycle analysis because of a combination of (1) short monitoring time frames and (2) the paucity of constructed projects that have reached ecological maturity. In response, we conducted an ecological functional and engineering benefit assessment of six historic (>40 years old) dredged material–supported habitat improvement projects where initial postconstruction beneficial use monitoring data was available. Conditions at natural reference locations were also documented to facilitate a comparison between natural and engineered landscape features. Results indicate the projects examined provide valuable habitat for a variety of species in addition to yielding a number of engineering (for example, shoreline protection) and other (for example, carbon storage) benefits. Our findings also suggest establishment of ecological success criteria should not overemphasize replicating reference conditions but remain focused on achieving specific ecological functions (that is, habitat and biogeochemical cycling) and engineering benefits (that is, storm surge reduction, navigation channel maintenance) achievable through project design and operational management.

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Preface

This study was conducted by the US Army Corps of Engineers, Research and Development Center, Vicksburg, MS. Funding was provided by the US Army Corps of Engineers through the Dredging Operations Environmental Research (DOER) and Engineering With Nature® (EWN) programs under Funding Account Code J38124 and W81EWF92826698. Technical monitor was Dr. Todd Bridges.

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Executive Summary

The following describes the results of an ecological and engineering assessment of six historic dredged material beneficial use sites constructed in the 1970s. The assessment included evaluations of vegetation and avian communities, as well as soil conditions and geomorphology. The results improve our understanding of ecological functional trajectories associated with long term beneficial use project outcomes. Additionally, the assessment identified seven positive engineering outcomes derived from the implementation of the dredged material beneficial projects including: elevation maintenance, dewatering effects, landscape evolution, water quality improvements, navigation channel maintenance, shoreline stabilization, and storm surge reduction.

Notably, the study sites have persisted with little or no intervention for more than four decades and the projects continue to provide a wide array of ecological functions and engineering benefits. The integration of ecological functions and engineering benefits in a single assessment highlights the value of the Engineering With Nature® (EWN) initiative, an intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes. The sections below summarize the major findings of the report.

Vegetation community assessment

- The projects generally achieved the target habitat types.
- The study locations are stable features that will effectively provide habitat for a variety of species into the future.
- Initial planting efforts had limited effects on the long-term occurrence and distribution of plant species. However, establishing appropriate species provides advantages even if some plant communities do not persist. Plantings can stabilize soils, accelerate dewatering, provide habitat, help prevent establishment of undesirable plant species, trap sediment, and improve soil health.
- The ecological complexity of study locations increased as plant communities adjusted to local conditions and succession occurred. The study sites were generally more ecologically complex than un-engineered reference areas.

- The habitat improvement projects have reached a moderate level of maturity yet do not directly mimic the plant community assemblages of reference areas.
- Both habitat improvement locations and reference areas appear to be responding to environmental conditions in similar ways despite the observed differences in species composition and structural complexity.
- Results suggest that additional management activities could further improve site conditions, especially with regard to selective species management, and in some cases the implementation of periodic disturbance regimes.

Avian habitat assessment

- The habitat improvement projects have provided important habitat for a diverse assemblage of avian communities since their creation.
- The study sites support a wide range of bird species, including numerous US Fish and Wildlife Services (USFWS) Species of Conservation Concern.
- Differences in species assemblages and abundances exist between the current data set and both (1) previous survey efforts and (2) observations made at un-altered reference areas.
- The intentional placement and manipulation of dredged materials resulted in the development of a wider range of target habitat types compared to reference sites. As a result, the project sites generally had higher species richness compared to reference sites because of a greater diversity of habitats.
- In the years immediately following construction of the project sites, numerous shorebirds, terns, and skimmers were documented using unvegetated or sparsely vegetated sandy dredged material deposits. However, beach-nesting habitat is no longer widely available in areas not subject to intermittent patterns of disturbance, and additional management activities would be required to sustain habitat for these species.
- Future projects that seek to maximize avian community diversity should focus on creating a variety of appropriate target habitats as opposed to mimicking the landforms observed at reference areas.

Soils assessment

- Each of the habitat improvement projects displayed improvements in soil physicochemical properties with age.

- After 40 years, the study locations display the ability to sustain the soil physical substrate needed to support the growth of robust rooted vegetation communities and as a result are performing ecological functions and associated engineering benefits within each target habitat type.
- Soil characteristics have trended toward reference conditions over time, despite the persistence of differences in some parameters at a subset of study locations.
- Findings suggest that while some soil and biogeochemical processes (such as denitrification) are likely rapidly initiated following project implementation, other processes (such as recalcitrant carbon accumulation) occur at much longer time intervals.
- The soils assessment further supports the conclusion that the projects successfully obtained the target habitat types, although the sites remain on trajectories that do not directly mimic unaltered reference conditions.
- The success of the dredged material beneficial use sites highlights the need to focus restoration objectives and milestones on (1) developing highly functional projects that maximize ecological functions and engineering benefits, and that (2) practitioners should avoid placing too much emphasis on mimicking reference conditions with respect to soil parameters.

Ecological function and engineering benefits

- This analysis links observed ecological functions with engineering benefits to communicate project outcomes to a variety of stakeholders.
- Results promote project design, construction, and management based on anticipated ecological functional trajectories that can be translated into predictive engineering benefit curves. Practitioners can use these curves to estimate the relative effect of a design feature, management action, or alternatives analysis on ecological functions and associated engineering benefits.
- The variety of ecological functions and engineering benefits identified occur at magnitudes and timescales that vary regionally and across different landscape settings.
- This study provides tools to further incorporate engineering benefits into dredged material beneficial use project life-cycle analysis.
- This research can also be expanded to better monetize and operationalize beneficial use initiatives within an ecosystem functions and engineering benefits context.

Opportunities for additional research

- The habitat improvement projects represent unique opportunities to conduct manipulation studies because of the availability of existing historical data and the analysis reported herein. In many instances, beneficial use studies and management activities are conducted at relatively new project areas that have not undergone significant ecological succession or have limited information regarding project trajectory. As a result, the habitat improvement areas, which have been self-sustaining for decades, can continue to inform beneficial use practices moving forward.
- Because these study locations represent some of the oldest dredged material beneficial projects in the United States, they have the capacity to play a valuable role in the development of restoration chronosequences if they can be placed in a context with more recent beneficial use sites in their respective regions. The availability of mature study sites is often a major limitation of chronosequence studies, and the projects investigated herein can play a valuable role for conducting retrospective studies when they can be combined with more recent beneficial use projects.
- There is a growing interest in improving project life-cycle analysis from a number of standpoints. The availability of these habitat improvement projects provides an outstanding opportunity to consider the annualized benefits and services provided within each project area. This analysis may include determinations of annual habitat units or valuation of ecological functions and engineering benefits related to water-quality improvements, navigation channel maintenance, or other factors. These historic beneficial use projects represent an asset for practitioners seeking to incorporate long-term perspectives into the determination of project costs, benefits, and sustainability.

1 Introduction

1.1 Background

The US Army Corps of Engineers (USACE) and cooperating agencies constructed multiple habitat improvement projects using dredged material from 1974 to 1978 (Landin et al. 1989). The projects were monitored intermittently until 1987 to document the benefits of using dredged materials to improve environmental outcomes while supporting objectives of the navigation program (for example, dredged material management, reduction of erosion and channel infilling)—representing some of the first research investigating dredged material beneficial use applications in an environmental context. Early monitoring results suggested the projects improved habitat and demonstrated the utility of incorporating the beneficial use of dredged materials into federal navigation, sediment management, and ecosystem restoration-creation programs.

Subsequent research began at dozens of other dredged material placement locations over the last four decades, providing valuable contributions to our understanding of the interplay between habitat restoration and creation, engineering design, and environmental outcomes (Edwards and Proffitt 2003). For example, Faulkner and Poach (1996) assessed the functional capacity of created and natural wetlands and highlighted similarities and differences between natural and built environments; Mallach and Leberg (1999) evaluated avian community use at natural islands and those created using dredged material composed of varying substrates, identifying variables that affected faunal community composition and density; and Yozzo et al. (2004) reported edged materials successfully supported a variety of habitat creation and restoration objectives including construction of artificial reefs, oyster reef restoration, intertidal wetland and mudflat creation, and the development of bird and wildlife islands as part of a regional sediment management strategy.

Approaches to dredged material management continue to evolve in response to this growing body of literature. Recent efforts focused on the capacity of natural processes to improve ecological endpoints while accomplishing engineering objectives and reducing project costs within a dredged materials management context. The newest phase of ecosystem and dredged material management is encapsulated by the Engineering

with Nature (EWN) initiative, an intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes (https://ewn.el.erdc.dren.mil/). The beneficial use of dredged material is consistent with EWN, which is enabling more sustainable delivery of economic, social, and environmental benefits associated with water resources infrastructure (Bridges et al. 2014, King et al. 2020).

The EWN concepts addressed through the current project include (1) the use of science and engineering to produce operational efficiencies supporting sustainable delivery of project benefits and (2) the use of natural processes to maximum benefit, thereby reducing demands on limited resources, minimizing the environmental footprint of projects, and enhancing the quality of project benefits. Additionally, the relative biological contribution constructed habitats provide compared to similar natural habitats is of concern, and more research is required to improve the design and construction of dredged material–supported features in the future.

1.2 Objective

Previously completed studies demonstrate that the use of dredged materials for habitat restoration and creation supports some of the ecosystem functions observed in natural systems, although the magnitude and trajectory of functions may differ (Faulkner and Poach 1996). Additionally, project designs incorporating engineering elements mimicking natural processes begin to display ecosystem characteristics similar to natural systems to a greater extent than landscape features created using traditional techniques (Streever 2000; Berkowitz et al. 2017).

Following the early work conducted prior to the 1970s, the implementation of dredged material beneficial use projects continued to expand through the 1980s and 1990s, and the practice of evaluating beneficial use alternatives is now commonly incorporated into the nation's navigation programs, regional sediment management plans, and agency regulations and guidelines. For example, an analysis of small-draft dredging projects conducted by USACE–Baltimore District demonstrates the growth and expansion of beneficial use projects over time (Figure 1-1; Berkowitz and Szimanski 2020).

However, the long-term trajectory of many habitat restoration-creation projects remains unclear. The observed uncertainties result from the

limited period (several decades) dredged material management designed for ecosystem improvements has been implemented, representing much shorter time frames than reflected in natural systems, where ecological succession occurs over long periods (centuries to millennia) (Coleman et al. 1998). In other words, the lack of constructed projects >50 years old precludes the collection and analysis of data from "mature" beneficial use study locations. Additionally, few studies track the trajectory of habitat restoration-creation sites for extended periods, with most monitoring efforts occurring over short durations (often <2–5 years), which D'Avanzo (1989) and others recognize is not sufficient for documenting the long-term benefits and outcomes of restoration-creation projects. The paucity of information reflecting the long-term ecological conditions at historic dredged material development sites represents a significant knowledge gap, limiting the ability to account for project benefits over decadal timescales and develop data-driven trajectory curves used to develop ecological success criteria and project milestones. This paucity also represents an ecological trajectory gap that persists between documenting conditions at recently constructed habitat improvement projects and projecting those conditions across project life spans (Figure 1-2). In response, a research effort evaluated conditions at six of the oldest dredged material–supported habitat improvement projects to analyze the long-term ecological trajectory of engineered systems and compare them with their natural counterparts.

Figure 1-1. Temporal distribution of shallow draft dredging and beneficial use projects conducted by US Army Corps of Engineers (USACE)–Baltimore District. Note, the abundance and relative proportion of beneficial use projects being implemented increased each decade since the 1980s, including >60% of all shallow-draft dredging projects implemented after 2010 (Berkowitz and Szimanski 2020). (BU: beneficial use).

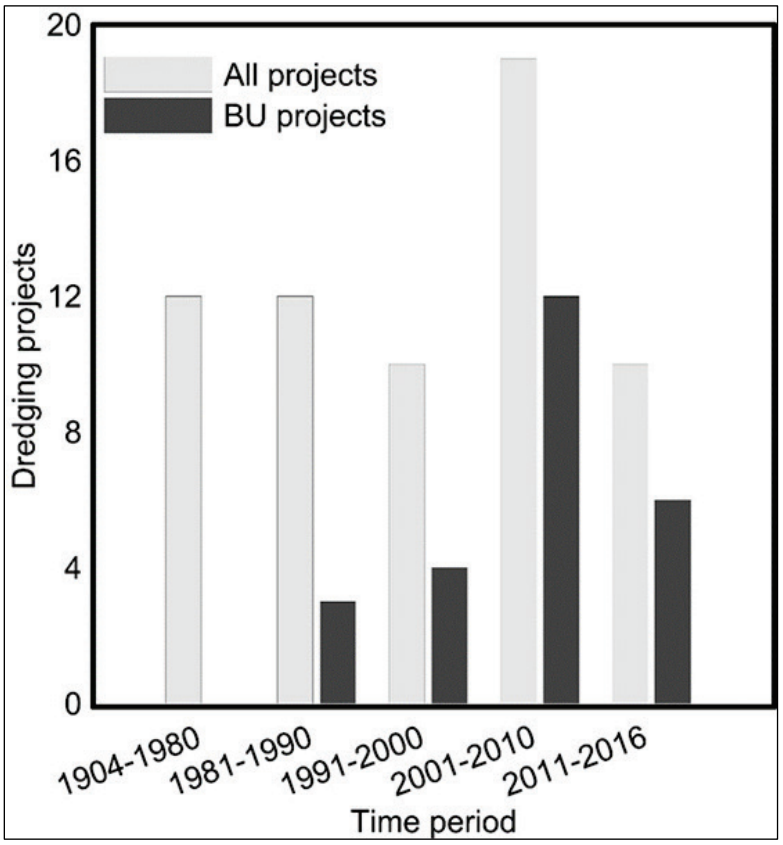
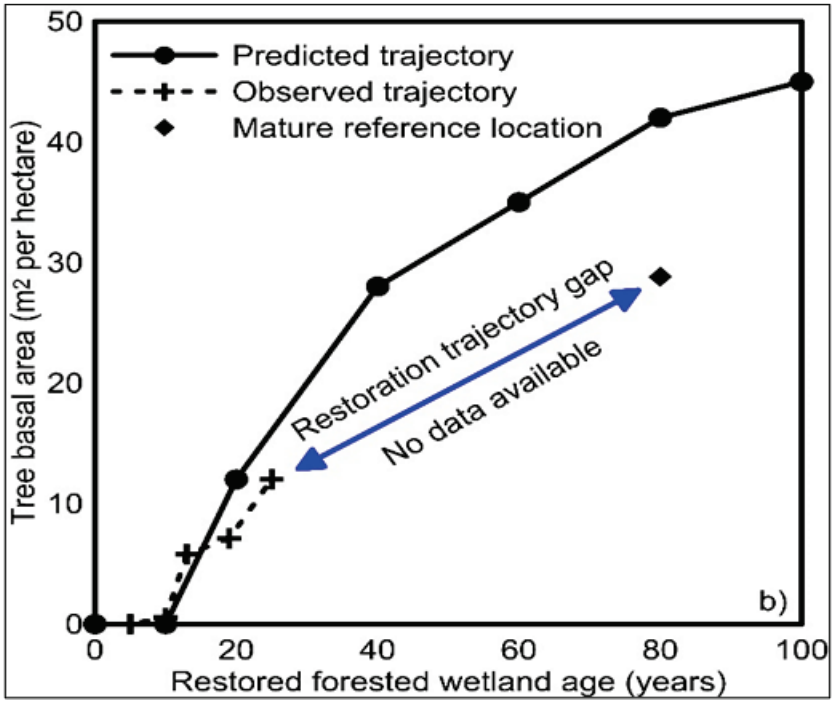


Figure 1-2. Example of a restoration trajectory curve evaluating tree basal area responses following construction of habitat improvement projects. The figure highlights the knowledge gap and ecological trajectory gaps between conditions documented at natural reference areas (♦), observation at established habitat improvement projects (+), and estimated conditions under postconstruction scenarios (●). (Berkowitz and Szimanski 2020).

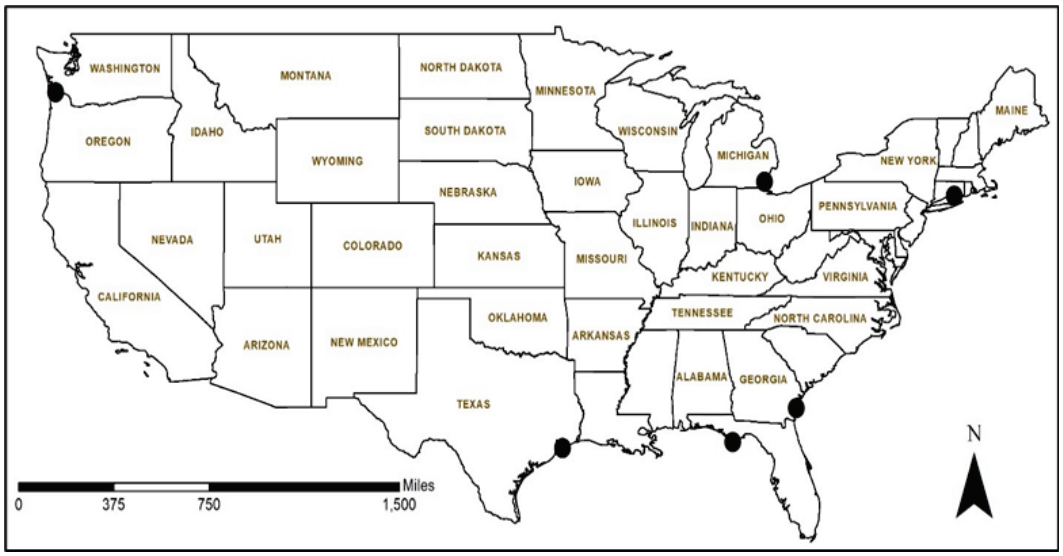


1.3 Approach

During the summer of 2019, scientists from the US Army Engineer Research and Development Center (ERDC) revisited six historic habitat improvement projects constructed using dredged materials to evaluate and document the long-term trajectory of the projects and compare project outcomes with natural, reference conditions. The six locations were Bolivar Peninsula, Texas; Apalachicola Bay, Florida; Buttermilk Sound, Georgia; Pointe Mouillee, Michigan; Nott Island, Connecticut; and Miller Sands, Oregon (Figure 1-3). Where available, data from reference locations in the vicinity of the habitat improvement projects were also collected and evaluated. The research effort sought to determine the level of success in the habitat development efforts by comparing initial conditions after construction reported by Landin, Webb, and Knutson (1989) to the conditions observed in 2019. This research allows for long-term metrics of project success to be determined, supports establishment of project milestones and trajectories using observed data, and documents the long-term project benefits of each habitat improvement location. This

research will also support current and future efforts aimed at developing wetland and upland habitat using dredged material that can improve environmental outcomes while maximizing navigation benefits and minimizing costs. The results provide valuable data to fill the ecological trajectory gap between recently restored systems and their natural counterparts, thus providing a framework to develop restoration trajectory curves allowing for extrapolation of EWN benefits throughout a project's life span.

Figure 1-3. The six USACE habitat improvement projects evaluated included Bolivar Peninsula, Texas; Drake Wilson Island, Florida; Buttermilk Sound, Georgia; Nott Island, Connecticut; Pointe Mouillee, Michigan; and Miller Sands, Oregon.



2 Historical Investigations of Habitat Improvement Projects

2.1 Overview

Construction of the six habitat improvement projects occurred between 1974 and 1978. Initial construction efforts were supported by the USACE Dredged Material Research Program. A monitoring program was initiated in 1974 under the Dredging Operation Technical Support (DOTS) Program to document the stability and successional changes of the habitat improvement sites and relate the observed conditions at the project sites to natural, reference systems (Newling and Landin 1985). The monitoring program concluded in 1982 at several locations, with additional data collection continuing until 1987 at some locations. The following section provides a general overview of each habitat improvement project and outlines the construction and initial monitoring results available for each study location. Subsequent sections describe the results of the 2019 data collection effort and compare results to both (1) the early (1974–1982) study data and (2) conditions observed at reference systems.

2.2 Bolivar Peninsula

Located 16 km east of Galveston, Texas, the Bolivar Peninsula (also known as Goat Island) is immediately adjacent to the Gulf Intercostal Waterway near the entrance to the Houston ship channel, one of the busiest navigation channels in the world. The Bolivar Peninsula location was selected for development of a habitat improvement project because it exhibited representative conditions observed at many of the dredged material placement sites along the portion of coastal Texas and the Gulf of Mexico (Allen et al. 1978; Figure 2-1). In 1976, a 11.1 ha area of dredged materials previously deposited on the peninsula were contoured using construction equipment to create an elevation gradient capable of supporting the establishment of upland, high marsh and low marsh and intertidal habitats oriented perpendicular to Galveston Bay. A temporary sandbag dike was constructed to protect the dredged material placed into a lower intertidal marsh environment from the erosive forces of waves and encourage stabilization and consolidation of the dredged materials (Newling and Landin 1985). Experimental vegetation plantings were established in 1976 and 1977 in both wetland and upland areas using different fertilizer treatment and planting methods. A reference marsh,

Pepper Grove, was identified just east of the study site in 1978 that had similar wind and wave characteristics as the habitat improvement project location (Landin, Webb, and Knutson 1989).

The marsh ecosystems were planted with alternating rows of smooth cordgrass (*Spartina alterniflora*) and salt-meadow cordgrass (*S. patens*). A variety of species were planted in the upland area according to differences in elevation, with grasses planted in rows along the lowest elevations in the upland area, followed by shrubs in the intermediate elevations, and trees at the highest elevations (Allen et al. 1978). Planted grasses included coastal Bermuda grass (*Cynodon dactylon var. alecia*), bitter panic (*Panicum amarum*), and bluestem (*Andropogan perangustatus*). Shubs included wax myrtle (*Myrica cerifera*), Gulf croton (*Croton punctatus*), and winged sumac (*Rhus copallina*). Planted trees included sand pine (*Pinus clausa*), live oak (*Quercus virginiana*), and salt cedar (*Tamarix gallica*).

Postconstruction monitoring within the habitat improvement area documented six distinct plant communities, distributed across elevation zones dominated by bluestem grass, salt-meadow grass, seashore dropseed (*Sporobolus virginicus*), Drummond sesbania (*Sesbania drummondii*) and mixed grasses, lemon beebalm (*Monarda citriodora*), and smooth cordgrass (Newling and Landin 1985; Dodd et al. 1978). In the experimental planning areas smooth cordgrass (lower intertidal elevations) and salt-meadow cordgrass (all intertidal elevations) were successfully established. In the upland zone, survival over a 15-month period ranged from 5.4% for bluestem grass to 96.5% for live oak (Landin, Webb, and Knutson 1989, 128).

Differences in elevation were identified as important during the study, with robust smooth cordgrass (average height ≥1.0 m) occurring at the intertidal edge of the marsh and decreasing in height at higher elevations through the transition to the high-marsh plant communities (Landin, Webb, and Knutson 1989). From lowest to highest elevation zones, the following species were encountered by order of appearance: smooth cordgrass (*Spartina alterniflora*), salt-meadow cordgrass (*S. patens*), salt grass (*Distichlis spicata*), perennial glasswort (*Salicornia virginica*), fimbristylis (*Fimbristylis spadicea*), groundsel tree (*Baccharis halimifolia*), marsh fleabane (*Senecio congestus*), seaside goldenrod (*Solidago sempervirens*), American three-square (*Schoenoplectus*

americanus), salt-marsh aster (*Aster tenuifolius*), plantain (*Plantago* spp.), fire wheel (*Gaillardia pulchella*), common ragweed (*Ambrosia artemisiifolia*), aster, camphorweed (*Heterotheca subaxillaris*), soft camphorweed (*Chrysopsis pilosa*), Drummond sesbania (*Sesbania drummondii*), fleabane (*Erigeron*), broom sedge (*Andropogon virginicus*), bushy beard grass (*A. glomeratus*), and beach-tea (*Croton punctatus*) (Newling and Landing 1985; Landin, Webb, and Knutson 1989, 133). The development and vigor of the plant community at the marsh improved after initial planting in 1976, with observations made in 1980 reporting that smooth cordgrass had spread throughout and dominated the tidal marsh zone (Newling and Landin 1985, 4–5).

Preliminary analysis indicated plant growth and production using stem height and aboveground biomass equaled or exceeded the Pepper Grove reference area; however, root biomass remained lower than observed in the unaltered natural marsh (Newling and Landin 1985, 5). In the upland areas, invasions by other plants were reported, including several hydrophytic species (for example, salt-meadow cordgrass, seashore dropseed, and American three-square) (Newling and Landin 1985, 5).

General findings of the early monitoring efforts indicated smooth cordgrass and salt-meadow cordgrass can be established on dredged materials, but elevation gradients strongly influenced survival and vigor of the species and should be considered during project design and implementation. The establishment of vegetation in the upland areas was only partially successful, with coastal Bermuda grass, bitter panic grass, live oak, winged sumac, and wax myrtle responding well to initial planting efforts. However, plant invasion by some opportunistic and undesirable species was observed, resulting in the recommendations that weed control efforts be incorporated into future restoration designs to support the establishment of target plant communities.

This project adheres to the principles and objectives of EWN because it mimicked natural elevation gradients to establish a variety of habitats and target vegetation community types using observations made at natural, unaltered locations in the region. Additionally, the project avoided the inclusion of hardened engineering features (for example, riprap) and, following initial construction, allowed for natural tidal processes to drive the evolution of the project area.

Figure 2-1. The Bolivar Peninsula habitat improvement site (star) and Pepper Grove reference site (circle) located in Galveston Bay, Texas (inset star).



2.3 Drake Wilson Island

Drake Wilson Island is one of two islands developed using sandy dredged material derived from the adjacent Two-Mile Channel, a navigation route used to access the city of Apalachicola Florida, the Gulf Intercostal Waterway, Apalachicola Bay, and the Gulf of Mexico. The navigation channel is used by the local commercial fishery fleet, recreation boaters, and those transporting materials through northeast Florida waterways. In early 1976, the habitat improvement project site (5 ha) on Drake Wilson Island sought to develop an emergent wetland marsh by placing hydraulically pumped dredged material in a saline intertidal environment (Newling and Landin 1985; Figure 2-2). The habitat improvement location was selected because it typifies the northeast Gulf Coast intertidal islands in the region, which often exhibit shallow bays fringed with emergent

saline intertidal wetlands. Prior to dredged material placement, a dike and weir were installed on the western side of the adjacent navigation channel to prevent erosion until consolidation occurred, allow intertidal exchange, and protect the newly established marsh vegetation. During construction, fine-grained, silty dredged material was pumped into the habitat improvement site, covering older course-grained, sandy dredged material deposited during previous dredging operations.

Following site preparation and dredged material placement, transplants of smooth cordgrass and salt-meadow cordgrass were installed in June 1976 at various spacings, using transplants from nearby St. Vincent's Island. By 1977, all smooth cordgrass plots with 0.9 m[1] or less spacing had already reached 100% vegetation cover (Landin, Webb, and Knutson 1989, 117). However, transplants installed at 1.8 m and 2.7 m spacings did poorly (Landin, Webb, and Knutson 1989, 117). Salt-meadow cordgrass plots achieved approximately 75% cover using 0.3 m and 0.6 m spacings within one year (September 1977) and achieved 100% cover by September 1978, (117). Both species planted completely covered test plots at 0.9 m spacing or less within two growing seasons (117).

Landin, Webb, and Knutson (1989) reported that by 1982 the site was almost totally covered with a stand of smooth cordgrass with only one small open-water pond located at the dredged material dispersal outlet pipe (118). Researchers noted the weir had stopped functioning, but two breaches in the remaining dike had developed to provide intertidal flow (5).

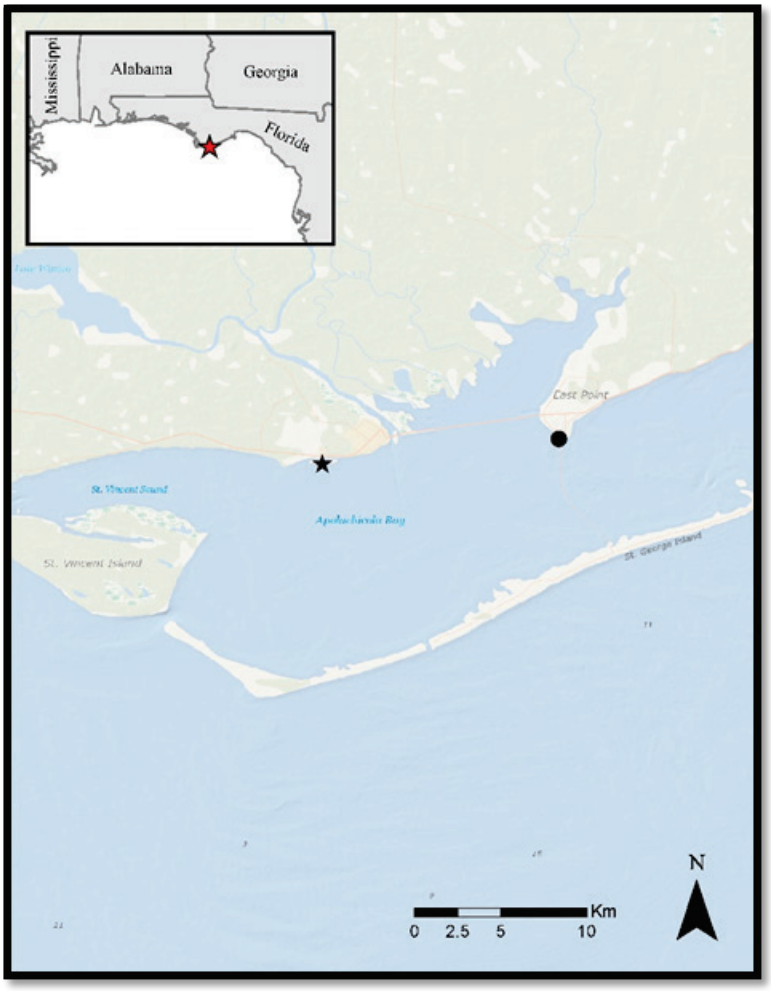
The upland sites on the island were planted with trees and grasses, and the entire complex was vegetated and heavily used by wildlife in 1986, 10 years after project construction (Landin, Webb, and Knutson 1989, 5). A floristic survey of Drake Wilson Island was made during three sampling periods (that is, December 1976, April 1977, and September 1977) to document natural plant species recruitment and succession. A total of 42 species were documented on the island, including 17 species within the wetland area (Kruczynski, Huffman, and Vincent 1978; Newling and Landin 1985).

1. For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

A reference marsh, Cat Point, was located east of the study site (Figure 2-2). While not located on a barrier island, Cat Point served as a nearby wetland reference area to assess vegetation and site characteristics of a naturally evolved, south-facing coastal marsh ecosystem in close proximity to the habitat development site at Drake Wilson Island (Landin, Webb, and Knutson 1989).

This project adheres to the principles and objectives of EWN because it used fine-grained sediments characteristic of natural marshes within the region, encouraged natural patterns of marsh inundation using the weir during the initial postconstruction phase, and allowed natural processes to degrade the weir and dike needed for initial stabilization, ensuring tidal exchange would continue. Plantings used locally sourced materials selected according to appropriate landscape positions and salinity and inundation tolerances to establish a variety of habitats and target vegetation community types based upon observations made at natural, unaltered locations in the region. Additionally, the project avoided the inclusion of hardened engineering features (for example, riprap) and, following initial construction, let natural tidal processes drive the evolution of the project area.

Figure 2-2. The Drake Wilson Island habitat improvement (star) and Cat Point reference site (circle) located in the Apalachicola Bay, Florida (inset star).



2.4 Buttermilk Sound

The Buttermilk Sound habitat improvement project (2.1 ha) was located adjacent to the Atlantic Intracoastal Waterway near the mouth of the Altamaha River, Georgia (Figure 2-3). The area is used by the local fishing community, those transporting goods along the intercostal waterway, and those accessing the barrier islands and open ocean from the nearby cities of Brunswick and Darien, Georgia.

The habitat improvement project site was selected because it was representative of a South Atlantic sandy disposal site in a salt marsh. The areas surrounding the habitat improvement project were very dense intertidal salt marshes interspersed with higher-elevation islands of sand deposited during past dredging operations and old rice plantation dikes

(Landin, Webb, and Knutson 1989, 101). The objectives for this study were to

> (1) restore the sand mound to an intertidal marsh habitat; (2) document changes in the field site over time; (3) demonstrate that a stable marsh could be created using dredged material in the South Atlantic region; and (4) test various marsh plant species to determine which propagules, fertilizer treatments, and planting densities were more conducive to optimum marsh establishment in sandy soil. (101)

A nearby reference marsh location, Hardhead Island, was selected to assess vegetation and site characteristics of a naturally evolved wetland ecosystem in close proximity to the habitat development site at Buttermilk Sound.

The unaltered salt marshes in the area are flooded twice daily by a ~2 m tide, and the marshes are bisected by small meandering tidal creeks that migrate over time (Newling and Landin 1985, 36, citing Cole 1978, Landin, Webb, and Knutson 1989). The most common dominant species in lower tidal marshes were smooth cordgrass (*Spartina alterniflora*) and at slightly higher elevations rough cordgrass (*S. cynosuroides*) or southern wild rice (*Zizaniopsis miliacea*). Areas inundated periodically by spring tides, storm tides, and high river discharge support brackish-water marsh plants such as arrow arum (*Peltandra virginica*), pickerelweed (*Pontederia cordata*), cattail (*Typha domingensis*), and wild rice (*Z. aquatica*). On sandy soils of lower salinity in the tidal marsh, the most common plants were black needlerush (*Juncus roemerianus*) and salt-marsh oxeye (*Borrichia frutescens*), with the transition between marsh and high tide dominated by salt grass (*D. spicata*), salt-meadow cordgrass (*S. patens*), and marsh elder (*Iva frutescens*) (Cole 1978, 6).

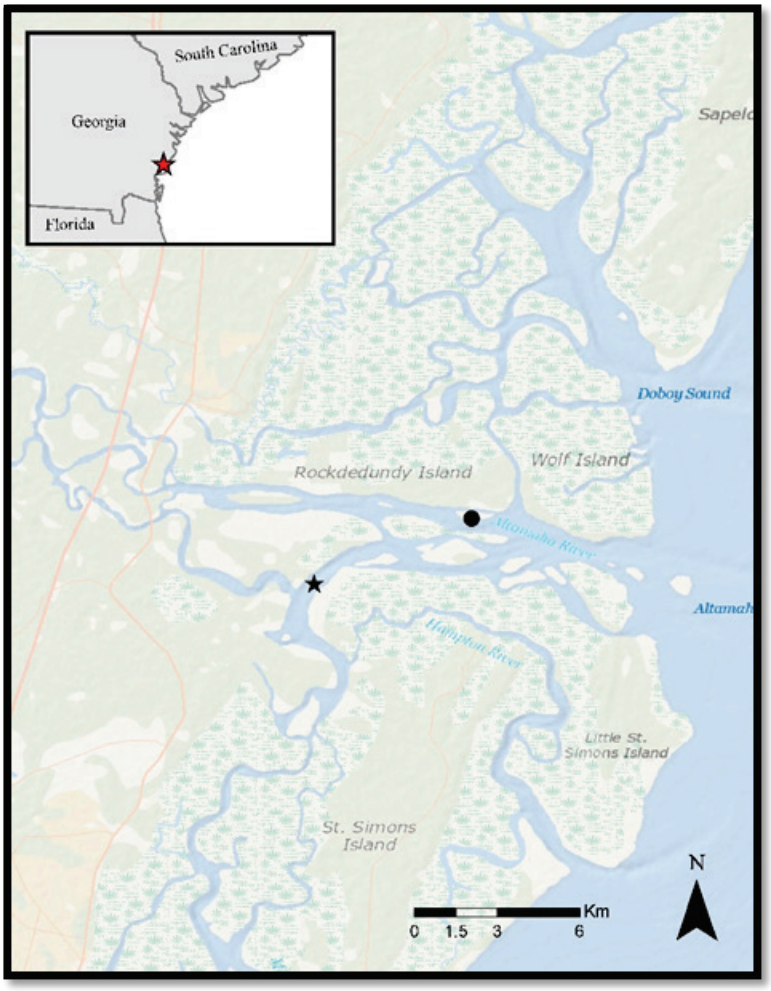
Prior to development of the habitat improvement project, the location was used as a dredged material placement area, where a large mound of dredged material was deposited to an elevation approximately 5 m above the mean low tide level over a 7–10 year period (Reimold et al. 1978). The sandy, dredged material mound remained unvegetated until implementation of the habitat improvement project, which sought to re-establish the natural contour of the area, intertidal exchange, and wetland vegetation similar to the surrounding marshes common throughout the region (Landin, Webb, and Knutson 1989).

During construction of the habitat improvement project in 1975, the area was graded to a 3.7% slope and partitioned into three elevation zones according to estimated tidal inundation intervals (that is, <6 hours per day, 6–18 hours per day, >18 hours per day). Each elevation zone was planted with seven marsh plant species using various species combinations and fertilizer application rates, followed by subsequent monitoring.

The seven species planted at the habitat improvement site were sea oxeye (*B. frutescens*), salt grass (*D. spicata*), marsh elder (*I. angustifolia*), black needlerush (*J. roemerianus*), smooth cordgrass (*S. alterniflora*), big cordgrass (*S. cynosuroides*), and salt-meadow cordgrass (*S. patens*), with additional plantings of smooth cordgrass performed in May 1976 (Landin, Webb, and Knutson 1989, 103). The project established 80 test plots with all plant materials, including seeds, collected from nearby marshes (103). By 1982, little evidence of the test plots planted in 1975 remained (108). The lowest elevation zone was mostly an unvegetated mud flat, and the upper two zones were nearly indistinguishable from the reference marsh in terms of plant composition and density. Nonplanted plant species recruitment was also documented over time, and aquatic and wildlife species surveys were performed in the vicinity of the habitat improvement project.

This project adheres to the principles and objectives of EWN because it re-established the environmental gradient of elevation, inundation, and salinity observed in unaltered areas in the region. Also, the project allowed for natural processes (for example, tidal creek evolution and migration) to occur while avoiding the use of hardened engineering features (for example, riprap).

Figure 2-3. The Buttermilk Sound habitat improvement site (star) and Hardhead Island reference site (circle) located in the Altahama River, Georgia (inset star).



2.5 Nott Island

The Nott Island habitat project site is located on the Connecticut River, one of the state's most vital waterways servicing recreational harbors and commercial waterfronts in the communities of Old Saybrook, Old Lyme, Essex, Lyme, Deep River, Chester, East Haddam, Haddam, East Hampton, Middletown, Portland, Cromwell, Rocky Hill, Glastonbury, Wethersfield, East Hartford, and Hartford. The habitat restoration site was developed in 1974 on a 31 ha natural island situated near Old Lyme, Connecticut (Landin, Webb, and Knutson 1989; Figure 2-4). The project site occupied 3.2 ha of upland habitat on Nott Island.

Nott Island had historically been used a dredged material placement area during periodic channel maintenance activities, resulting in development

of a large unvegetated mound of sand covering the northern portion of the island. The location was selected for habitat improvement because it reflected conditions at many islands in the northeastern United States where past navigation channel maintenance dredging deposited sandy materials on top of natural upland and wetland landforms. The sandy dredged material deposits were considered low-quality habitat, and limited vegetation established on the sites, potentially because of nutrient limitations, the course soil texture, and the steep grades associated with the sand mounds. In response, the Nott Island habitat improvement project sought to incorporate a mixture of fine-grained dredged materials into the existing sandy substrate, grade the site, and initiate vegetation establishment. The long-term objectives of the project were to (1) document the conversion of a previously unvegetated sandy disposal area into useful upland habitat and (2) monitor ecological succession over time to determine degree of success of the habitat development effort (Landin, Webb, and Knutson 1989, 79).

During construction the dredged material sand mound was first graded, then temporary dikes were built to create a containment area for the deposition of finer-grained materials. The diked area was filled with 14,520 m^3 of sandy silts dredged from the navigation channel (Landin, Webb, and Knutson 1989, 77). Once dewatering had occurred, the sand and sandy silt substrates were homogenized using construction equipment and farming implements (for example, disking). Follow mixing, the site was treated with lime and fertilizer. Vegetation was planted with the goal to create a nesting and feeding meadow for mallards, Canada geese, and other waterfowl (Landin, Webb, and Knutson 1989). The vegetation at the Nott Island project was monitored from 1979–1986, using transects and general observations of plant community changes (Landin, Webb, and Knutson 1989). A nearby natural island, Eustasia Island, which also displayed unvegetated areas of sandy deposits, was selected as a reference monitoring site because of its similar geomorphology, substrate, and proximal location 8.5 km north of Nott Island.

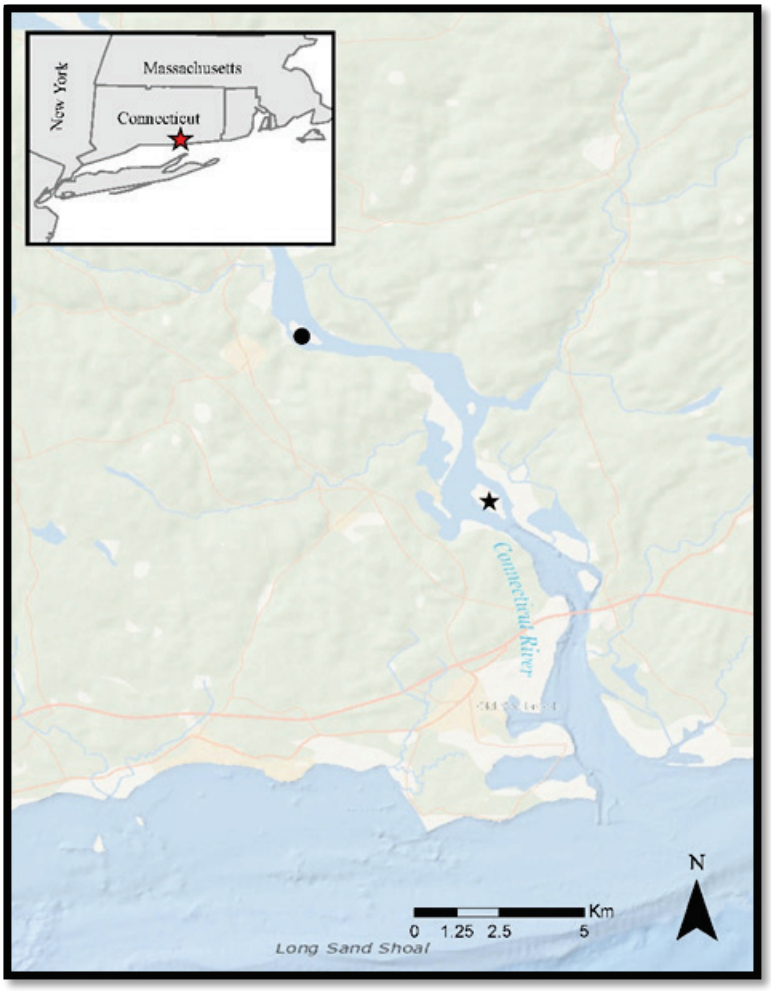
The majority of the Nott Island habitat improvement area was planted with tall fescue (*Schedonorus arundinaceus*) and white Dutch clover (*Trifolium repens*). Additionally, a seed mixture of tall fescue, orchard grass (*Dactylis glomerata*), timothy (*Phleum*), perennial ryegrass (*Lolium perenne*), native red clover (*Trifolium pratense*), and white Dutch clover was applied in a subset of areas (Landin, Webb, and Knutson 1989, 77,

citing Hunt et al. 1978). In general, the grasses were successfully established, while the legumes responded less favorably. For example, grass species occupied approximately 80% of the planted area within the first growing season, while the two legume species occupied less than 20% cover. By 1978, tall fescue had become the dominant species across the entire project area, with orchard grass and timothy present as minor components and trace amounts of white Dutch clover observed in some areas (Landin, Webb, and Knutson 1989, 79).

Overall, monitoring data indicated there was little change to the vegetation community over the eight-year monitoring period. The habitat improvement area remained a grassy meadow, in line with the target ecosystem outlined in the project design. The meadow was slowly evolving to resemble the vegetation communities observed in abandoned fields and fallow pasture lands common throughout New England. The most robust vegetation growth was documented in areas where higher percentages of silt had been mixed with the historic sandy dredged material deposits, suggesting substrate amendments may facilitate habitat improvements at other project locations (Newling and Landin 1985). Results also highlighted the need for pH adjustments to support plant growth and reproduction, promoting the success of habitat development objectives at upland habitat improvement sites in the region (Landin, Webb, and Knutson 1989). Concurrently, the sandy areas at Eustasia Island naturally revegetated, with species associated with wet meadow communities becoming established. The observed divergence in plant community succession at the two study sites was attributed to differing water regime, with the lower-elevation Eustasia Island exhibiting higher water tables than the upland conditions present at Nott Island.

This project adheres to the principles and objectives of EWN because it incorporated finer-grained sediments into the sandy dredged material deposits to mimic soil textures found in unaltered habitats within the region, encouraged the establishment of plant communities of high habitat value, and allowed natural patterns of plant species succession to occur following initial construction efforts. Additionally, the project avoided the inclusion of hardened engineering features and attempted to diversify the variety of habitat types found within the project area.

Figure 2-4. The Nott Island habitat improvement site (star) and Eustasia Island reference site (circle) located in the Connecticut River, Connecticut (inset star).



2.6 Pointe Mouillee

The Pointe Mouillee habitat improvement project is located on the western shore of Lake Erie, Michigan, and is part of the Pointe Mouillee State Game area owned by the State of Michigan Department of Natural Resources. The area played a key role in the development of the greater Detroit region because of the presence of an expansive coastal marsh and protective barrier beach complex heavily utilized for wildlife hunting by early settlers (Landin, Webb, and Knutson 1989). The State of Michigan purchased 567 ha of land in 1945 that included the marsh and the barrier beach protecting the marsh from Lake Erie's wind- and wave-driven erosion. However, the barrier beach was destroyed in the 1960s by a series of high-energy storm events occurring during a period of high lake levels. Following degradation of the barrier beach, wind and wave action induced

extensive erosion within the marsh. Concurrently, sediments from the Huron River historically supporting and nourishing the Pointe Mouillee marshes were reduced by the construction of dams and reservoirs, which prevented sediment transport and deposition. The loss of the protective barrier beach and sediment sources resulted in marsh degradation, including the inundation of >1,618 ha of marshes and game areas and conversion of much of the marsh complex to open water (Landin, Webb, and Knutson 1989).

In response, 148 ha were diked in 1963 to allow for development of water-level control structures using pumps and dewatering procedures to manage the remaining marsh habitats. In 1967, USACE initiated a two-year pilot project investigating alternative methods to manage dredged material owing to increased water-quality and other environmental concerns related to open-water dredged material discharges into the Great Lakes. In 1970, Congress authorized the development of a confined disposal facility (CDF) at Pointe Mouillee, which was constructed beginning in 1976 to hold dredged materials removed from the Lake Erie Ship Channel. The CDF was strategically situated and designed to match the configuration of the historic barrier island in order to protect the remaining marsh from erosion and support revitalization of portions of the degraded marsh. The CDF complex encompassed 277 ha, with a capacity to store 14.1 million m^3 of dredged material, within five cells spanning an area 5.6 km long by 0.4 km wide. Dikes facing the open expanse of Lake Erie are armored with riprap to protect the feature from erosion, and a system of culverts and water-control structures are used to manage water levels within the project area.

The Pointe Mouillee habitat improvement project was selected because it shares a number of similarities with other CDFs in the large Great Lakes region, many of which hold contaminated dredged materials and are used for a combination of ongoing dredged material and natural resource management operations (Figure 2-5). The long-term objectives of the project were to (1) protect and stabilize the wetlands and shoreline in the state game area; (2) re-establish the degraded marsh through sedimentation and plant colonization; (3) establish a multiuse site on both the CDF and the game area that includes a visitor center and multiple recreational activities; and (4) provide opportunities for the deposition of dredged material from western Lake Erie harbors and channels as part of

recurring maintenance dredging operations (Landin, Webb, and Knutson 1989, 45).

Monitoring at Pointe Mouillee was conducted intermittently between 1980 and 1987, incorporating observational surveys of wildlife and vegetation within the CDF and adjacent marsh habitats. Vegetation communities inside the CDF included emergent cattail and bulrush wetlands and a high marsh component dominated by common reed (Landin, Webb, and Knutson 1989, 47). Between 1980 and 1985, the southern portion of the CDF grew into a dense stand of common reed (47), with the higher-elevation zones exhibiting colonization by a mixture of low-growing herbs and grasses such as reed canary grass (*Phalaris arundinacea*), red clover, and small cottonwood (*Populus deltoides*) trees (52). Small ponded areas were fringed by cattails and bulrushes. The middle portion of the CDF contained large ponds surrounded by cattails and bulrushes, with higher-elevation areas colonized with herbs, grasses, and small cottonwood trees. An additional middle CDF compartment maintained as open, deep-water habitat allows barge access to deliver dredged materials throughout the CDF. The northernmost portions of the CDF were being filled with dredged material during the 1981–1987 observation period, resulting in the persistence of shallow, unvegetated ponds and extensive mud flats.

Overall, vegetation data collected from transects and random quadrats indicated plant colonization took place in the two southernmost portions of the CDF within three growing seasons (Landin, Webb, and Knutson 1989, 46). The analysis suggested the availability of wet fringe habitat had a controlling influence of colonization rates, as cattail and bulrush communities quickly occupied newly formed ponds. Common reed rapidly colonized the toe of the dike interiors, with less vigorous growth reported on higher-elevation portions of the CDF where mounding occurred during dredged material placement (for example, near the outlet of the dredged material discharge pipe). No reference monitoring location was selected near the Pointe Mouillee habitat improvement site.

The Pointe Mouillee project adheres to the principles and objectives of EWN because it protected the existing marshes to the west while providing habitat and recreational opportunities and maintaining the capacity to manage dredged materials and navigation channels within the western Lake Erie basin. Unlike the other projects examined in the study, the Pointe Mouillee project did use hard infrastructure, including protected

dikes to stabilize project features and prevent wind and wave erosion from occurring. However, the development of the CDF was needed to replace ecological function (that is, wave and wind attenuation) provided by the eroded barrier beach previously protecting the surrounding marshes.

Figure 2-5. The Pointe Mouillee study site (star) located in western Lake Erie, Michigan (inset star).



2.7 Miller Sands

The Miller Sands habitat development site is located in the Columbia River, 8 km upriver from Astoria, Oregon, and within the Lewis and Clark National Wildlife Refuge (Figure 2-6). The site is a large, horseshoe-shaped dredged material island within the freshwater intertidal reach of the river. The original island was constructed in 1932 and continued to receive additional dredged materials during maintenance operations at approximate four-year intervals (Landin, Webb, and Knutson 1989).

Additionally, dredged materials were deposited at the large sand spit to the north of the main island annually for several years following the eruption of the Mount Saint Helens volcano.

Landin, Webb, and Knutson (1989) reported the vegetation, soils, and faunal (for example, fish and wildlife) characteristics found at Miller Sands were similar to other islands in the vicinity, where upland areas are characterized by sandy soils of low fertility, and the tidal range of the river greatly influenced the distribution, morphology, and persistence of wetland and upland habitats (155). As a result, the Miller Sands habitat improvement site was selected to improve the management of other sandy dredged material deposition locations in the Columbia River Basin and more broadly in the Pacific Northwest region. Long-term objectives for the site were to (1) develop wetland, upland, and dune habitats on the island complex; (2) document the successional changes and success of these efforts over time; and (3) develop and demonstrate techniques and methods for other large-scale dredged material habitat improvement projects in the Pacific Northwest (Figure 2-6) (Landin, Webb, and Knutson 1989, 157).

Three distinct habitats were developed at Miller Sands including (1) upland habitat on the main island, (2) wetland habitat between the sand spit and the main island, and (3) dune habitat on the sand spit designed to protect the adjacent wetlands and other features from wind- and wave-driven erosion (Landin, Webb, and Knutson 1989, 157). In 1974, the upland portion was disked using farming implements and heavy machinery to prepare a seed bed. Additionally, the interior cove of the sand spit was graded to an intertidal elevation to support development of the wetland habitat using construction equipment (157). A nearby marsh habitat, Snag Island, was selected as a reference location for comparison with the wetland habitat improvement project. In 1977, the outer portions of the sand spit were planted with sprigs of European beach grass (*Ammophila arenaria*) interspersed with snow and sand fencing, rapidly inducing the formation of dunes tat persisted throughout the monitoring period circa 1987 (157).

The upland habitat improvement site comprised a large 94.7 ha area (Landin, Webb, and Knutson 1989, 158). The disked, fertilized, and planted area was designed to create a nesting and feeding meadow for waterfowl. Seed mixtures of native red clover (*T. pratense*), white Dutch clover (*T.*

repens), hairy vetch (*Vicia villosa*), barley (*Hordeum vulgare*), tall wheatgrass (*Thinopyrum ponticum*), Oregon bent grass (*Agrostis oregonensis*), reed canary grass (*Phalaris arundinacea*), red fescue (*Festuca rubra*), and tall fescue (*Schedonorus arundinaceus*) were planted in 1976 (158). Test plots with various fertilizers and untreated control plots were also evaluated as part of the upland habitat study. Seven of the initial planted species established rapidly, while red fescue and reed canary grass did not survive (158). All surviving species responded well to fertilization. However, in 1977 an invasion of scouring rush (*Equisetum hyemale*), common velvet grass (*Holcus lanatus*), and rattail fescue (*Vulpia myuros*) was noted. In 1980, the upland meadow was reported as reverting to a dry, infertile, overgrazed (by nutria) upland, and by 1982, scouring rush, cat's ear (*Hypochaeris radicata*), and moss were reclaiming the site (162). Trees and shrubs were also observed encroaching into the meadow.

At the time of project construction, few data were available to guide the establishment of marshes and other wetlands on anthropogenic or engineered landscape features in the Pacific Northwest region. In response, a pilot study identified appropriate vegetation species for subsequent planting efforts. Using the pilot study results, eight species were selected for planning at Miller Sands, including tufted hair grass (*Deschampsia cespitosa*), Lyngbye's sedge (*Carex lyngbyei*), slough sedge (*C. obnupta*), blue flag (*Iris versicolor*), broadleaf arrowhead (*Sagittaria latifolia*), soft rush (*J. effusus*), American three-square (*Schoenoplectus americanus*), and water plantain (*Alisma*) (Landin, Webb, and Knutson 1989). Monotypic and mixed-species plots, as well as fertilizer treatments, were installed and evaluated.

Vegetation transects in the marsh habitat improvement site were evaluated from 1978–1982. Results indicate that after one year the entire planted areas was successfully vegetated. All species were noted to survive; however, tufted hair grass, slough sedge, and Lyngbye's sedge were the most successful with respect to survival, growth, and reproduction. Over time, planted species in higher-elevation portions of the marsh were replaced by invading species and encroachment of the adjacent dunes. At least 55 species were recorded in the wetland transects by 1982; however, many species occupied small areas (that is, <1% aerial cover) (Landin, Webb, and Knutson 1989, 161). The most abundant species remained tufted hair grass, followed by Lyngbye's sedge and slough sedge. Other common species included pointed rush (*J. oxymeris*), beggar-ticks

(*Bidens*), bird's-foot trefoil (*Lotus corniculatus*), water foxtail (*Alopecurus geniculatus*), and yellow monkey flower. Outside of the established transects, alsike clover (*Trifolium hybridum*), common forget-me-not (*Myosotis scorpioides*), English plantain (*Plantago lanceolata*), purple loosestrife (*Lythrum salicaria*), water horehound (*Lycopus*), water parsnip (*Sium suave*), willow (*Salix*), and alder (*Alnus*) were observed during general vegetation surveys of the study location (162).

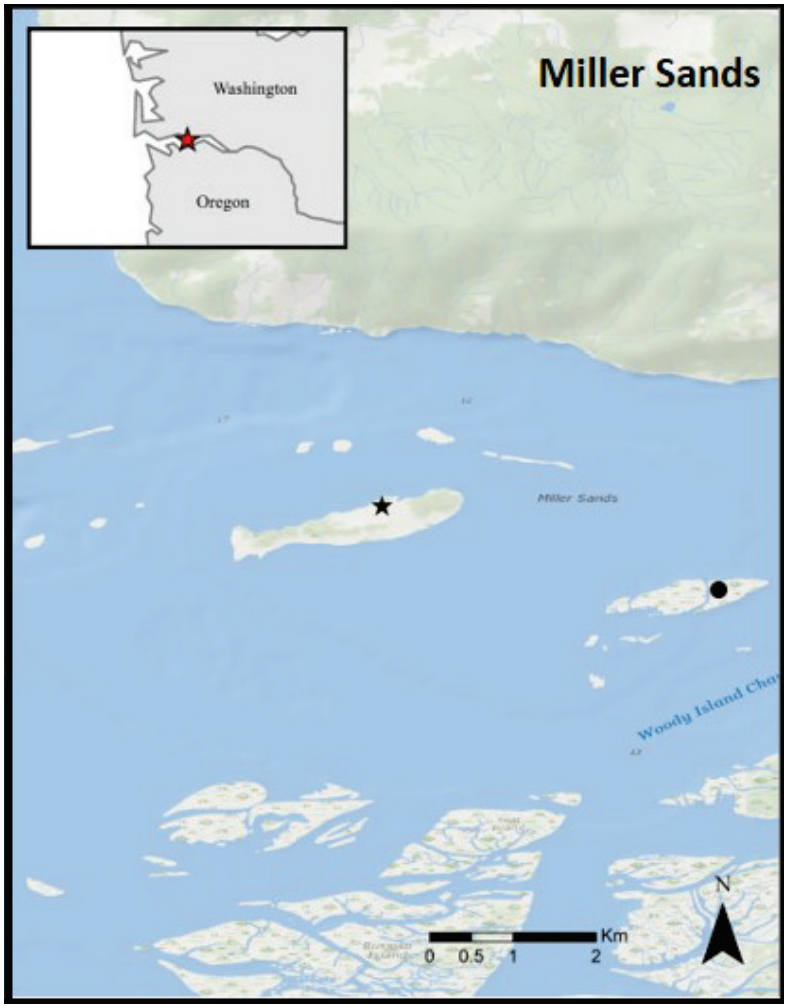
During the monitoring period, the wetland habitat improvement project documented the constructed marsh elevation increased via sediment accumulation. The sediment was derived from both continued dredged material placement and aeolian sand deposition originating from unvegetated portions of the sand spit. The marsh elevation eventually exceeded those observed at the Snag Island reference marsh. Additionally, the upriver chute between the sand spit and the main island deepened and widened over time, and a large portion of the of the constructed wetland was eroded; however, the chute was largely reconstituted in 1988 using maintenance dredged material to stabilize the wetland feature (Landin, Webb, and Knutson 1989, 167).

The Snag Island reference site was characterized by marsh vegetation, with no upland or dune habitat areas available for comparison. While Snag Island was not actively managed, the feature was in part the result of natural accretion on top of previously deposited dredged materials (Newling and Landin 1985). The Miller Sands wetland site generally had less aboveground biomass, root biomass, percent cover, and shorter stem height (overall mean by elevation) than Snag Island during the 1979–1982 monitoring period (Newling and Landin, 91). However, Newling and Landin (1985) suggested the documented trends in vegetation community succession at the Miller Sands habitat improvement site were shifting towards the conditions observed at the Snag Island reference location. The authors further proposed that the wildlife habitat available at Miller Sands was of equal to or greater quality than the habitat available at Snag Island.

This project adheres to the principles and objectives of EWN because it was designed to provide a variety of habitat types (uplands, wetland, sand dune) common in the region according to the gradient of elevations constructed and their associated inundation patterns. Additionally, the project used natural processes (for example, erosion of the sand berm and dunes, sediment accretion in wetlands) to naturally contour and shape the

island postconstruction while providing for the management of dredged materials in the Columbia River navigation channel. Plantings materials were selected according to appropriate landscape positions and inundation tolerances to establish a variety of habitats and target vegetation community types using observations made at natural, unaltered locations in the region. Additionally, the project avoided the inclusion of hardened engineering features (for example, riprap) and, following initial construction, let natural processes drive the ecological evolution of the project area.

Figure 2-6. The Miller Sands habitat improvement site (star) and Snag Island reference site (circle) located in the Columbia River, Oregon (inset star).



3 Assessment of Vegetation Communities at Habitat Improvement Projects

3.1 Overview

The following provides a description of current vegetation community conditions at each habitat improvement project location. Additionally, comparisons are made between current vegetation community metrics at habitat improvement projects and (1) observations made at corresponding reference locations (where available) and (2) historic monitoring data collected between 1975 and 1987.

3.2 Methods

The 2019 assessment effort established triplicate vegetation sample points within representative locations of each plant community observed within the habitat improvement sites and at corresponding reference locations. A 1 m^2 quadrat was used to estimate percent cover by species, and a 1/4 m^2 quadrat was used to calculate stem densities at each vegetation sampling point and the results of the three triplicates were averaged for reporting purposes. In some cases, transects were used to stratify sampling across elevation gradients and associated plant community types (for example, low marsh, high marsh, herbaceous upland, forested upland).

Sample locations and data collection techniques were designed to mirror the historic monitoring efforts to the extent possible. However, the exact locations and sample methodologies applied during previous studies were not available in all cases. For example, Landin et al (1989) provide very limited sample location coordinates, annotated maps, or other metadata. This lack of location information represents a limitation of the retrospective study approach and highlights the need to improve documentation related to ecological monitoring efforts to maximize the capacity to replicate sampling protocols through the establishment of monumented sample locations and other means.

Plant communities were classified according to dominant or diagnostic species assemblages or both. Values for community composition and species abundance reported by previous studies (Allen et al. 1978; Dodd et al. 1988; Newling and Landin 1985) were compared to current data to assess contemporary conditions and development and maintenance of

target ecological outcomes. Genus-level identifications are provided for species that could not be identified to the species level because of timing of the site visits or to account for any ambiguity induced by the use of common-name usage in the previously published monitoring reports.

3.3 Bolivar Peninsula

3.3.1 Current vegetation community characteristics

The Bolivar Peninsula habitat improvement project occupies 48.2 ha and exhibits a diverse assemblage of community types, each strongly associated with elevation, disturbance history, and original planting designs. Smooth cordgrass marsh was one of the primary target communities on the basis of conditions observed at reference wetlands in the region. This community was patchy and only accounted for 2.8 ha, and it appears to have experienced extensive losses from erosion and smothering from applications of additional sediment from ongoing dredged material management activities and natural deposition. The upper margins of the smooth cordgrass marsh community near mean high water shifted to a narrow band (not mapped) of saltwort, pickleweed (*Salicornia* spp.), and sea blite (*Suaeda linearis*). Allen (1978) described this zone as an area of poor survival and growth, likely explained by salinity toxicity. Salt-meadow cordgrass marsh occupied 7.7 ha, commonly occupying areas at higher elevation than smooth cordgrass, and occasionally occupied well-drained convex landscape features. Marsh fimbry (*Fimbristylis castanea*) and three-square bulrush (*Schoenoplectus americanus*) were frequently observed within the salt-meadow cordgrass community. Sturdy bulrush marsh was documented on 0.08 ha within depressions that likely experience high salinity conditions driven by evaporation. This species also frequently occurred in areas dominated by smooth cordgrass.

Shrublands dominated by marsh elder, eastern Baccharis, and sea oxeye daisy (*Borrichia frutescens*) occurred on 9.4 ha. Wolfberry (*Lycium carolinianum*) and wax myrtle (*Morella cerifera*) were commonly observed but rarely as codominants. Grassland dominated by Elliott's bluestem (*Andropogon gyrans*) and bushy bluestem (*A. glomeratus*) occupied 1.0 ha along midslope positions. According to Allen (1978), the grassland community, along with salt-meadow cordgrass, dominated approximately 62% of the site.

Hercules club (*Zanthoxylum clava-herculis*) woodland occupied 4.0 ha on higher portions of the habitat improvement site, with mustang grape (*Vitis mustangensis*) and sweet acacia (*Vachellia farnesiana*) occurring as common components. This woodland community fits the description of Gulf Coast maritime dwarf forest documented only from coastal Louisiana (NVCS 2017). These tree species were not observed by Webb (1978) or Allen (1978). Vinelands dominated by Southern dewberry, poison ivy (*Toxicodendron radicans*), and mustang grape occupied the majority of the study area on 15.5 ha (Figure 3-1). A variety of forbs and short-statured shrubs previously documented at the site (*Ambrosia psilostachya*, *Croton punctatus*, *Gaillardia pulchella*, and *Monarda citriodora*) occurred in this community and occasionally dominated small inclusions. The highest portions of this community along the berm were often codominated by Texas lantana (*Lantana urticoides*), camphor weed (*Heterotheca subaxillaris*), and Texas prickly pear (*Opuntia engelmannii*).

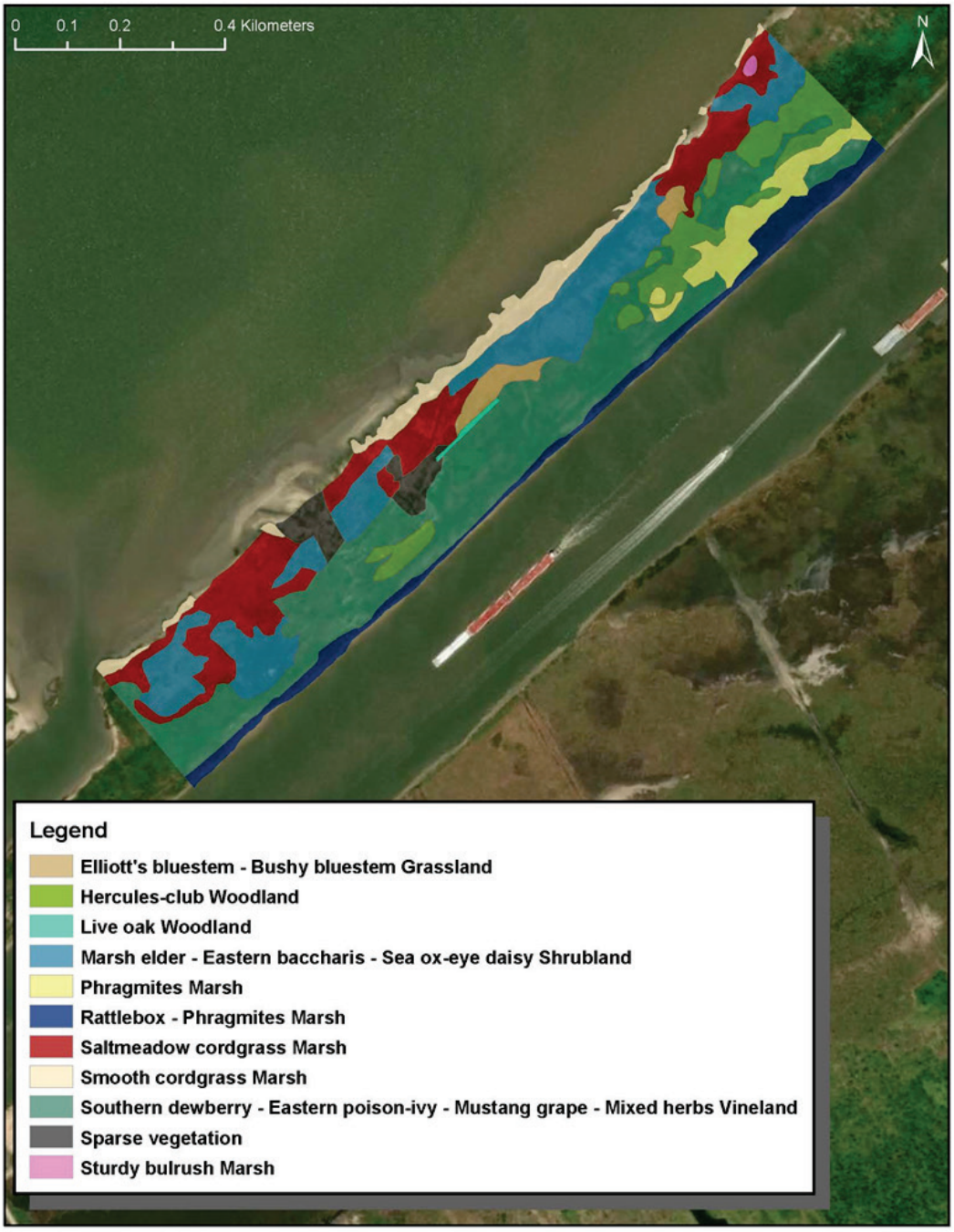
Live oak (*Q. virginiana*) woodland composed of short-statured trees occupied a narrow 0.1 ha remnant from designed plantings. The local landform indicates additional material was placed immediately to the northwest of the trees after planting, forming a slight trough. This species was reported by Allen (1978) as having excellent survival, with an average of 96.5% several years after construction but has since experienced steep population declines.

Phragmites occurred as near monotypic stands on 2.5 ha along the northern portion of the study area. The species community was not recorded by Webb (1978) or Allen (1978), although collections from Galveston County date back to 1884 (SERNEC 2019). Rattlebox (*Sesbania drummondii*) and Phragmites codominated areas along the adjacent shipping channel on approximately 3.6 ha. Rattlebox was described by Webb (1978) as invasive throughout much of the study area, requiring control and removal to allow for establishment of target plant species. It was observed as scattered individuals or small clumps throughout the site, but its dominance along the channel may be derived from frequent disturbance by boat wakes and other anthropogenic activities. All plant communities at the Bolivar Peninsula study site are shown in Figure 3-2.

Figure 3-1. Vineland and shrubland communities at the Bolivar Peninsula study site, Port Bolivar, Texas.



Figure 3-2. Plant community classification of the Bolivar Peninsula study site, Port Bolivar, Texas.



3.3.2 Comparison with reference location

The Pepper Grove reference site occupied approximately 61.4 ha and was dominated exclusively by expansive stands of smooth cordgrass (Figure 3-3 and 3-4). This species is considered dominant in tidal marshes along the Texas Gulf Coast (Tiner 1993). Salt grass occasionally occurred on higher

zones, but these features were too small to delineate at the scale used for this effort. Pepper Grove abuts a maintained levee and lacks the elevation gradient and resultant plant community diversity found at the Bolivar Peninsula habitat improvement site.

Figure 3-3. Smooth cordgrass dominated marsh at Pepper Grove (Goat Island) reference site, Port Bolivar, Texas.



Figure 3-4. Plant community classification of Pepper Grove (Goat Island) reference site, Port Bolivar, Texas.



3.3.3 Comparison with historic monitoring data

Dodd et al. (1978) identified six plant community types at the Bolivar Peninsula habitat improvement project site, three of which are still present. The remaining vegetation community types have undergone significant changes in species composition because of patterns of natural

succession and disturbance (Table 3-1). Seashore dropseed was observed but did not occur as a significant component of any community type. The rattlebox community that was formerly widespread according to Allen (1978) was largely limited to a narrow band along the navigation channel occurring with phragmites. Lemon beebalm (*Monarda citriodora*) was frequently observed but rarely as a codominant in vinelands and mixed herb communities on higher-elevation portions of the site.

Table 3-1. Dominant plant communities at the Bolivar Peninsula study site recorded by Dodd et al. (1988) and their contemporary status according to an April 2019 site visit.

1988 plant communities	2019 Status
Bluestem grass (*Andropogon gyrans*)	Present
Lemon beebalm (*Monarda citriodora*)	Community component
Rattlebox (*Sesbania drummondii*)	Codominant with Phragmites
Smooth cordgrass (*Spartina alterniflora*)	Present
Salt-meadow cordgrass (*S. patens*)	Present
Seashore dropseed (*Sporobolus virginicus*)	Community component

Sand pine and winged sumac (*R. copallinum*) were part of the original planting design at the Bolivar Peninsula habitat improvement site but were not observed in the study site despite reported average survival rates of 31.9% and 66.0%, respectively, several years after construction (Allen et al. 1978). Sand pine is a common component of xeric dune and scrub communities on acidic, marine-deposited sands along the eastern Gulf Coast (Weakley 2015). It is suited to the climatic conditions found at the site but would be well outside of its native range, with the westernmost naturally occurring population recorded in Jackson County, Mississippi (Kartesz 2015). Many of the species that are typically associated with sand pine also do not occur along the western Gulf Coast and may reflect differences in biogeography as well as parent material, soil texture, and pH. Winged sumac is considered native to Galveston County but may have experienced steep declines on the island because of storm events, salt spray, and other adverse conditions. Bermuda grass (*Cynodon dactylon*) and bitter panic grass (*Panicum amarum*) were planted along lower-elevation portions of the upland areas and reported survival rates exceeding 80% percent but appeared to have become other community types through succession and disturbance (that is, overgrazing). Bitter panic grass (*P. amarum*) was a planted species infrequently observed on lower-elevation portions of the site. Salt cedar (*Tamarix* sp.) was incorporated into the planting design but was observed only as scattered

individuals or small clumps. This non-native invasive species may have been targeted for control efforts in subsequent years.

Aggressive nontarget species were recorded previously by Allen et al. (1978; seashore dropseed, three-square, marsh fimbry, yellow nutgrass [*Cyperus esculentus*], pickleweed) were commonly observed but did not appear to have excluded desirable target species. Areas with intermediate moisture regimes were described by Webb et al. (1978) as the most likely to be invaded. Conditions within this zone would be favorable to a wider variety of species both native and non-native that are not specifically adapted to either hydric or xeric conditions. Chinese tallow tree (*Triadica sebifera*) was observed infrequently but may become problematic on some areas of the island unless control measures are implemented.

The stem densities of smooth cordgrass at Bolivar Peninsula and Pepper Grove were comparable (148.0 and 155.1 per m^2 respectively); however, the previously reported values indicate a continued decrease over time at both sites (Table 3-2). Differences at Bolivar Peninsula may be explained by a combination of sea-level rise and erosion resulting from the relatively long fetch distance in Galveston Bay. Decreases at Pepper Grove were slight but may be a product of subsidence or sea-level rise or both, since the fetch distance is considerably lower. It must also be considered that the stem densities reported from April 2019 may be affected slightly by seasonal differences from previous studies that occurred in late summer to autumn, when additional tillers produced during the growing season may be present. *Salicornia* was abundant after site establishment at Bolivar Peninsula, then declined significantly by 1982, and was absent from sample locations in 2019. It was predominantly located on the upper margins of low marsh near the high tide line. This species has been absent from sample locations at the Pepper Grove site since studies began in 1979.

Table 3-2. Comparison of stem densities of low marsh species recorded at the Bolivar Peninsula study site and Pepper Grove (Goat Island) reference site, Port Bolivar, Texas (species with dense growth forms were not counted in previous studies and recorded as percent cover values only).

	Stems/m^2					
	Bolivar Peninsula			Pepper Grove		
	1979	1982	2019	1979	1982	2019
Batis maritima	0.0	0.0	0.7	0.0	0.0	0.0
Borrichia frutescens	0.0	0.0	1.3	0.0	0.0	0.0
Distichlis spicata	0.0	No count	0.0	0.0	No count	12.9

	Stems/m²					
	Bolivar Peninsula			Pepper Grove		
	1979	1982	2019	1979	1982	2019
Fimbristylis castanea	0.0	No count	0.0	0.0	0.0	0.0
Salicornia spp.	140.5	51.0	0.0	0.0	0.0	0.0
Spartina alterniflora	201.7	173.8	148	246.4	161.2	155.1
S. patens	0.0	No count	0.0	0.0	0.0	0.0
Suaeda linearis	0.0	0.0	3.3	0.0	0.0	0.0

Landin, Webb, and Knutson (1989) noted the placement of additional material in 1985 had smothered much of the target community of smooth cordgrass marsh that had previously established in the intertidal zone (142). The change in elevation caused a shift to high marsh dominated by salt-meadow cordgrass and three-square bulrush (142). Areas of high marsh that received additional material were described as sparsely vegetated after two growing seasons (Landin, Webb, and Knutson 1989). After 32 years of succession, these areas are presumably within portions of the various plant communities observed in 2019. The smooth cordgrass community appears to be continuing its decline at Bolivar Peninsula and will likely require applications of additional material near shore to provide suitable substrate within its preferred tidal regime and to overcome losses from erosion.

The exceedingly complex experimental design implemented after site construction, establishment of plant species well outside of their native range, and subsequent disturbance activities (that is, additional material placement, grazing) not fully implemented into a long-term study severely complicates the interpretation of how current conditions fit with predicted successional trajectories and desired outcomes. The plant communities found at Bolivar Peninsula provide valuable wetland functions and wildlife habitat for numerous species but diverge from the planting design and target plant communities at the reference sites. Some of these deviations are explained by succession and impacts from storm events, but much of it can be attributed to species selection, variable management applications, and extended lapses in monitoring that could have potentially informed appropriate corrective measures.

3.4 Drake Wilson Island

3.4.1 Current vegetation community characteristics

The habitat improvement site at Drake Wilson Island was dominated by 0.8 ha of sturdy bulrush–smooth cordgrass marsh (*Bolboschoenus robustus–Spartina alterniflora*), with 0.2 ha of black needlerush (*J. roemerianus*) and smooth cordgrass forming a narrow band of high marsh (Figure 3-5). These two zones were originally planted in smooth cordgrass and salt-meadow cordgrass (*S. patens*), respectively, following construction of the project, but have since turned into other community types or developed other codominant species (Landin, Webb, and Knutson 1989). Phragmites marsh (*Phragmites karka* [*P. australis*]) narrowly occurred on 0.008 ha in the southeast corner of the study location but was also observed on other portions of the island. Gulf Coast populations of phragmites have generally been treated as the non-native *P. australis*, and at subordinate ranks as *P. australis* ssp. *berlandieri* and *P. australis* var. *berlandieri*, because morphological differences between Atlantic Coast and interior US populations. Molecular studies of North American phragmites indicated Gulf Coast populations have experienced multiple hybridization events and backcrossing with a potentially native haplotype, resulting in a close genetic relationship with *P. karka* rather than *P. australis* (Lambertini et al. 2012).

Figure 3-5. Low marsh dominated by sturdy bulrush and smooth cordgrass (foreground), high marsh dominated by black needlerush (center), and xeric slash pine hammock (background), Drake Wilson Island, Apalachicola, Florida.



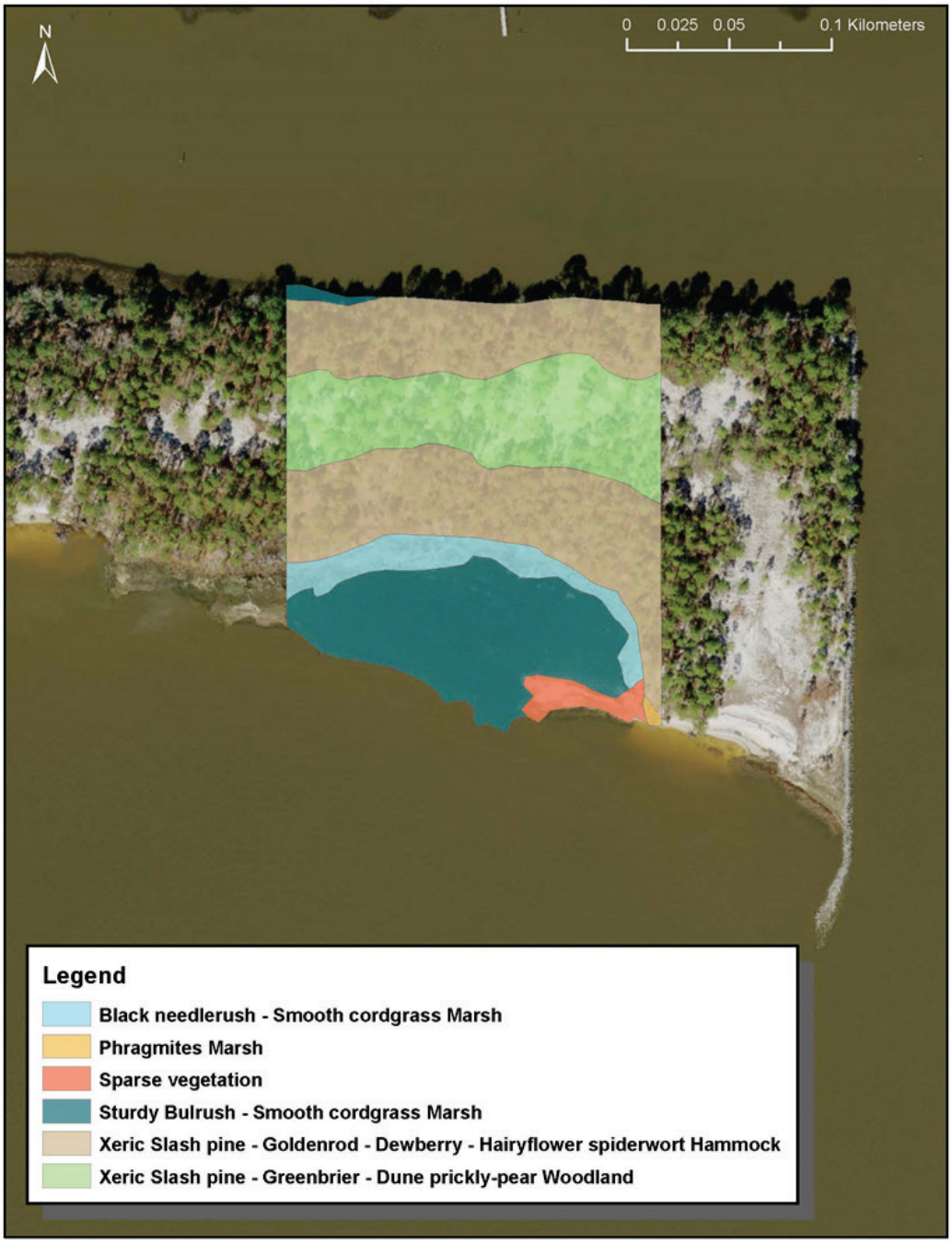
Landscape features dominated by woody plants were classified as xeric slash pine–greenbrier–dune prickly pear woodland (*Pinus elliottii–Smilax* spp.–*O. drummondii*), which had an open canopy and sparse understory, and xeric slash pine–goldenrod–dewberry–hairy flower spiderwort hammock (*P. elliottii–Solidago* sp.–*Rubus trivialis–Tradescantia hirsutiflora*), which had higher densities of trees and significant cover by understory components (Figure 3-6). Cabbage palm (*Sabal palmetto*) was an occasional understory component. It was planted on upland areas of the island, but all individuals had died by 1980 according to Landin, Webb, and Knutson (1989). It is unclear if these plants colonized the site or resulted from replanting at a later date. Sand pine (*P. clausa*) was also planted in upland areas but has largely been suppressed by other *Pinus* species that are larger and longer lived. Bald cypress (*Taxodium distichum*), red maple (*Acer rubrum*), and overcup oak (*Q. lyrata*) occurred as scattered trees in a narrow band along the upper margin of the marsh and are visible in the center of Figure 3-5. An area of sparse vegetation on deep sand occupied 0.08 ha along the southeast portion of the former placement area. This feature appears to be a remnant of a low frontal dune formed along the original site construction dike, but it largely

disappeared during the early 2000s. All plant communities in the Drake Wilson Island study site are shown in Figure 3-7.

Figure 3-6. Uplands dominated by slash pine at Drake Wilson Island, Apalachicola, Florida.



Figure 3-7. Plant community classification of the Drake Wilson Island study site, Apalachicola, Florida.

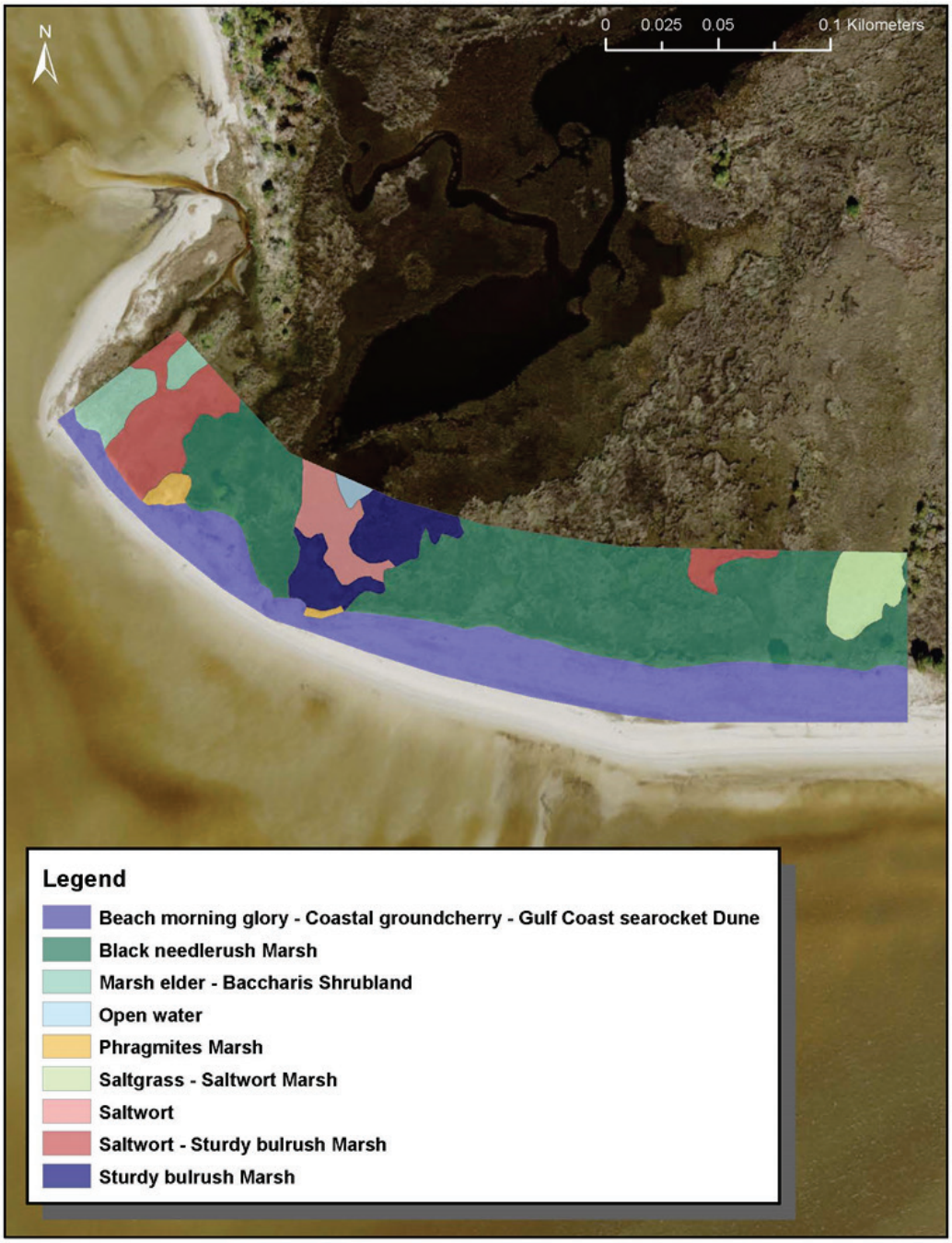


3.4.2 Comparison with reference location

Wetland features at the Cat Point reference area were dominated by black needlerush, which is typical for tidal marshes along the eastern portion of the Gulf Coast (Tiner 1993). Sturdy bulrush dominated lower elevation zones inundated by daily tidal fluctuations. Inclusions within the marsh

exhibited saltwort (*Batis maritima*) or combinations of saltwort and salt grass (*Distichlis spicata*), or saltwort and sturdy bulrush. Saltwort did not occur within the study site at Drake Wilson Island and may be indicative of higher salinity concentrations at Cat Point. The highest-elevation zones within the marsh were dominated by marsh elder–*Baccharis* shrubland (*Iva frutescens–B. glomeruliflora* or *–B. halimifolia*). These species were present at the study site but did not form a distinct community. Phragmites marsh occurred as small isolated stands occupying 0.02 ha. Slash pine dominated hammocks and woodlands similar to those on uplands at the habitat improvement site. Cat Point had a more pronounced beach and low frontal dune dominated by beach morning glory (*Ipomoea imperati*), coastal ground-cherry (*Physalis angustifolia*), and Gulf coast sea rocket (*Cakile constricta*), with scattered clumps of sea oats (*Uniola paniculata*), salt-meadow cordgrass, seashore dropseed (*Sporobolus virginicus*), and dune prickly pear. All plant communities within the Cat Point reference site are shown in Figure 3-8.

Figure 3-8. Plant community classification of Cat Point reference site, Apalachicola, Florida.



3.4.3 Comparison with historic monitoring data

The average stems per square meter of graminoids at Drake Wilson Island and Cat Point has increased since the previous study in 1986 from 135.1 to 153.7 and 146.3 to 154.0, respectively. However, smooth cordgrass has declined significantly from 160.3 stems/m^2 to 58.7 stems/m^2 at Drake

Wilson Island and from 146.3 to zero at Cat Point (Figure 3.9), while sturdy bulrush has increased. This trend has continued since the initial site construction and evaluation (Table 3-3; Landin, Webb, and Knutson 1989). Sturdy bulrush also appeared to be dominant in areas near shore on the landward side of the island, with smooth cordgrass forming narrow bands along channel margins. Sturdy bulrush is considered a pioneer species and may reflect changing conditions in the area or recent disturbance from storm events.

Figure 3-9. Sturdy bulrush marsh (foreground), black needlerush marsh, and pine-dominated uplands (background), Cat Point, Apalachicola, Florida.



Table 3-3. Stem density of low marsh species at Drake Wilson Island and Cat Point, Apalachicola, Florida.

	Stems/m²			
Drake Wilson Island	1977	1982	1986	2019
Bolboschoenus robustus	n/a	1.8	4.7	95.0
Spartina alterniflora	160.3	137.8	130.4	58.7
Cat Point				
Batis maritima	0.0	0.0	0.0	30.7
Bolboschoenus robustus	0.0	0.0	0.0	154.0
S. alterniflora	n/a	161.0	146.3	0.0

High marsh zones dominated by salt-meadow cordgrass did not occur at the reference sites; therefore, previous studies did not compare those planted at Drake Wilson Island (Landin, Webb, and Knutson 1989). The growth form of some of the species found is this zone is not conducive to counting stems; therefore, percent cover was compared to the reported values from Newling and Landin et al. (1985) (Table 3-4). The average total cover in the high marsh zone has increased from 61.3% to 72.6%. Many of the species recorded in 1982 are frequently found on recently disturbed soils or reflect drier site conditions or both and appear to have been outcompeted by other species through a combination of succession and increasing site wetness. Smooth cordgrass was planted only on lower portions of the study site and was not detected in the high marsh in 1982 but has since migrated upslope. Black needlerush was neither planted at the study area nor present during the 1982 sampling period but now dominates the high marsh, with an average of 47.7% cover. This species was dominant at Cat Point and at other high marsh features found nearby.

Table 3-4. Mean percent cover by species from high marsh at Drake Wilson Island, Apalachicola, Florida.

	Mean % cover	
Drake Wilson Island (high marsh)	1982	2019
Amaranthus cannabinus	0.0	0.8
Baccharis glomeruliflora and *B. halimifolia*	0.3	0.0
Bolboschoenus robustus	0.0	6.1
Bothriochloa laguroides and *Polypogon monspeliensis*	12.0	0.0
Bromus sp.	0.3	0.0
Cladium jamaicense	0.0	5.4
Eleocharis sp.	0.0	1.3
Erechtites hieracifolia	0.3	0.0
Eupatorium capillifolium	1.8	0.0
Hydrocotyle sp.	0.8	0.0
J. roemerianus	0.0	47.7
Juncus sp.	1.0	0.0
Liatris sp.	0.3	0.0
Lycopodium sp.	21.0	0.0
Lythrum lineare	1.8	0.0
Osmunda regalis	0.3	0.0
Paspalum notatum	6.3	0.0

	Mean % cover	
Drake Wilson Island (high marsh)	1982	2019
Pluchea odorata	0.0	0.3
Sesbania vesicaria	0.0	0.2
Spartina alterniflora	0.0	7.5
S. patens	9.3	2.7
Typha domingensis	0.0	0.3
Unknown	6.3	0.3
Total	61.3	72.6

Postconstruction monitoring concluded that the created marsh at Drake Wilson Island was largely successful and target plant species were becoming well established on the dredged material placement area. Short-term monitoring revealed conditions at the site had changed somewhat, potentially informing future planting designs, but no contrasting conclusions or predictions could be made without additional periodic monitoring, which was not conducted. Long-term monitoring showed the site has been highly influenced by hydrology, volunteer plant species, and stochastic events, so established communities have now adapted to align with conditions found at portions of the reference site and other nearby localities. The current conditions deviate from the target conditions established in the initial site design, implying limited success or partial failure to achieve and maintain desired outcomes; however, the resultant plant communities have largely followed the trajectory of comparable landscape features in the immediate vicinity and continue to provide appropriate functions and values.

3.5 Buttermilk Sound

3.5.1 Current vegetation community characteristics

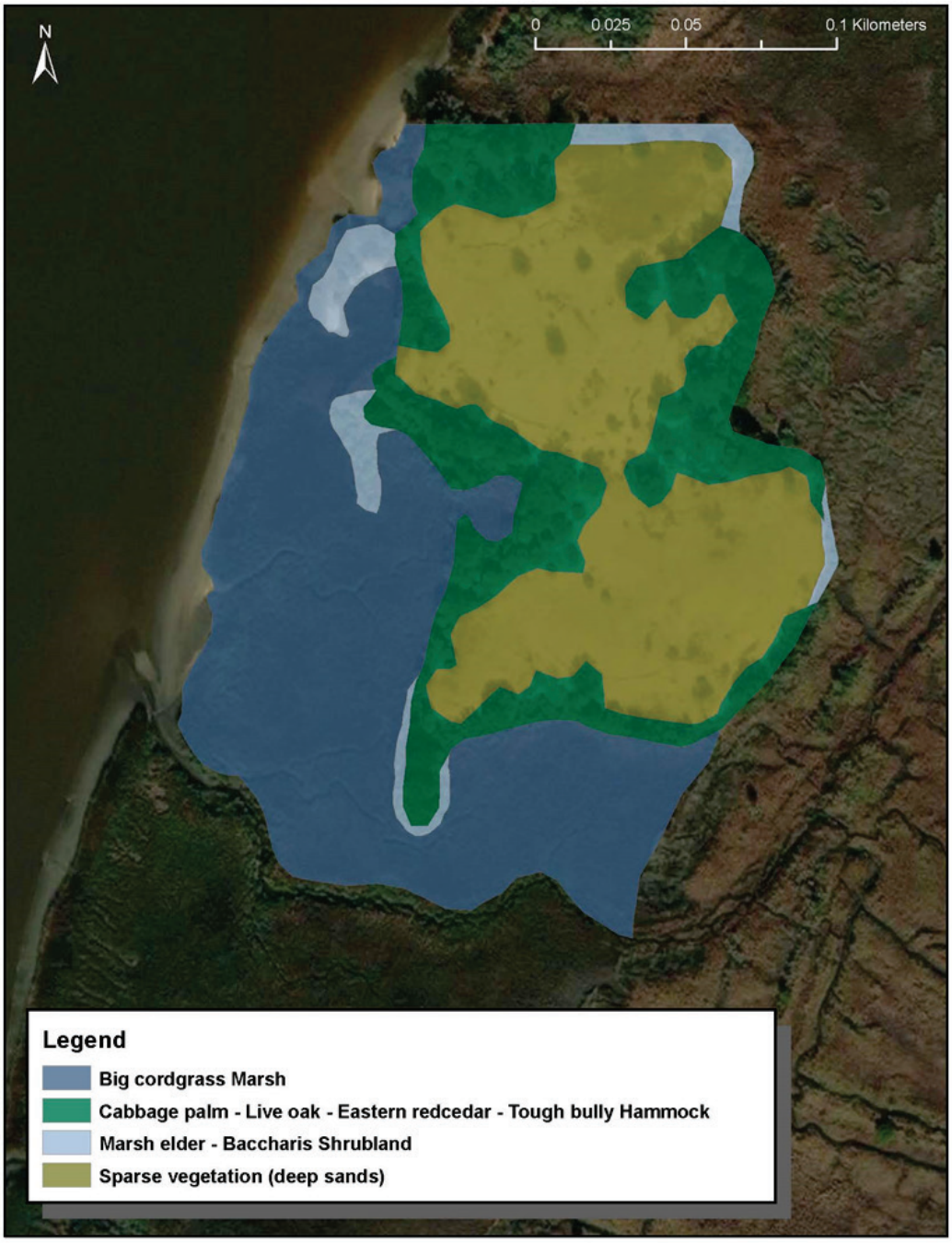
The Buttermilk Sound habitat improvement project site occupies 4.4 ha along the western edge of Little St. Simons Island. Wetland plant communities were strongly dominated by big cordgrass (*Spartina cynosuroides*) marsh in landscape positions that experience daily tidal inundation. Sturdy bulrush, soft-stem bulrush (*Schoenoplectus tabernaemontani*), salt-marsh loosestrife (*Lythrum lineare*), and sweet scent (*Pluchea odorata*) occurred in this community as minor components. Higher zones in the marsh and narrow transitional bands at the upper edges were occupied by marsh elder–*Baccharis* shrubland

(0.2 h). The dominant woody plant community at Buttermilk Sound was cabbage palm–live oak–eastern redcedar–tough bully hammock (*Sabal palmetto–Q. virginiana–Juniperus virginiana–Sideroxylon tenax*), which occupied 0.9 ha (Figure 3-10). These components represent several natural community types documented in the southeastern Atlantic Coastal Plain and may indicate arrival at a midpoint in seral stage development. Saw palmetto and red bay (*Persea borbonia*) were frequent understory components. The hammock community moved upslope to the highest portions of the study site that were sparsely vegetated over deep, coarse sands (1.5 h). Pine-barren frostweed (*Crocanthemum corymbosum* [Michx.] Britton) occasionally formed small mats, and young or stunted cabbage palms, or both, occurred as scattered shrubs. All plant communities at the Buttermilk Sound study site are shown in Figure 3-11.

Figure 3-10. Cabbage palm–live oak–eastern red cedar–tough bully hammock community at the Buttermilk Sound study site, Brunswick, Georgia.



Figure 3-11. Plant community classification of the Buttermilk Sound study site, Brunswick, Georgia.



3.5.2 Comparison with reference location

The reference site was a 6.0 ha section of Hardhead Island, located in the Altamaha River. It was occupied by expansive stands of big cordgrass marsh (5.4 h) similar to portions of the habitat improvement site, but with sturdy bulrush often occurring as a codominant (Figure 3-12). This

community type is documented only on the Atlantic Coast, from New Jersey to Georgia, and may be driven in part by the tidal regime within this region (NVCS 2017). Black dominated–marsh occurred as inclusions occupying approximately 0.6 ha. This species was planted at the Buttermilk Sound study site but had disappeared by 1986 according to Landin, Webb, and Knutson (1989). Marsh elder and eastern *Baccharis* occurred as scattered shrubs along the northern edge of the island but did not form a distinct community. No areas at the reference site supported the hammock community found at the Buttermilk Sound study site. All plant communities at the Hardhead Island reference site are shown in Figure 3-13.

Figure 3-12. Big cordgrass–dominated marsh at the Hardhead Island reference site, Brunswick, Georgia.



Figure 3-13. Plant community classification of the Hardhead Island reference site, Brunswick, Georgia.



3.5.3 Comparison with historic monitoring data

Landin, Webb, and Knutson (1989) reference smooth cordgrass as being dominant or codominant with big cordgrass at both the Buttermilk Sound study site and Hardhead Island reference site (Table 3-5). In 2019, smooth cordgrass was observed primarily along channel margins and only

occasionally within the marsh at both sites. The site investigation took place in early May, well before the production of inflorescences; therefore, each *Spartina* specimen that occurred within a quadrat sample was physically examined for glabrous (*S. alterniflora*) or scabrous (*S. cynosuroides*) leaf margins as described by Weakley (2015). It appears that stem density of big cordgrass has increased significantly since 1985, from 10.4 to 57.8 stems/m^2 at Buttermilk Sound and from 3.5 to 43.6 stems/m^2 at Hardhead Island. Smooth cordgrass was absent from sampled locations at both of these sites; however, it may be underreported because of limitations on the number of plants that could be physically inspected across each site during the available time constraints while locating representative sampling locations. Values for mean percent cover appear relatively stable, although there was an apparent decrease from 95.0% to 70.2% at Buttermilk Sound. This decrease could be explained by the study location continuing to equilibrate with reference sites nearby, as Landin, Webb, and Knutson (1989) noted that Buttermilk Sound has continuously showed higher productivity than all reference sites.

Table 3-5. Stem density of marsh species and total mean percent cover at Buttermilk Sound study site and Hardhead Island reference site, Brunswick, Georgia.

	Stems/m^2					
	Buttermilk Sound			Hardhead Island		
	1982	1985	2019	1982	1985	2019
Bolboschoenus robustus	10.0	7.5	5.8	N/A	0.0	21.8
Lythrum lineare	0.0	0.0	1.33	N/A	0.0	0.0
Schoenoplectus tabernaemontani	7.0	3.5	0.0	N/A	15.4	0.0
Solidago sempervirens	0.0	0.0	0.0	N/A	0.0	10.2
Spartina alterniflora	79.0	82.6	0.0	N/A	93.2	0.0
S. cynosuroides	8.8	10.4	57.8	N/A	3.5	43.6
Mean total % cover	88.8	95.0	70.2	63.7	60.1	61.58

The hammock community found at Buttermilk Sound is recognized as an important colonizer and stabilizer of barrier islands and newly exposed maritime sediments and appears to have established itself and performed these functions in areas with favorable hydrology and available nutrients on the ungraded portion of the site (NVCS 2017). However, this community was noted as an obstruction for utilization of the open sandy substrate by some wildlife species of concern. Landin, Webb, and Knutson (1989) indicated that the density of vegetation on upper portions of the

site had begun to preclude nesting shorebirds by the early 1980s. The embedded landscape position of the Buttermilk Sound site within the marsh, and its inherent sediment transport properties, are not favorable for the formation or maintenance of unobstructed open-dune communities. Open sandy conditions created for wildlife in this particular landscape setting would provide transient habitat at best, otherwise requiring recurrent vegetation management. Efforts intended to provide this substrate type should be allocated to alternative sites for dune rehabilitation or re-establishment if available.

3.6 Nott Island

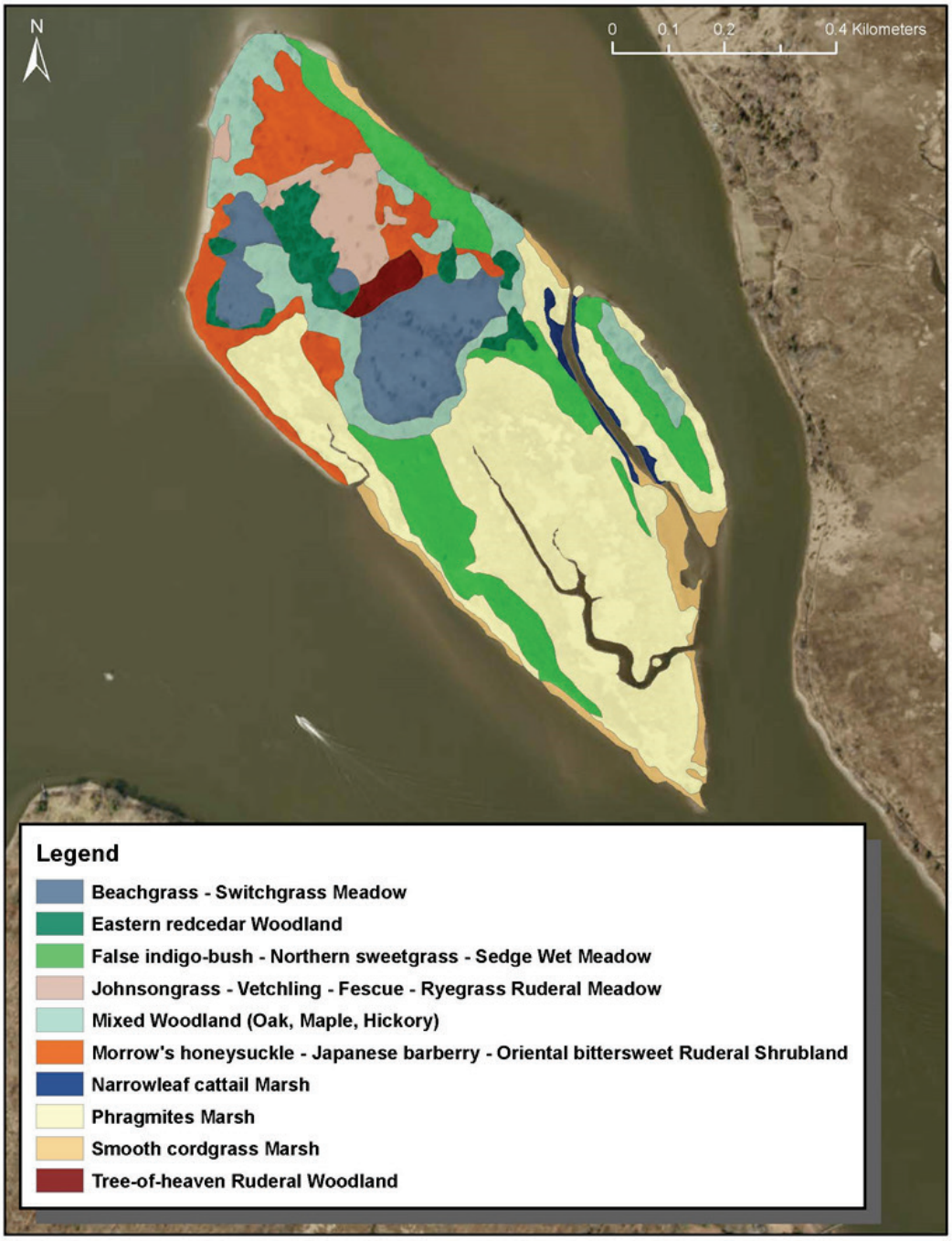
3.6.1 Current vegetation community characteristics

The Nott Island habitat improvement site occupies 35.7 ha and is divided by a minor channel along its eastern side. The lowest areas inundated by daily tidal fluctuations were dominated by smooth cordgrass and occupied 1.6 ha. Phragmites (*Phragmites australis*) marsh occurred on slightly higher portions of the marsh on 13.9 ha, with small inclusions of narrowleaf cattail (*Typha angustifolia*) occupying 0.4 ha along channels and depressions. The marsh shifted to wet shrublands dominated by false indigobush (*Amorpha fruticosa*), *Carex* spp., and northern sweet grass (*Anthoxanthum hirtum*). A created meadow dominated by Johnson grass (*Sorghum halepense*), vetchling (*Lathyrus* sp.), fescue (*Schedonorus* spp.), and perennial ryegrass (*Lolium perenne*) occurred in the north-central portion of the island (Figure 3-14). According to Landin, Webb, and Knutson (1989), tall fescue (*S. arundinacea*) was the primary planted species; however, many areas also appeared to have meadow fescue (*S. pratensis*). These species could not be verified because of the timing of the site visit and were therefore listed here at the genus level. Areas over deep xeric sands were dominated by American beach grass (*Amophila breviligulata*) and switch grass (*Panicum virgatum*). These features appeared to be on placement areas that predate the establishment of the constructed meadow feature. Eastern red cedar woodland occupied 1.5 ha and was positioned along margins of the created meadows. A 0.4 ha woodland feature dominated by tree of heaven (*Ailanthus altissima*) occurred near the center of the island, within a slight depression with fine-textured soils. All plant communities classified at Nott Island are shown in Figure 3-15.

Figure 3-14. The constructed meadow dominated by non-native grasses at Nott Island, Old Lyme, Connecticut.



Figure 3-15. Plant community classification of the Nott Island, Old Lyme, Connecticut.



3.6.2 Comparison with reference location

The 10.3 ha reference site, Eustasia Island, is located approximately 8.5 km north of Nott Island. Eustasia Island lacks much of the topographic relief found on Nott Island and was dominated by floodplain forests of silver maple (*Acer saccharinum*), American elm (*Ulmus americanus*), and green ash (*Fraxinus pennsylvanica*) that occupied 3.9 ha. This forest type

is commonly associated with high floodplain terraces on lower portions of major rivers from New Jersey to Massachusetts (NVCS 2017). Ruderal woodlands dominated by eastern red cedar, multiflora rose (*Rosa multiflora*), and Japanese barberry (*Berberis thunbergii*) occupied 2.7 ha on higher positions near the center of the island. These features often shifted into ruderal meadows dominated by leafy spurge (*Euphorbia esula*), meadow fescue, multiflora rose, and stilt grass (*Microstegium vimineum*), with inclusions of woody vines and shrubs (Figure 3-16). Phragmites marsh occurred on lower landscape positions, occupying 2.1 ha. Yellow-flag iris and narrowleaf cattail were commonly observed in this community. The plant community classification of Eustasia Island is shown in Figure 3-17.

Figure 3-16. Ruderal meadow dominated by non-native plant species at the Eustasia Island reference site, Old Lyme, Connecticut.



Figure 3-17. Plant community classification of the Eustasia Island reference site, Old Lyme, Connecticut.



3.6.3 Comparison with historic monitoring data

The goal at the Nott Island habitat improvement site was to create an upland habitat on sandy unvegetated dredge material by incorporating fine-textured soils and planting species typical of meadows in the north-central United States. The feature has largely maintained this character, although additional species have colonized, and established species adapted to, dry conditions that have expanded into the margins where sandy deposits occurred. Stem densities reflect a decline for early

successional plants such as Canadian horseweed (*Conyza canadensis*) and Baldwin's flat sedge (*Cyperus croceus*), while the total density of graminoids remained relatively stable (Table 3-6). Vetchling was not recorded in previous field efforts but occurred as a codominant species in the meadow, with an average of 23.6 stems/m^2. Landin et al (1989) noted that the legumes planted for soil amelioration were not successful, likely because of substrate pH and insufficient inoculants. Areas with deep sands remained sparsely vegetated or demonstrated expansions by American beach grass and switch grass. The recruitment of wooly beach heather (*Hudsonia tomentosa*) was noted on older sand deposits south of the planted meadow. The development of these species on the placement areas indicates that xeric conditions are a major limiting factor for the establishment of species typical of a meadow in the region.

Table 3-6. Stem densities within the meadow feature at Nott Island, Old Lyme, Connecticut.

	Stems/m^2			
	1982	1983	1985	2019
Ammophila breviligulata	0.0	0.0	0.0	0.4
Amorpha fruticosa	0.0	0.0	0.0	1.3
Beckmannia syzigachne	0.0	2.4	0.0	0.0
Celastrus orbiculatus	0.0	0.0	0.0	2.2
Conyza canadensis	95.6	84.3	81.2	0.0
Cyperus croceus	32.4	0.0	16.7	0.0
Dactylis glomerta	0.0	0.0	0.0	2.2
Galium aparine	0.0	0.0	0.0	7.6
Krigia virginica	0.0	0.0	0.0	1.3
Lathyrus sp.	0.0	0.0	0.0	23.6
Lolium perenne	0.0	0.0	0.0	53.3
Nuttallanthus canadensis	0.0	0.0	0.0	0.9
Schedonorus arundinaceus	166.4	172.6	170.3	38.2
Sinapis arvensis	0.0	0.0	0.0	1.3
Solidago spp.	1.0	3.2	2.7	0.0
Sorghum halepense	0.0	0.0	0.0	100.0
Unknown	0.0	0.0	0.0	9.8
Urtica dioica	0.0	0.0	0.0	0.9
Veronica arvensis	0.0	0.0	0.0	0.4
Vulpia octoflora	0.0	0.0	0.0	12.0

Meadow features at the Eustasia reference site occurred as narrow, discontinuous stands dominated by non-native grasses and forbs (Table 3-7). The species assemblage diverged somewhat from the meadow at Nott Island, where stilt grass and leafy spurge occurred as minor components. The overall appearance of these features at Eustasia Island suggests that they are changing into shrublands that will likely be dominated by multiflora rose and Japanese barberry. The historic monitoring data for Eustasia Island referenced in Landin, Webb, and Knutson (1989) and Newling and Landin (1985) could not be located, precluding inclusion of comparative analysis herein.

Table 3-7. Percent cover by species from meadow features at the Eustasia Island reference site, Old Lyme, Connecticut.

	Mean % cover
Arisaema triphyllum	0.9
Carex sp.	1.0
Celastrus orbiculatus	1.4
Convolvulus arvensis	0.3
Cyperus sp.	9.1
Dichanthelium sp.	2.8
Euphorbia esula	20.9
Galium aparine	1.8
Ligustrum sp.	0.9
Lonicera japonica	0.2
Microstegium vimineum	25.6
Oxalis stricta	0.1
Parthenocissus quinquefolia	3.9
Rosa multiflora	24.2
Rubus sp.	0.8
Schedonorus spp.	5.3
Thelypteris noveboracensis	1.1
T. palustris	0.3
Toxicodenron radicans	6.4
Unknown	1.8
Vitis aestivalis	3.9

3.7 Point Mouillee

3.7.1 Current vegetation community characteristics

The Point Mouillee habitat improvement site is a 292.1 ha CDF mostly occupied by dense monotypic stands of phragmites marsh (183.1 ha; Figure 3-18). Cattail occurred as narrow bands (not mapped) restricted to water control drainageways and ditches that were slightly lower than areas with phragmites. These communities were described by Landin, Webb, and Knutson (1989) as occupying approximately 60.7 ha of high and low marsh but have expanded greatly with the periodic addition of dredged materials into several cells within the CDF. Open water occurs on 72.8 ha and is located primarily in the north-central cell, which has a direct connection to Lake Erie. A significant area of open water remains in the northernmost cell and supports a 0.9 ha bed of yellow pond lily (*Nuphar lutea*) and white water lily (*Nymphaea odorata*).

Figure 3-18. Expansive stands of phragmites marsh at Point Mouillee confined disposal facility (CDF), Estral Beach, Michigan.



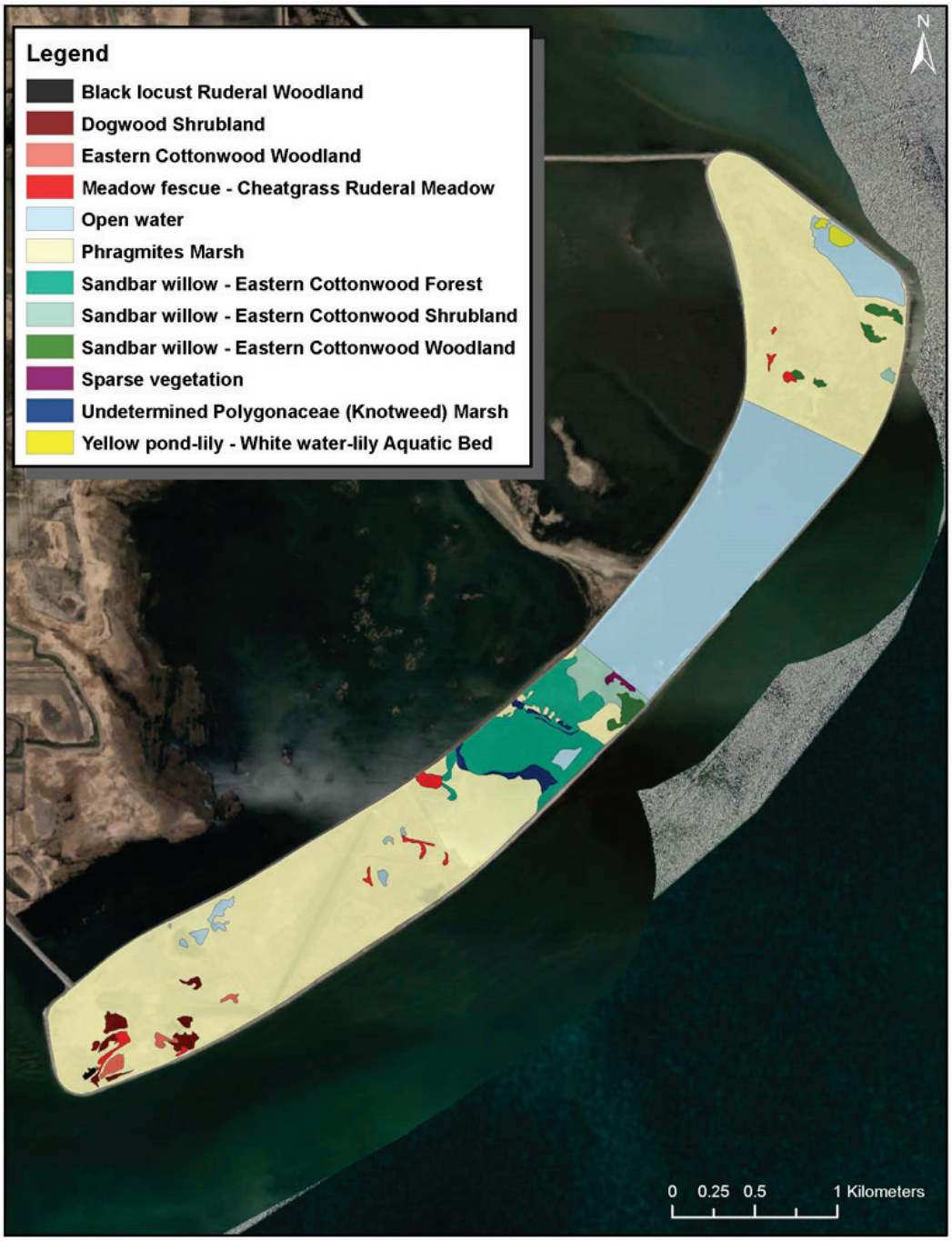
Sandbar willow–eastern cottonwood (*Salix exigua–Populus deltoides*) was the dominant woody plant community at Point Mouillee (Figure 3-19), occupying 26.4 ha in total, and was subdivided into forest (19.3 ha),

woodland (2.7 ha), and shrubland (4.5 ha) categories. The three categories result from both age differences in stand establishment and routine vegetation management that creates earlier successional stages. Black locust (*Robinia pseudoacacia*) ruderal woodland occurred as a single 0.2 ha stand near the southwestern tip of Point Mouillee. This location appears to be on a well-drained convex landscape position. Eastern cottonwood woodlands occurred nearby on similar areas and apparently lacked sufficient hydrology to support sandbar willow, which co-occurs with cottonwood on the remainder of Point Mouillee. Dogwood shrublands (*Cornus* spp.) occupied 2.6 ha and occurred on landscape positions slightly higher than those occupied by phragmites. Recently disturbed areas contained a mix of cool-season non-native grasses and forbs (mapped as meadow fescue–cheatgrass ruderal meadow) and occupied approximately 2.3 ha. All plant communities at Point Mouillee CDF are shown in Figure 3-20.

Figure 3-19. Dense stands of Eastern cottonwood and sandbar willow inside the Point Mouillee contained disposal facility, Estral Beach, Michigan.



Figure 3-20. Plant community classification of the Point Mouillee contained disposal facility, Estral Beach, Michigan.



3.7.2 Comparison with reference location

Because of the uniqueness of the Point Mouillee CDF and its primary benefit and design purpose as a control structure and breakwater protecting natural communities along the shore, no reference location was available in the nearby area to provide useful comparisons.

3.7.3 Comparison with historic monitoring data

Available data from the previous monitoring efforts at Pointe Mouillee was limited, and the surveys were conducted at different times of the year. The percent cover of species observed within the phragmites marsh community is provided in Table 3-8. Note that the percent cover of species located was 12.8%, approximating the value of 12.7% cover reported by Newling and Landin (1989) from the summer of 1987. However, the 2019 site visit was conducted in spring and would be much higher by late summer according to the standing biomass from the previous growing season (estimate of >75%). Solidago had the highest mean cover during the spring but would be suppressed later in the growing season by the much taller and more abundant phragmites.

Table 3-8. Percent cover by species in *Phragmites australis* marsh recorded May 2019, at the Point Mouillee contained disposal facility, Estral Beach, Michigan.

Phragmites marsh	
	Mean % cover
Artemisia sp.	2.5
Cardamine pensylvanica	0.8
Carex sp.	1.2
Galium tinctorium	5.0
Phragmites australis	12.8
Solidago sp.	20.0
Urtica diocia	1.2

3.8 Miller Sands

3.8.1 Current vegetation community characteristics

The Miller Sands habitat improvement project site occupies 123.6 ha and supports eight distinct plant communities. Red alder–Douglas fir–Sitka spruce–western hemlock (*Alnus rubra–Pseudotsuga menziesii–Picea sitchensis–Tsuga heterophylla*) riparian forest was the dominant community, occupying 27.9 ha. This forest type is common in lowland riparian areas along the Pacific coast from Oregon to Alaska (NVCS 2017). Narrow strands of forest dominated by willows (*Salix* spp.), black cottonwood (*Populus trichocarpa*), and red alder occurred mostly on the northern and eastern portions of the site. Herbaceous wetlands (Figure 3-21) occupied 15.6 ha and were concentrated in the interior protected zones of the island along secondary channels. These features were mostly

dominated by non-native invasive species such as purple loosestrife (*Lythrum salicaria*), yellow-flag iris (*Iris pseudacorus*), and water forget-me-not (*Myosotis scorpioides*). Higher portions of the marsh contained native components such as willowherb (*Epilobium* spp.), and tufted loosestrife (*Lysimachia thyrsiflora*). Flowering quillwort (*Triglochin scilloides*), western grasswort (*Lilaeopsis occidentalis*), and water smartweed (*Persicaria amphibia*) were common native components on the lowest portions of the marsh (Figure 3-22).

Figure 3-21. Marsh dominated by non-native species along the interior of Miller Sands, Astoria, Oregon.



Figure 3-22. Lower portions of the marsh at Miller Sands, dominated by Western grasswort and water smartweed, Astoria, Oregon.



The southern half of the island featured a 14.0 ha meadow (Figure 3-23) dominated by mosses, bearberry (*Arctostaphlyos uva-ursi*), Himalayan blackberry, and sheep sorrel (*Rumex acetosella*). Himalayan blackberry shrubland occupied 2.0 ha, situated along the margins of meadows and forests dominated by red alder. This invasive shrub also extended into the understory of riparian forests dominated by red alder on 10.8 ha. European beach grass (*Ammophila arenaria*) occupied a 1.5 ha area along the eastern portion of the island, where it was established in 1977 (Landin, Webb, and Knutson 1989). Areas of bare ground (10.1 ha) and sparsely vegetated (28.2 ha) zones are concentrated on the north side of the island, where active placement of additional dredged material routinely takes place. All plant communities are shown in Figure 3-24.

Figure 3-23. Upland meadow dominated by mosses, sheep sorrel, Himalayan blackberry, and bearberry at the Miller Sands study site, Astoria, Oregon.



Figure 3-24. Plant communities of Miller Sands study site and Snag Island reference site, Astoria, Oregon.



3.8.2 Comparison with reference condition

Snag Island is positioned just upriver from Miller Sands, separated by a secondary channel within the Columbia River (Figure 3-24). The island was relatively uniform in elevation compared to Miller Sands and dominated by 20.5 ha of reed canary grass (*Phalaris arundinacea*; Figure 3-25), Lyngbye's sedge (*Carex lyngbyei*), and cattail (*Typha* sp.). Lower portions of the marsh contained significant amounts of western grasswort and water smartweed similar to Miller Sands but formed a narrower band that abruptly became extensive mudflats.

Figure 3-25. Reed canary grass dominated portion of the Snag Island reference site, Astoria, Oregon.



3.8.3 Comparison with historic monitoring data

The primary objective at Miller Sands was to create wetland, upland meadow, and dune habitats. Short-term monitoring indicated that all three habitat types had been established on dredged material; however, midphase monitoring revealed shifts in community composition and extent resulting from succession, climatic events, impacts from invasive species (that is, nutria), and wind-blown sediment accumulation. Long-term monitoring showed that some of the target communities had experienced dramatic shifts in species composition while others have remained stable in composition and structure but have contracted because of woody encroachment.

The marsh created at Miller Sands was planted with eight native species that became well established by 1978 (Landin, Webb, and Knutson 1989). Slough sedge (*C. obnupta*), Lyngbye's sedge, and tufted hair grass (*Deschampsia cespitosa*) were noted as the best-performing species during postconstruction monitoring (Table 3-9). Midphase monitoring in the 1980s indicated that the marsh had accumulated additional wind-

blown sediment so that its elevation had increased slightly and therefore some of the target species appeared to be declining. By 2019, all eight of the planted species have since been outcompeted by non-native species and occur only as minor components or small inclusions.

Table 3-9. Mean stems per square meter recorded from the marsh feature at Miller Sands, Astoria, Oregon.

	Stems/m²			
	1982	1984	1986	2019
Alopecurus geniculatus	250.0	238.9	265.8	0.0
Bidens sp.	12.0	15.2	14.9	0.0
Callitriche palustris	0.5	0.0	0.0	1.8
Calystegia sepium	0.0	0.0	0.0	0.2
Carex lyngbyei	17.0	22.5	23.5	0.0
C. obnupta	2.2	10.5	6.3	0.0
Deschampsia cespitosa	399.8	426.3	412.6	240.4
Eleocharis sp.	0.2	0.1	1.0	0.0
Epilobium ciliatum	3.8	9.3	4.5	2.7
Erythranthe guttata	10.5	15.8	14.7	0.0
Galium sp.	0.0	0.0	0.0	158.4
Iris pseudacorus	0.0	0.0	0.0	8.9
Juncus acuminatus	1.0	0.3	0.0	0.0
J. oxymeris	9.5	12.0	10.5	0.0
Lilaeopsis occidentalis	138.5	127.8	134.5	91.1
Lotus corniculatus	5.8	4.9	5.1	13.3
Lythrum salicaria	0.0	0.0	0.0	20.2
Myosotis scorpioides	0.0	0.0	0.0	80.0
Persicaria amphibium	0.0	0.0	0.0	15.6
Persicaria sp.	5.0	9.6	12.5	0.0
Phalaris arundinacea	1.3	2.5	2.0	0.0
Plantago lanceolata	0.0	0.0	0.0	1.8
Potentilla sp.	1.2	0.1	0.5	2.7
Raphanus sp.	0.0	0.0	0.0	0.2
Rorippa palustris	0.0	0.0	0.0	1.3
Sagina decumbens	0.0	0.0	0.0	36.7
Symphyotrichum subspicatum	3.0	5.5	4.8	0.0
Triglochin scilloides	1.0	0.5	0.3	5.0
Undetermined	0.0	0.0	0.0	3.3

The Snag Island reference site has also experienced significant declines in native species since 1980 (Table 3-10). *Carex* spp. continue to have the highest stem densities of all species present but have deteriorated from an average of 172.2 to 60.9 stems/m^2. Most of the specimens appeared to be Lyngbye's sedge but collectively had an average cover estimate of 21.3%. The most notable increase at the site was reed canary grass, which was a minor component in 1980 (0.6 stems/m^2) but had average density of 34.7 stems/m^2 and an average cover estimate of 21.9% in 2019.

Table 3-10. Mean stems per square meter recorded at Snag Island reference site, Astoria, Oregon.

	Stems/m^2	
	1980	2019
Alisma triviale	2.2	0.9
Bidens sp.	0.1	0.0
Carex sp.	172.2	60.9
Cakile sp.	0.1	0.0
Deschampsia cespitosa	43.5	0.0
Distichlis spicata	0.7	0.0
Eleocharis sp.	44.0	0.0
Elodea nuttallii	0.7	0.0
Epilobium ciliatum	0.1	0.0
Erythranthe guttata	0.0	0.0
Iris sp.	0.0	3.1
Juncus acuminatus	19.3	38.2
Lilaeopsis occidentalis	0.1	15.6
Limosella aquatica	19.0	0.0
Ludwigia hexapetala	0.0	2.7
L. palustris	3.8	0.0
Lysimachia thyrsiflora	0.0	4.0
Lythrum salicaria	0.0	13.8
Persicaria amphibia	0.0	35.1
Phalaris arundinacea	0.6	34.7
Schoenoplectus tabernaemontani	13.1	1.8
Sium suave	3.1	0.0
Sparganium sp.	0.0	3.1
Symphyotrichum subspicatum	0.3	1.2
Triglochin scilloides	1.8	2.2
Typha sp.	0.0	8.9
Unknown	1.9	4.0

The meadow at Miller Sands was a mix of native and non-native components whose overall appearance suggests an abandoned field or recently disturbed dry meadow. This appearance reflects the sandy substrate, its disturbance history, previous management, and encroachment by species typical of older stabilized dunes near the Pacific coast (that is, bearberry). Landin at al. (1989) noted that the planted species had declined significantly in cover from their initial establishment, which was accompanied by intensive applications of fertilizer. The continued dominance by short-statured species, mosses, and plants adapted to nutrient-poor, well-drained substrates suggests that soil properties are limiting further development of the upland plant community. Strategic placement of fine-textured dredged material in the target area for the meadow would have promoted a more diverse species composition but would also encourage the establishment of a more woody plant community. Miller Sands lacks landscape processes that promote and maintain grassland features (that is, fire, grazing) and would require continuous vegetation management to sustain the meadow feature. Landin, Webb, and Knutson (1989) did not compare the meadow to a nearby reference site because no similar site occurred within close proximity.

The total cover recorded in the meadow has continued to increase from 52.4% to 133.0%, although much of it is the result of mosses that have expanded while many target species of vascular plants have declined or disappeared (Table 3-11). Mosses are often pioneer species on substrates with harsh conditions (for example, high pH, low nutrients) and can facilitate establishment of vascular plants through protection of the soil and its microbial community and increase of macronutrient availability (Bu et al. 2015). The meadow feature has displayed an apparent reversal in seral-stage development to a pioneer community, while simultaneously experiencing encroachment by woody plants such as bearberry, Himalayan blackberry, and Scotch broom. Intensive efforts to remove Scotch broom from the meadow have taken place periodically; however, legacy effects of its allelopathic compounds in the soil may continue to affect recruitment of desirable species (Grove et al. 2012).

Table 3-11. Percent cover by species recorded from the upland meadow at Miller Sands, Astoria, Oregon.

	1982	1984	1986	2019
Agrostis gigantea	1.0	13.9	15.3	0.0
Agrostis oregonensis	1.3	0.0	2.0	0.0
Anaphalis margaritacea	0.1	0.0	0.2	0.0
Arctostaphlyos uva-ursi	0.0	0.0	0.0	14.3
Bromus sterilis	0.1	0.0	0.3	0.0
Bromus tectorum	0.1	0.0	0.5	0.0
Capsella bursa-pastoris	0.0	0.0	0.0	0.3
Cerastium sp.	1.0	0.0	0.3	0.0
Conyza canadensis	0.0	0.0	0.0	0.1
Cytisus scoparius	0.0	0.0	0.0	5.9
Digitalis purpurea	0.0	0.0	0.0	0.3
Equisetum hymale	9.3	13.9	10.4	1.4
Festuca rubra	5.9	14.3	13.7	2.0
Holcus lanatus	0.0	0.0	0.0	4.9
Hypericum sp.	0.0	0.0	0.0	0.4
Hypochaeris radicata	0.0	2.2	2.0	0.2
Leucanthemum vulgare	0.0	0.0	0.0	0.6
Lolium sp.	0.0	0.1	0.1	0.0
Lotus corniculatus	0.0	0.1	0.3	0.0
Lupinus rivularis	4.0	1.8	2.2	0.0
Medicago sp.	0.0	1.3	1.6	0.2
Oemleria cerasiformis	0.0	0.0	0.0	0.1
Pascopyrum smithii	0.7	0.0	0.0	0.0
Phalaris arundinacea	2.8	2.2	2.4	0.0
Plantago lanceolata	3.1	1.4	2.0	2.3
Poa compressa	0.1	0.0	0.3	0.0
Prunus sp.	0.0	0.0	0.0	0.1
Raphanus sp.	0.0	0.0	0.0	0.1
Rubus bifrons	0.0	0.0	0.0	20.7
R. laciniatus	0.0	0.0	0.0	0.6
Rumex acetosella	0.8	0.0	0.2	17.5
Schedonorus arundinaceus	6.7	9.4	10.6	0.0
Silene antirrhina	0.1	0.0	0.1	0.0
Trifolium dubium	0.4	0.7	0.9	0.0
Trifolium repens	0.3	0.0	0.1	0.0

	1982	1984	1986	2019
Trifolium sp.	0.0	0.2	0.6	0.0
Tsuga heterophylla	0.0	0.0	0.0	0.2
Unknown	0.0	0.0	0.0	0.7
Vicia sp.	0.1	0.0	0.0	0.1
Vulpia myuros	0.0	0.9	1.0	0.0
Nonvascular plants	14.5	30.4	29.8	60.0
Total	**52.4**	**92.8**	**96.9**	**133.0**

The dune community that was established now occupies approximately 1.5 ha. Landin, Webb, and Knutson (1989) noted an initial expansion by European beach grass well beyond the planted area but later showed signs of woody encroachment beginning in the 1980s. This species competes well on deep xeric sands that experience periodic shifts in depth and appears to have succeeded along frontal portions of sandy embankments. European beach grass and American beach grass (*A. breviligulata*) are considered invasive on the Pacific coast and capable of displacing native dune grass (*Elymus mollis*) communities (Seabloom and Wiedemann 1994).

Long-term maintenance of a dune community at Miller Sands may require higher features composed of unconsolidated material in order to create the instability and xeric conditions of a natural dune. Plant species that occupy dunes are also adapted to burial sediments deposited by prevailing wind or storm events. An alternative approach would be to initiate intermittent thin-layer additions of sand that simulate natural coastal processes and suppress or eliminate maladapted plant species. Landin, Webb, and Knutson (1989) did not match the dune community to a reference site because there were no nearby dune features to compare to those constructed at Miller Sands. These features occur approximately 25 km to the west, where there is a greater maritime influence of wind, wave action, and sediment transport along the Pacific Coast. Establishment of locally novel habitats, though desirable from a regional perspective, may create burdensome and recurrent management requirements in order to achieve and maintain target ecological outcomes.

3.9 Vegetation community assessment summary

The vegetation community data collected during the 2019 survey demonstrate that the habitat improvement projects continue to provide a

variety of habitat functions important to ecological processes. In general, the projects achieved the target habitat types (that is, marsh, meadow), and those features have been sustained for more than four decades (Table 3-12). Notably, the spatial extent of habitat components and the suite of vegetation species present today differ from the conditions observed during postconstruction and early monitoring surveys at some study locations. For example, a number of the vegetation species planted or initially established at the Bolivar Peninsula are either absent or occur as minor components of the plant community. One limitation of the study is the paucity of data related to sampling locations, methodologies, and other information associated with the historic monitoring data reports. For the current effort, the authors have attempted to provide more-detailed information to support future investigations of the habitat improvement areas.

Table 3-12. Summary of target vegetation community types, success of sustained development over the 40 year monitoring period, challenges, and management opportunities to improve vegetation conditions at the study locations.

Location	Habitat type	Present after >40 years	Sustainable without intervention	Challenges	Management opportunities
Bolivar Peninsula, TX	Low marsh	No	No	Erosion	Sediment placement
	High marsh	Yes	Yes	None	None
	Herbaceous upland	Yes	Yes	Undesirable species	Selective species control
	Woody upland	Yes	Yes	Planted some species outside of native range, poor survival	Selective species control
Drake Wilson Island, FL	Low marsh	Yes	Yes	Land surface decrease	Sediment placement
	High marsh	Yes	Yes	Land surface decrease	Sediment placement
	Woody upland	Yes	Yes	None	None
Buttermilk Sound, GA	Low marsh	Yes	Yes	None	None
	High marsh	Yes	Yes	None	None
	Unvegetated upland	Yes	No	Woody species encroachment	Selective species control

Location	Habitat type	Present after >40 years	Sustainable without intervention	Challenges	Management opportunities
Nott Island, CT	Upland meadow	Yes	Yes	Undesirable species, poor soil quality	Selective species control, soil amendments
Pointe Mouillee, MI	Freshwater marsh	Yes	No	Woody species encroachment, ongoing management	Selective species control
Miller Sands, OR	Upland meadow	Yes	No	Poor soil quality, woody vegetation encroachment	Selective species control, soil amendments
	Tidal marsh	Yes	Yes	Erosion, Invasive species	Selective species control
	Dune	Yes	No	Lack of sediment	Sediment placement

The shift in species composition following construction is not unanticipated, as ecological succession occurs in response to biotic and abiotic factors that drive the success of individual species and plant communities over time (Zedler 2000). In some cases the disconnect between project designs and steady state conditions can be attributed to inappropriate species selection, including the planting of some species (for example, sand pine in coastal Texas) outside of their native ranges. At other habitat improvement project locations, target communities may not be sustainable without further interventions to maintain favorable conditions. For example, additional periodic sediment placement may be required to maintain low marsh communities (Bolivar, Texas), woody plant removal would help sustain open sandy habitats (Buttermilk Sound, Georgia), and soil amendments would help improve the conditions for vegetative growth in areas subject to nutrient limitations (Miller Sands, Oregon). Additionally, nuisance, invasive, and non-native species pose a significant challenge to achieving ecological goals across many of the habitat improvement sites as well as at a subset of the reference locations evaluated. In general, the number of undesirable species and their abundance has increased throughout the postconstruction period.

The available data suggest that in some instances initial planting efforts had limited effects on the occurrence and distribution of plant species

after 40 years of ecological succession. Mitsch et al. (1998) have inferred that in areas with rapid natural recruitment postrestoration, plantings may not be necessary. In the current study, plantings of salt-meadow cordgrass and smooth cordgrass at Drake Wilson Island have become components of more complex communities, and other species (for example, black needlerush) that were not planted have been recruited. In other cases planted species (for example, black needlerush at Buttermilk Sound) are no longer observed within the project area or occur to a much lower extent. Despite the absence of some planted species at habitat improvement locations >40 years after construction, establishing appropriate species following project construction has advantages even if those plant communities do not persist or undergo alteration over decadal timescales. Initiating vegetative growth after disturbance has been shown to stabilize soils and sediments, accelerate dewatering, provide habitat, help prevent or decrease the establishment of undesirable plant species, improve soil health, and promote ecological functions (Bailey et al. 2019). Additionally, establishing plant communities can influence the trajectory of restoration areas, even if the initial species introduced fails to persist, migrates in response to environmental conditions, or becomes integrated into a more diverse plant assemblage (Simenstad et al. 2006). The establishment of desirable species has also been shown to preclude the invasion of nondesirable species and may provide other benefits as ecological succession takes place.

Despite the shifts in vegetation community composition since construction, several trends emerge across the monitoring period. First, the overall complexity of study location generally increased, as observed at Bolivar Peninsula, which exhibited six distinct vegetation communities during the 1988 assessment and increased to 10 vegetation communities in 2019 (Table 3-13). The increase in complexity over time is not unexpected given natural patterns of vegetation recruitment, response to disturbance, and the adjustment of plant communities to local conditions following four decades of plant succession. Increases in species complexity following restoration have been reported in other studies, especially as seed banks become enriched over time. Baldwin (2004) provides a model outlining patterns of plant distribution following restoration, planting, colonization, and expansion of clonal perennials in restored or created marsh habitats. As outlined in the model, observed increases in species richness are not expected to continue indefinitely as the habitat improvement sites reach maturity; however, the species composition will

respond to disturbances (for example, floods, fire) and changes in ecological conditions (for example, climate, invasive species introduction) in the future. These changes reflect natural and anthropogenic drivers occurring in both habitat improvement locations and reference communities.

Second, the vegetation community assemblages observed in the habitat improvement sites were also more ecologically complex than the reference areas, with the exception of the Cat Point reference area, which exhibited barrier-beach features absent at the Drake Wilson Island study location. The increased complexity results from a combination of factors, including the wider variety of topography within the constructed project areas relative to the reference areas. This finding may seem counterintuitive, as other studies have identified the lack of topographic heterogeneity (for example, microtopographic relief) as a limitation on many restoration projects (Bruland and Richardson 2005). However, within the sample locations examined, one of the driving factors behind the restoration design was to create appropriate ecological gradients that would support a variety of habitats. This effort included the intentional establishment of upland, transitional, high-marsh, and low-marsh target habitat types according to ecologically based landforms and hydropatterns.

Third, the number of species in target communities has generally remained stable or increased over time and displays higher species richness than the reference locations examined. This finding suggests that the habitat improvement project has reached a moderate level of maturity yet does not directly mimic the plant community assemblages of reference areas. The differences in species richness align with reports that engineered or restored areas often exhibit more species than their natural counterparts (Ehrenfeld 2000). The differences in species composition and richness may include intentionally or unintentionally introduced plants, the response of plant communities to substrate conditions, or reflect disturbance patterns associated with the restoration design and implementation (Baldwin and Derico 1999).

Finally, both habitat improvement locations and reference areas appear to be responding to environmental conditions in similar ways despite the observed differences in species composition and structural complexity. More invasive species were observed at the study locations and reference areas during 2019 than during previous investigations, and those species

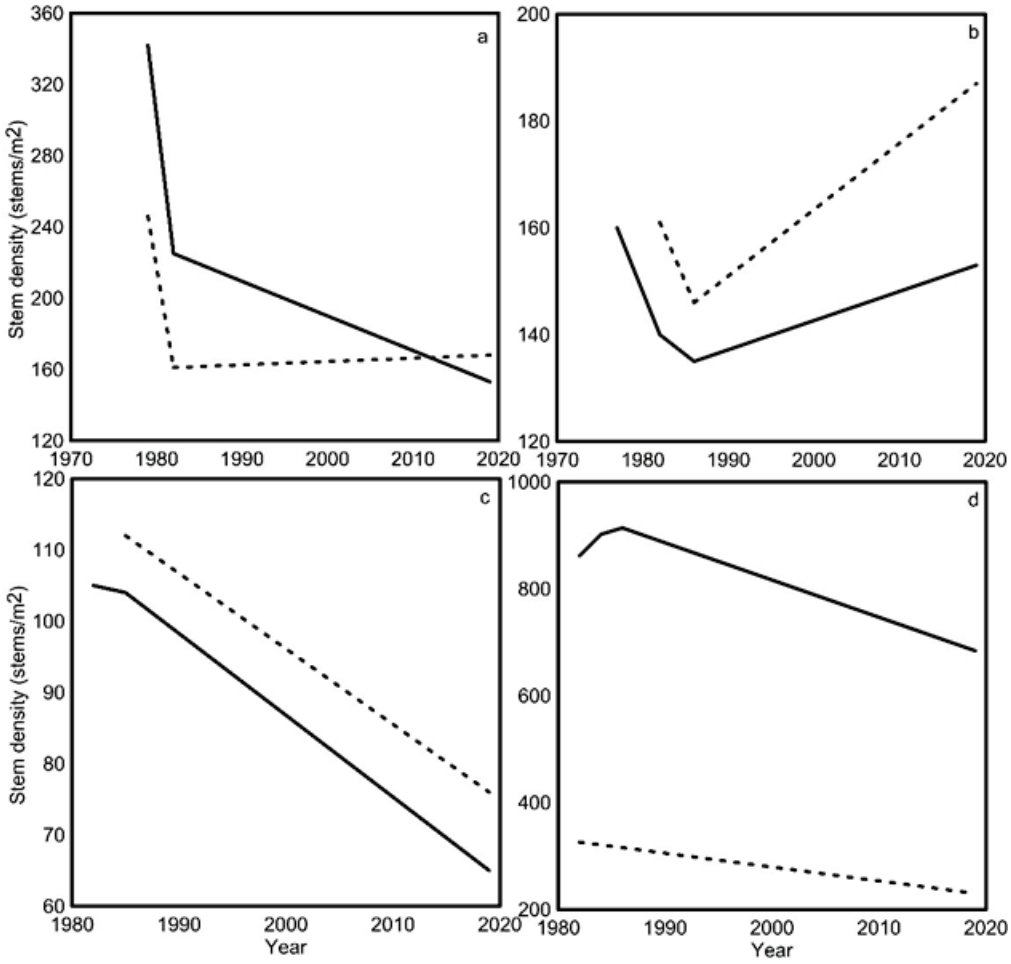
appear to be increasing in abundance. This trend has been reported in other areas and at large spatial scales, where anthropogenic landscape alterations coupled with natural patterns of disturbance and plant dispersal are leading to increased alien invasions (Richardson et al 2007). Additionally, stem densities in both restored and reference areas follow similar patterns over the multidecadal assessment period despite the observed differences (Figure 3-26). This similarity further suggests that the vegetation communities at habitat improvement locations are exhibiting the same responses to changing environmental conditions that affect plant distribution and growth at reference areas.

In summary, these findings suggest that the vegetation communities established at the habitat improvement sites generally reflect the conditions at reference areas but do replicate the species composition and distribution observed in un-engineered systems. However, the study locations are effectively providing habitat for a variety of species, and generally appear to be stable features that will persist into the future. Results also indicate that additional management activities could further improve site conditions especially with regard to selective species management, and in some cases the implementation of period disturbance regimes (for example, additional sediment deposition) may improve the sustainability of some landscape features including low marshes and coastal fringe wetlands.

Table 3-13. Summary of vegetation community characteristics. (NA = no data available.)

	Vegetation community assemblages (count)		Species richness in select community types (count)			
Location	Habitat improvement project	Reference location	Community type	Current conditions	Historic conditions	Reference locations
Bolivar Peninsula, TX	10	1	Low marsh	4	2	2
Drake Wilson Island, FL	6	8	Low marsh	2	2	2
Buttermilk Sound, GA	4	2	Marsh	3	4	3
Nott Island, CT	10	4	Meadow	16	5	N/A
Pointe Mouillee, MI	7	N/A	Marsh	7	4	N/A
Miller Sands, OR	7	1	Marsh	18	17	15

Figure 3-26. Comparison of stem density data from habitat improvement locations (solid lines) and reference areas (dashed lines) at (a) Bolivar Peninsula–Pepper Grove, Texas; (b) Drake Wilson Island–Cat Point, Florida; (c) Buttermilk Sound–Hardhead Island, Georgia, and (d) Miller Sands–Snag Island, Oregon. Note that while the magnitude of stem densities varies, the constructed and reference locations display similar patterns and responses to environmental conditions.



4 Assessment of Avian Communities at Habitat Improvement Locations

4.1 Overview

Avian communities can provide additional data as to the quality of habitat (Bock and Jones 2004) as well as the level of success achieved when managing environments through restoration or habitat improvement (Neckles et al. 2002; Zhao et al. 2016). One tool that can increase habitat in coastal environments is the targeted, intentional placement of dredged materials to develop new habitat or improve existing habitat. A wealth of knowledge exists about the use of dredged placement material to create and renourish coastal islands as suitable breeding habitat for numerous species of colonial nesters such as terns, gulls, skimmers, pelicans as well as numerous species of beach-nesting shorebirds (Parnell et al. 1986). In addition to providing breeding habitat, dredged-material islands are used extensively by birds for loafing, roosting, and feeding (Soots and Landin 1978). The creation of artificial islands through the placement of dredged material from maintaining navigational channels by USACE has been in place for over 100 years (Guilfoyle et al. 2006). These constructed islands have resulted in great benefits to wildlife, especially species such as waterbirds that rely on these habitats to successfully breed and reproduce (Erwin et al. 2003).

Restoration of marsh habitat for birds has been shown to be as productive as natural marshes in some circumstances (Streever 2000; Ratti et al. 2001) or productive with a different species assemblage from that of natural marshes (Melvin and Webb 1998). The US Army Engineer Research and Development Center–Environmental Laboratory (ERDC-EL) implemented various habitat improvement projects, as in areas where dredged material has been deposited as described in section 2.0. Most of these restoration efforts began in the early 1970s with the primary objectives to (1) document the long-term stability of each site, (2) determine successional changes taking place, (3) relate site functions and values to natural systems, and (4) demonstrate that habitat development could be accomplished using dredged material (Landin et al. 1989, 1). Initial studies by Landin, Webb, and Knutson (1989) monitored conditions at the habitat improvement locations, including the capacity of the areas to support avian communities. The following describes the results of a 2019 assessment to revisit a subset of the historic habitat improvement sites to

assess the overall bird community structure to determine whether sites still supported thriving avian populations or whether a change in community structure occurred with changing habitats over the past 40 years. Comparisons with data collected during the previous monitoring efforts are also included.

4.2 Methods and analysis

Avian surveys were conducted between 2 April and 7 June 2019 by the same observer at six beneficial use dredged island projects. Surveys during early April at Bolivar Peninsula were conducted during the migratory period and targeted spring migrants, particularly shorebirds. Surveys at the remaining five sites were conducted from late April to June to maximize detection of breeding individuals and decrease detection of migratory individuals. Fixed point-count locations were initially established at all sites using ArcGIS 10.6 using a systematic-random process. The survey began with high-resolution aerial imagery, placing a sampling point close to one end of the study location, and then proceeded down a practical route, where placing another sampling point to have sufficient coverage of habitats within the study site. The survey attempted to place at least one point for every 10 ha of habitat, roughly the size of a 125 m radius plot on all restoration sites except at Pointe Mouillee, where points were spaced approximately 1,000 m apart in order to sample the entire CDF during a single survey. Habitat at reference sites generally were more uniform; therefore, fewer point counts were established in order to sufficiently collect data on species presence. The geographic locations for all point-count stations were entered into BaseCamp (Garmin, Olathe, Kansas) software and downloaded into handheld GPS units so that the observer could find points in the field. A total of 117 unique points (appendices A and B) were sampled on 6 restoration and 5 reference sites.

Each time a point was visited, the observer conducted an unlimited-distance, five-minute point count during which all individual birds seen or heard from the sampling point were recorded. The observer spent part of the survey facing in each cardinal direction so as to detect as many birds as possible. Birds that were flying over the survey area were tallied separately, as the observer could not be confident that these birds were using the survey area. Birds that flushed because of the observer's approach were recorded, regardless of whether they remained in the survey area. Surveys were not conducted in heavy rain or in winds >32 km/hr, and all surveys were conducted between 0430 and 1100 with the

exception of Snag Island, which was completely inundated with tidal water until after 1100.

Each bird species encountered was first classified as either a land bird, waterbird, raptor, nightjar, or a swift or swallow, which allowed categorization of land bird occurrence data separately, because accurately assessing breeding residency for the other groups using point count methodology during a single site visit can prove challenging. Only birds encountered actually using habitat at a site were used in calculations, with those individuals that appeared to be flying over the area and not stopping considered transient individuals. For this reason, the survey separated calculations into two categories: (1) birds detected using the site and (2) birds observed flying over and not stopping. The survey then calculated total bird abundance and average abundance per point for all sites, species richness in the same manner as abundance at each site, and the mean value for all points located at a site. These calculations provided seasonal values for each variable at each site, which can be interpreted as the mean number of individuals or species one would expect to encounter at a random point on that site during a five-minute point count. As a caveat, this method ignores annual variation in bird communities that could indeed affect results.

The 2019 survey also generated tables for each site to reflect the total abundance by species, with the original objective to compare results from current surveys to those conducted by Landin, Webb, and Knutson (1989) during and immediately following marsh restoration on islands that received placement of dredged material. However, methods for surveying the avian community at those sites varied greatly and replicating any design from past surveys proved challenging. Interpreting and comparing results from Landin, Webb, and Knutson (1989) to the 2019 results also proved difficult because of survey periods and intensity. Prior studies surveyed for several months to year-round at sites, and most sites were surveyed for multiple years. This study was much smaller in scope, and funding levels only allowed for one site visit during a period that was determined optimal for detecting breeding or migratory birds. Therefore, statistical comparisons between the two studies was not possible. However, general comparisons between the two survey periods were, and this study was able to determine whether habitats established during restoration activities still provide beneficial habitat to avian communities, which was the primary objective.

4.3 Avian community assessment results across habitat improvement sites and comparisons with historic data

A total of 90 breeding and 27 spring migration bird point-count surveys were conducted in 2019, in which 3,790 individual birds were encountered. Pepper Grove, Snag Island, and Pointe Mouillee supported the greatest total bird abundances per point of all sites sampled during summer 2019 (Table 4-1). Pepper Grove also supported the greatest species richness, with Bolivar Peninsula and Pointe Mouillee supporting high species richness as well (Table 4-2). Pepper Grove, Snag Island, and Pointe Mouillee contained the highest average species richness per point (Table 4-2). For locations where both restoration and reference sites were surveyed during the breeding season, the survey documented higher total species richness and average species richness at restoration sites. Habitats were generally more diverse within restoration sites, which likely contributed to the higher levels of species abundance and richness compared to reference sites. However, we observed higher total and average species richness at the Pepper Grove reference site during the spring migration season. High total abundance and species richness at this site was likely due to the high numbers of waterbirds using the area as a winter or spring stopover site.

Table 4-1. Total and average abundance of avian species detected at point counts at the habitat improvement and reference locations during spring and summer 2019. Note, no reference area was available in the vicinity of the Pointe Mouillee habitat improvement location. (HI: habitat improvement; R: reference)

Site	Number of point counts surveyed	Total abundance including flyovers	Total abundance excluding flyovers	Average abundance per point including flyovers	Average abundance per point excluding flyovers
Bolivar Peninsula, TX (HI)	21	406	256	19	12.2
Pepper Grove, TX (R)	6	746	586	124	97.7
Drake Wilson Island, FL (HI)	8	129	78	16	9.8
Cat Point, FL (R)	6	100	60	17	10
Buttermilk Sound, GA (HI)	6	118	93	20	15.5
Hardhead Island, GA (R)	8	115	59	14	7.4
Nott Island, CT (HI)	11	202	179	18	16.3

Site	Number of point counts surveyed	Total abundance including flyovers	Total abundance excluding flyovers	Average abundance per point including flyovers	Average abundance per point excluding flyovers
Eustasia Island, CT (R)	9	132	127	15	14.1
Pointe Mouillee (HI)	16	871	558	54	34.9
Miller Sands, OR (HI)	22	776	715	35	32.05
Snag Island, OR (R)	3	155	147	52	49

Table 4-2. Total and average species richness of avian species detected at the habitat improvement and reference locations during spring and summer 2019. Note, no reference area was available in the vicinity of the Pointe Mouillee habitat improvement location. (HI: habitat improvement; R: reference)

Site	Number of point counts surveyed	Total species richness including flyovers	Total species richness excluding flyovers	Average species richness per point including flyovers	Average species richness per point excluding flyovers
Bolivar Peninsula, TX (HI)	21	61	49	7.5	4.52
Pepper Grove, TX (R)	6	60	57	18.33	14.17
Drake Wilson Island, FL (HI)	8	32	24	10.88	7.5
Cat Point, FL (R)	6	28	20	8.83	5.5
Buttermilk Sound, GA (HI)	8	16	12	8.0	6.17
Hardhead Island, GA (R)	6	14	5	6.0	3.5
Nott Island, CT (HI)	11	43	36	9.75	9.45
Eustasia Island, CT (R)	9	30	26	8.77	8.22
Pointe Mouillee (HI)	16	52	45	10.81	8.06
Miller Sands, OR (HI)	22	39	37	8.77	8.09
Snag Island, OR (R)	3	16	11	7.0	5.0

Wetland-dependent birds were present at all sites. Marsh wren, red-winged blackbird, and yellow warbler were the most commonly detected species that likely nested at the sites. Other common wetland-breeding species frequently detected included boat-tailed grackle, clapper rail, common yellowthroat, and willow flycatcher (appendix C). Numerous waterbirds were detected at all sites (appendix D); however, many waterbirds breed colonially in rookeries (for example, herons or egrets) or on large sections of exposed sandy areas (for example, terns or skimmers). Only one rookery was detected with great blue herons and a large colony detected of breeding white pelicans, both at Miller Sands.

Land bird use of a site is often more comparable, as other groups of birds such as raptors or waterbirds may incorporate multiple habitats associated with their life history into a large home range. Therefore, only surveying a site once can make detection of these species challenging if site use is to be considered. This survey detected a higher percentage of land birds at sites surveyed in 2019 compared to total species richness detected across multiple surveys throughout the year over multiple years, as documented by Landin et al (1989). The 2019 survey also detected more species of land birds at two sites (Buttermilk Sound and Pointe Mouillee CDF) in 2019 (Table 4-3; appendix D).

Table 4-3. Comparison of total land bird species richness detected at sites during previous surveys and during 2019. Note, previous study conducted multiple surveys year-round and over multiple years, while the 2019 effort included a single survey. As a result, the values are not directly comparable.

Habitat improvement location	2019 surveys	Landin, Webb, and Knutson 1989	Species observed at site during both time periods
Bolivar Peninsula, TX[a]	18	61	15
Drake Wilson Island, FL	15	21	7
Buttermilk Sound, GA	10	6	4
Nott Island, CT	27	31	16
Pointe Mouillee, MI	16	12	11
Miller Sands, OR	21	35	20

a. Bolivar Peninsula was surveyed during the spring migration season where species presence can change daily.

Raptors, like waterbirds, can be difficult to fully assess site occupancy because of their large home range size. Raptors hunting for prey may spend significant time in areas far from nesting locations. Two raptors that are associated with coastal environments and are notable to mention for sites in this study are ospreys and bald eagles. Osprey and bald eagle populations have greatly recovered following legislative protection (for example, Bald and Golden Eagle Protection Act,[2] Endangered Species Act,[3] Migratory Bird Treaty Act[4]) and the ban of the chemical dichlorodiphenyltrichloroethane (DDT). Ospreys were only observed at half the sites during Landin, Webb, and Knutson (1989) surveys but observed at all sites during 2019. During 2019 surveys, ospreys were observed nesting at Pointe Mouillee and very near to Nott Island. Bald eagles were observed nesting successfully at Miller Sands Island and at Eustasia Island (Table 4-4). Islands created from dredged materials continue to support habitat for both raptors, including suitable nesting sites. The sections below report the findings of the bird assessments conducted at each habitat improvement location and reference area.

Table 4-4. Comparison of observations of osprey and bald eagles at dredged islands for avian surveys conducted by Landin, Webb, and Knutson (1989) and the current 2019 surveys.

	Osprey		Bald Eagle	
Site	1989	2019	1989	2019
Bolivar Peninsula	X	X		
Apalachicola Bay		X		X
Buttermilk Sound	X	X		
Nott Island	X	X		X
Pointe Mouillee		X		
Miller Sands		X	X	X

4.4 Bolivar Peninsula

The Bolivar Peninsula habitat improvement project serves as a critical stopover site for migratory shorebirds. The Bolivar Peninsula habitat

2. Bald and Gold Eagle Protection Act of 1940, 16 U.S.C. § 668 et seq. (2019). https://www.govinfo.gov/content/pkg/USCODE-2019-title16/pdf/USCODE-2019-title16-chap5A-subchapII.pdf.

3. Endangered Species Act of 1973, 16 U.S.C. 35 § 1531 et seq. (2019). https://www.govinfo.gov/content/pkg/USCODE-2019-title16/pdf/USCODE-2019-title16-chap35.pdf.

4. Migratory Bird Treaty Act of 1918, 36 U.S.C. § 703 et seq. (2019). https://www.govinfo.gov/content/pkg/USCODE-2019-title16/pdf/USCODE-2019-title16-chap7-subchapII.pdf.

improvement site (Figure 4-1) established by ERDC-EL in 1978–1981 consists of multiple habitats along an elevational gradient from mudflat and sandy beach to an upland shrub and forest community. The restoration site is located in close proximity to the Bolivar Flats Shorebird Sanctuary owned by the Houston Audubon Society. Bolivar Flats Shorebird Sanctuary is approximately 486 ha and is a Western Hemisphere Shorebird Reserve Network site of International Importance because of its location along the Gulf of Mexico, which provides high-quality resting and feeding habitat for thousands of shorebirds and other waterbirds. Since the Bolivar restoration site is such an important area for spring migrant shorebirds, the avian community survey took place in early April rather than later into the breeding season.

The survey detected several waterbirds listed as species of conservation concern, including dunlin, willet, Wilson's plover, gull-billed tern, least tern, sandwich tern, ruddy turnstone, American oystercatcher, marbled godwit, reddish egret, and whimbrel (USFWS 2008; Table 4-5). A significant number of shorebirds and other waterbirds were detected at Bolivar Peninsula by Landin, Webb, and Knutson (1989). Over 40 years after the project was constructed, the habitat improvement site continues to support suitable conditions as a stopover site for numerous shorebirds according to observations made during 2019. Breeding sites for shorebirds such as Wilson's plover that use exposed sandy beach habitat are limited at Bolivar Peninsula, as fluctuating tides typically inundate most of these areas; however, the habitat may be capable of supporting a few breeding pairs. Allen et al. (1978) reported nesting Wilson's plover at Bolivar Peninsula in the experimental upland, and the Wilson's plovers detected during 2019 may still use these areas for nesting.

Figure 4-1. Bolivar Restoration Site, Bolivar Peninsula, Texas, April 2019.



Pepper Grove is a reference site to Bolivar Peninsula located east of the restoration site. Compared with the Bolivar habitat improvement project, Pepper Grove represents a much larger area composed of coastal marsh vegetation (Figure 4-2) and is located immediately adjacent to a series of freshwater impoundments associated with the Intercoastal Waterway navigation channel. As a result, Pepper Grove supported a higher species richness of shorebirds and waterbirds (40 species) than Bolivar Peninsula (33 species), likely because of the availability of abundant coastal and freshwater habitats within the immediate area. Given the limited survey efforts, the number of waterbird detections was very high at both sites—even prior multiyear surveys only detected slightly higher species richness (62 species; Landin, Webb, and Knutson 1989). The reference site also supported a much higher abundance of birds, mainly waterbirds, including large numbers of American coots and blue-winged teal (Table 4-6). However, previous surveys comparing species richness showed greater diversity at Bolivar Peninsula than at the other reference sites (Landin, Webb, and Knutson 1989).

A previous study investigating differences in bird communities between natural and created salt marshes in the Galveston Bay area showed species richness was higher in natural salt marshes during all months except May, June, and July, which coincides with the nesting period for a large number of gulls and terns that use areas around created marshes (Melvin and Webb 1998). The 2019 survey findings align with the previously completed research. However, the Bolivar Peninsula site supports a high diversity of birds because of the variety of habitat components present despite lacking the very productive freshwater impoundments that abut Pepper Grove.

Figure 4-2. Pepper Grove Reference Site. Bolivar Peninsula, Texas, April 2019.



Table 4-5. All species observed at Bolivar Peninsula restoration site that either appeared to be using the site or only passing over during avian surveys on 2 April 2019 near Galveston, Texas. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Laughing gull	59	31	Sandwich tern†	3	2
Dunlin†	32	32	Savannah sparrow	3	3
Willet†	32	25	Snowy egret	3	2
Brown pelican	31	0	Swamp sparrow	3	3
Cattle egret	22	0	Unidentified dowitcher	3	3
Royal tern	19	16	White-tailed kite	3	3
Black-bellied plover	18	17	American oystercatcher†	2	2
Forster's tern	18	16	Herring gull	2	0
White ibis	15	0	Marsh wren	2	2
Tree swallow	11	7	Red-breasted merganser	2	0
Lesser scaup	10	10	Scissor-tailed flycatcher	2	2
Northern rough-winged swallow	10	0	Yellow-throated warbler	2	2
Black-necked stilt	9	9	Carolina Wren	1	1
Barn swallow	8	3	Great blue heron	1	0
Prothonotary warbler†	8	8	Great egret	1	0
Song sparrow	6	6	Indigo bunting	1	1
Least sandpiper	4	4	Marbled godwit†	1	1
Red-winged blackbird	4	4	Mottled duck	1	1
Roseate spoonbill	4	0	Northern harrier	1	1
Unidentified tern	4	4	Northern parula	1	1
Wilson's plover†	4	4	Orange-crowned warbler	1	1
Boat-tailed grackle	3	1	Osprey	1	0
Common tern	3	3	Reddish egret†	1	1
Double-crested cormorant	3	0	Red-tailed hawk	1	1
Eastern meadowlark	3	3	Tricolored heron	1	1
Gull-billed tern†	3	2	Unidentified rail	1	1
Least tern†	3	0	Unidentified sparrow	1	1
Mourning dove	3	3	Unidentified warbler	1	1

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Northern mockingbird	3	3	Whimbrel†	1	1
Palm warbler	3	3	Yellow-rumped warbler	1	1
Ruddy turnstone†	3	3			

Eleven shorebird species occurred at both the Bolivar restoration site and the Pepper Grove reference site; however, species composition differed between sites, with only four species occurring at both sites. Daily temporal conditions likely affected detection of some species, as fluctuating tides exposing beaches or inundating marsh vegetation affects foraging behavior of numerous waterbirds. Even with these changing environmental conditions, the 2019 survey detected a high number of species using both areas, further supporting each site's importance as habitat as both a breeding and migratory stopover site for several species of conservation concern.

Surveys conducted at the Bolivar Peninsula habitat improvement site in 1977 detected 27 least tern nests (Allen et al. 1978). Least terns require sandy beaches or sandbars with little vegetation in which to nest (Thompson et al. 1997). Historic descriptions and photographs of the site show more suitable beach-nesting habitat available in 1977 compared to very little remaining beach habitat during 2019 as a result of vegetation establishment over the past 40 years. Placement of additional dredged deposits in the area could support beach-nesting birds such as least terns, especially given the fact that these species were nesting at the site during early successional stages. Numerous least terns were observed foraging offshore of the island, which indicates that suitable nesting habitat is likely nearby.

Unfortunately, surveys were only conducted early during the migration season with a focus on migratory shorebirds, likely missing the best window to detect neotropical migratory songbirds using the area as a stopover site or songbirds typically breeding at the site that had not yet arrived. The survey did detect several prothonotary warblers using the site as a migratory stopover at Bolivar restoration site and Nelson's sparrow using Pepper Grove as wintering habitat. Both of these passerines are considered species of conservation concern (USFWS 2008). A previous

study by Landin, Webb, and Knutson (1989) conducted surveys throughout the year and across multiple years, with many neotropical songbirds detected using the sites. Given the diverse habitats on the islands, which includes scrub-shrub and forested areas in addition to the coastal marsh, it is likely that these areas still serve as important stopovers for multiple species that arrived after our survey period in early April.

Table 4-6. All species observed at Pepper Grove reference site that either appeared to be using the site or only passing over during avian surveys on 3 April 2019 near Galveston, Texas. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
American coot	125	125	Lesser scaup	4	4
Blue-winged teal	84	81	American wigeon	3	3
Brown pelican	75	1	Black-necked stilt	3	3
Boat-tailed grackle	53	51	Northern mockingbird	3	3
Unidentified dowitcher	44	30	Pectoral sandpiper	3	3
Red-winged blackbird	36	35	Song sparrow	3	3
Short-billed dowitcher†	25	25	Whimbrel†	3	1
Willet†	24	16	Common gallinule	2	2
Double-crested cormorant	22	19	Eastern kingbird	2	2
Western sandpiper	21	21	Green-winged teal	2	2
Unidentified peep	20	20	Tricolored heron	2	1
Snowy egret	18	17	Unidentified duck	2	2
Gadwall	17	17	Barn swallow	1	1
White ibis	16	0	Brown-headed cowbird	1	1
Least sandpiper	15	15	Clapper rail†	1	1
American white pelican	13	9	Great egret	1	1
Royal tern	12	12	Gull-billed tern†	1	0
White-faced ibis	11	5	Lesser yellowlegs†	1	1

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Laughing gull	10	0	Little blue heron	1	1
Northern shoveler	6	6	Mourning dove	1	1
Purple martin	6	6	Osprey	1	1
Black-crowned night heron	5	5	Pied-billed grebe	1	1
Forster's tern	5	2	Nelson's sparrow†	1	1
Long-billed dowitcher	5	5	Savannah sparrow	1	1
Roseate spoonbill	5	4	Semipalmated sandpiper†	1	1
Sandwich tern	5	2	Sora	1	1
Tree swallow	5	3	Swamp sparrow	1	1
Turkey vulture	5	1	Unidentified yellowlegs	1	1
Black-bellied plover	4	4	Yellow-crowned night heron	1	1
Great blue heron	4	3	Yellow-rumped warbler	1	1

4.5 Drake Wilson Island

Drake Wilson Island was created in 1976 from dredged material in Apalachicola Bay, Florida. Smooth cordgrass and salt-meadow cordgrass were planted to initiate development of the marsh at the project site. Currently, the island continues to support a small but thriving marsh consisting mostly of sturdy bulrush and smooth cordgrass with black needlerush along the edge of the marsh (Figure 4-3). The remainder of the island is composed of upland vegetation, including a canopy of slash pine and a variety of understory vegetation. We detected numerous least terns foraging around Drake Wilson Island, though the island no longer appears to support suitable beach-nesting habitat. Clapper rail and willet were detected in the marsh, both species of conservation concern that use marsh habitat for nesting (Table 4-7). Marsh-nesting species, including marsh wren, boat-tailed grackle, and red-winged blackbirds, were detected using the marsh. Three bald eagles were observed using the island, and although Drake Wilson Island contains larger trees capable of supporting nesting bald eagles, no nesting individuals were observed. Pine trees are

the dominant tree species present on the island, which is notable, as numerous brown-headed nuthatches were detected. Prior surveys by Landin, Webb, and Knutson (1989) failed to detect any brown-headed nuthatches, likely because suitable habitat was not present, as the island supported an early-successional plant community. Currently, the island supports an avian community dominated by upland breeding species. The survey detected red-winged blackbirds in high densities around the fringe of the island where marsh habitat existed. Few neotropical migrants were detected on the island; however, the survey efforts were focused on the breeding community and not migrant species populations. However, it is likely that the island serves as important stopover habitat to migrating individuals crossing the Gulf of Mexico during spring migration, as was indicated by repeated surveys conducted by Landin, Webb, and Knutson (1989), which detected numerous neotropical migrants.

Figure 4-3. Marsh habitat surrounded by pine woodland and scrub-shrub at Drake Wilson Island restoration site in Apalachicola Bay, Florida, 2019.



Table 4-7. All species observed at Drake Wilson Island restoration site that either appeared to be using the site or only passing over during avian surveys on April 29, 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Red-winged blackbird	16	15	Downy woodpecker	2	2
Least tern†	12	0	Forster's tern	2	0
Blue jay	11	11	Royal tern	2	0
Caspian tern	9	1	Spotted sandpiper	2	2
Northern cardinal	8	8	Belted kingfisher	1	1
Laughing gull	7	0	Blue-gray gnatcatcher	1	1
Barn swallow	6	0	Clapper rail†	1	1
Brown pelican	6	0	Eastern towhee	1	1
Brown-headed nuthatch	6	6	Great egret	1	1
Carolina wren	6	6	Green heron	1	1
Osprey	6	0	Marsh wren	1	1
Boat-tailed grackle	4	4	Mourning dove	1	1
Bald eagle†	3	3	Northern parula	1	1
Great-crested flycatcher	3	3	Northern rough-winged swallow	1	0
Northern mockingbird	3	3	Red-shouldered hawk	1	1
Red-bellied woodpecker	3	3	Willet†	1	1

The diversity of habitats surrounding the habitat improvement project on Drake Wilson Island supported a more diverse avian community than the reference site at Cat Point. Cat Point was characterized mostly by a much larger salt marsh consisting of black needlerush, saltwort, sturdy bulrush, salt grass, and smooth cordgrass (Figure 4-4). Cat Point did have more suitable shorelines with more exposed sandy beaches and mudflats, which is likely why species including American oystercatcher, ruddy turnstone, black-bellied plover, least sandpiper, and semipalmated plover were observed at the reference site compared to the restoration site (Table 4-8).

Figure 4-4. Cat Point reference site in Apalachicola Bay during Spring 2019 breeding bird surveys within a large coastal marsh.



Table 4-8. All species observed at Cat Point reference site that either appeared to be using the site or only passing over during avian surveys on 30 April 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Red-winged blackbird	27	22	Marsh wren	2	2
Bobolink†	11	8	Osprey	2	1
Least tern†	9	0	Red-bellied woodpecker	2	2
Laughing gull	7	0	Semipalmated plover	2	2
Brown pelican	5	0	American oystercatcher†	1	1
Boat-tailed grackle	4	3	Bald eagle	1	0
Turkey vulture	4	3	Blue jay	1	1
Northern cardinal	3	3	Caspian tern	1	0
Black-bellied plover	2	1	Clapper rail†	1	1
Blue-gray gnatcatcher	2	2	Eastern meadowlark	1	1
Carolina wren	2	2	Pied-billed grebe	1	1
Fish crow	2	1	Ruddy turnstone†	1	1
Forster's tern	2	0	Sora	1	1
Least sandpiper	2	2	Tricolored heron	1	0

4.6 Buttermilk Sound

Over four decades after implementation of the habitat improvement project, Buttermilk Sound continues to support obligate marsh breeding species. Clapper rails were abundant at Buttermilk Sound, likely because of the extensive salt-marsh vegetation (Figure 4-5). Marsh wrens, boat-tailed grackles, red-winged blackbirds, and common yellowthroats were also very abundant at this site, indicating its continued existence as high-quality breeding coastal marsh habitat (Table 4-9). The site also continues to exhibit a large sand deposit in the center of the site. This site could potentially be used for nesting by shorebirds and terns that require open sandy habitats if the surrounding woody vegetation were to be cleared. The survey detected numerous species that commonly occur in shrubby habitats, such as Carolina wren, common yellowthroat, eastern towhee, and northern cardinal, none of which were detected during the past study (Landin, Webb, and Knutson 1989), but did not detect many of the waterbirds likely to use the open sandy habitats, as the site has changed to a later successional stage characterized by woody vegetation encroachment. Previous surveys (Landin, Webb, and Knutson 1989) documented least terns using the large sand mound for nesting and hundreds of seabirds at the site for resting. Landin, Webb, and Knutson (1989) did note the Buttermilk Sound study site supported greater wildlife diversity than did the reference sites. This difference is due to more habitat types related to the elevational gradient from low marsh to sandy mound, which has experienced years of plant succession. The current habitat continues to support a thriving saltwater marsh in addition to the upland areas supporting a diversity of herbaceous and shrubby vegetation types.

Figure 4-5. Buttermilk Sound restoration site supporting multiple habitats including large expanses of coastal marsh, scrub-shrub, and sandy beach.



Table 4-9. All species observed at Buttermilk Sound habitat improvement site that either appeared to be using the site or only passing over during avian surveys on 1 May 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Red-winged blackbird	35	35	Northern cardinal	3	3
Barn swallow	16	2	American robin	1	1
Boat-tailed grackle	16	14	Black-crowned night heron	1	0
Clapper rail†	15	15	Carolina wren	1	1
Common yellowthroat	9	9	Eastern towhee	1	1
Marsh wren	7	7	Mourning dove	1	1
Forster's tern	6	0	Osprey	1	0
Blue-gray gnatcatcher	4	4	Unidentified yellowlegs	1	0

The Hardhead Island reference site also supported a similar avian community within marsh habitats (Figure 4-6) to that of the habitat improvement site; however, the reference site lacked upland habitats and the concomitant avian community. The dominant species that were abundant and are all likely to breed at Hardhead Island included clapper rail, marsh wren, red-winged blackbird, and boat-tailed grackle (Table 4-10). Notable fly-over observations at the reference site include the threatened wood stork and a species of conservation concern, the whimbrel. Both species occasionally may use the reference or study site as foraging habitat.

Figure 4-6. Buttermilk Sound reference site consisting of coastal marsh vegetation across entire island.



Table 4-10. All species observed at Hardhead Island reference site that either appeared to be using the site or only passing over during avian surveys on 2 May 2019 in Buttermilk Sound, Georgia. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Royal tern	33	0	Forster's tern	3	0
Boat-tailed grackle	20	17	Black-bellied whistling duck	2	0
Marsh wren	20	20	Wood stork†	2	0
Red-winged blackbird	12	12	Double-crested cormorant	1	0
Clapper rail†	9	9	Great blue heron	1	1
Caspian tern	6	0	Ring-billed gull	1	0
Unidentified peep	4	0	Whimbrel†	1	0

4.7 Nott Island

The Nott Island habitat improvement project supports a diverse assemblage of avian species, with the greatest abundance of birds being associated with shrubby habitats, including gray catbird, yellow warbler, song sparrow, and willow flycatcher. Nott Island differed from the other habitat improvement projects in that the target habitat did not include wetlands but instead focused on developing a productive upland meadow (Figure 4-7). However, several species associated with marsh habitats were

detected, including marsh wrens, red-winged blackbirds, and common yellowthroats (Table 4-11), and undisturbed marsh habitat does occur along the southeastern portion of the island.

Landin et al (1989) observed 70 bird species on Nott Island, and as observed during the current study, most species detected were not associated with marsh habitats. On the basis of habitat availability and species life history traits, it is likely that at least 23 species detected during this study were present at Nott Island because of its suitability as a nesting site. This result is similar to results from surveys during 1975 and 1976, in which 18 and 23 species, respectively, used the island for breeding (Warren et al. 1978). The top five most abundant land birds detected during May surveys in 1977 included common yellowthroat, yellow warbler, song sparrow, American goldfinch, and gray catbird (Barry et al. 1978). Only common yellowthroat was replaced by red-winged blackbirds among most abundant land birds in this study, showing similarities in the avian community between the two time periods.

Figure 4-7. The Nott Island habitat improvement site consisted of meadow and shrub-scrub habitat within the project area and undisturbed marsh habitat, including large stands of the invasive phragmites, in other portions of the island.



Past studies also observed both northern bobwhite and ring-necked pheasant on Nott Island, but the 2019 survey failed to detect either species. Habitat succession has occurred on the northern section of Nott Island that previously supported habitat for these species, and sustainable populations for these gamebirds likely no longer occur.

Table 4-11. All species observed at Nott Island habitat improvement site that either appeared to be using the site or only passing over during avian surveys on 23 May 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Gray catbird	22	22	Ruby-throated hummingbird	2	2
Red-winged blackbird	21	21	Tufted titmouse	2	2
Yellow warbler	20	20	Alder flycatcher	1	1
American goldfinch	18	18	American robin	1	1
Song sparrow	14	14	Bald eagle†	1	0
Cedar waxwing	13	13	Blue jay	1	1
Marsh wren	10	10	Blue-gray gnatcatcher	1	1
Unidentified peep	10	0	Double-crested cormorant	1	0
Willow flycatcher	7	7	Great blue heron	1	0
Mute swan	5	1	Great egret	1	1
Barn swallow	4	2	Greater yellowlegs	1	1
Carolina wren	4	4	Herring gull	1	0
Common grackle	4	0	Hooded warbler	1	1
Common yellowthroat	4	4	House finch	1	1
Mourning dove	4	4	Indigo bunting	1	1
Osprey	4	0	Least sandpiper	1	1
Chestnut-sided warbler	3	3	Northern cardinal	1	1
Semipalmated plover	3	3	Red-eyed vireo	1	1
American crow	2	1	Snowy egret†	1	1
Great black-backed gull	2	0	Swamp sparrow	1	1
Orchard oriole	2	2			

The Eustasia reference site generally exhibited similar avian habitat characteristics as Nott Island; however, the presence of larger trees likely influenced the observed differences in species composition (Figure 4-8). Most species detected at this site were common songbirds associated with upland habitats (Table 4-12). Two notable observations include a pair of bald eagles nesting on the island and several blue-winged warblers that are a species of conservation concern in the region (Table 4-12). The only marsh-breeding species observed at Eustasia were red-winged blackbirds. Landin, Webb, and Knutson (1989) noted between 1978 and 1986 that there were over three times as many wildlife species using Nott Island compared with reference areas (83). Differences between Eustasia and Nott Islands were more subtle than during the 2019 survey, although Nott Island continued to display higher species richness and abundance per point-count results compared to Eustasia Island after more than 30 years of forest succession (Tables 4-1 and 4-2).

Figure 4-8. Eustasia Island reference site supporting mainly shrub and forested habitats with limited marsh vegetation.



Table 4-12. All species observed at Eustasia Island habitat improvement site that either appeared to be using the site or only passing over during avian surveys on 24 May 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Canada goose	20	20	Baltimore oriole	2	1
Yellow warbler	15	15	Mallard	2	1
Red-winged blackbird	14	14	Mute swan	2	0
Song sparrow	13	13	American crow	1	1
Common grackle	8	8	American robin	1	1
American goldfinch	7	7	Belted kingfisher	1	1
Common yellowthroat	6	6	Black-capped chickadee	1	1
Warbling vireo	6	6	Black-throated green warbler	1	1
Brown-headed cowbird	5	5	Common raven	1	0
Barn swallow	4	4	Eastern kingbird	1	1
Blue-winged warbler†	4	4	Gray catbird	1	1
Northern cardinal	4	4	Great egret	1	0
Carolina wren	3	3	Osprey	1	0
House finch	3	3	Tree swallow	1	1
Bald eagle†	2	2	Tufted titmouse	1	1

4.8 Pointe Mouillee

The habitat improvement project at Pointe Mouillee is a dredged-material CDF that serves a dual purpose: supporting maintenance of the navigation program while providing a buffer protecting an adjacent freshwater marsh ecosystem. The habitat improvement site includes a combination of emergent-marsh, open-water, and sapling-shrub habitats that support a number of bird species (Figure 4-9). The 2019 survey detected 50 bird species in and around the CDF, with 39 species in common with previous surveys at Pointe Mouillee (Landin, Webb, and Knutson 1989; appendix D.5). Over 50% of the species detected were waterbirds (27 of 50 species; Table 4-13). The emergent-wetland portions of the project area do not

provide optimal breeding habitat for most species of wetland-dependent birds, and only red-winged blackbirds were abundant at the site. Common yellowthroats, yellow warblers, willow flycatcher, and eastern kingbirds were observed during the survey at moderate abundance, but overall marsh-breeding bird richness and abundance remained limited (Table 4-1 and 4-2). Landin, Webb, and Knutson (1989) also noted low numbers of passerines using the emergent-vegetation habitats during the previous surveys (1978–1987). Open-water habitats supported a greater diversity and abundance of birds, mainly gulls, terns, waterfowl, and wading birds (Table 4-13). Mute swans, an exotic species, were detected in both emergent and open-water portions of the project.

Table 4-13. All species observed at the Pointe Mouillee CDF habitat improvement site that either appeared to be using the site or only passing over during avian surveys on 25 May 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Red-winged blackbird	301	256	Pied-billed grebe†	4	3
Double-crested cormorant	53	36	American robin	3	3
Larus spp.	50	0	Caspian tern	3	0
Unidentified tern	50	0	Common gallinule	3	3
Mute swan	49	19	Herring gull	3	0
Canada goose	41	15	Northern cardinal	3	3
Common tern†	34	17	Tree swallow	3	3
Common grackle	28	28	Blue-winged teal	2	2
Mallard	27	20	Dickcissel†	2	2
American white pelican	25	8	Eastern wood pewee	2	2
Lesser scaup	22	22	Gadwall	2	2
Ring-billed gull	22	2	Green heron	2	2
Great egret	21	21	Northern shoveler	2	2
Common yellowthroat	16	16	Whimbrel†	2	2
Yellow warbler	10	10	Alder flycatcher	1	1
Great blue heron	9	3	American coot	1	1
Redhead	9	7	Black-crowned night heron	1	0

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Ruddy duck	9	9	Carolina wren	1	1
Eastern kingbird	8	8	Gray catbird	1	1
Purple martin	8	0	Magnolia warbler	1	1
Barn swallow	7	3	Red-breasted merganser	1	1
Indigo bunting	6	6	Red-eyed vireo	1	1
Killdeer	6	4	Ruddy turnstone	1	1
European starling	4	4	Song sparrow	1	1
Forster's tern	4	0	Willow flycatcher†	1	1
Osprey	4	4	Wood duck	1	1

Figure 4-9. Diversity of habitats within and surrounding the CDF at the Pointe Mouillee habitat improvement site. The area is mostly comprised of wetland-emergent (top right) and open-water habitats, with smaller areas of sapling-shrub habitat (bottom left).



4.9 Miller Sands

The Miller Sands habitat improvement site supports a wide diversity of habitats, including wetland marshes, upland meadows, and sand dunes (Figure 4-10). Results of the 2019 assessment indicate that the habitats on Miller Sands have persisted and remain relatively unchanged from the conditions documented in the 1970s and 1980s by Landin Webb, and Knutson 1989. For example, bird surveys conducted in the 1970s report similar avian communities to those encountered today (appendix D.6), with some exceptions. No savannah sparrows were observed in 2019, whereas this species appeared to be abundant and nest during the previous surveys. The lack of savannah sparrows suggests that thick stands of grasses were more prevalent in the past than what currently occurs in the meadows on the island, a transition that is anticipated as ecological successional progresses. Shrub habitats have also increased over time, as indicated by the increased abundance of species such as yellow warbler and white-crowned sparrow compared to previous surveys (Crawford and Edwards 1978).

The Miller Sands habitat improvement site is the only habitat improvement site examined that continues to provide extensive beach-nesting habitat. The north section of the island is composed of a large sand spit likely used by many shorebirds, terns, gulls, and wading birds throughout the year, especially during migration periods. The 2019 survey observed 140 American white pelican using the westernmost section of the sand spit, with pelicans known to nest on the island since 2010. In April 2015, surveys by the Washington Department of Natural Resources counted 261 adults and 144 nests (Stinson 2016). The Pacific Flyways Council estimated 366 breeding individuals in 2014. The persistence of the sand spit likely results from a combination of hydrodynamics, tidal regime, and the power associated with the Columbia River; ample sediment sources; and management activities, including dredging operations, that place sediments in the vicinity of Miller Sands. These factors, in combination, create the dynamic conditions required to sustain beach-nesting species habitat while preventing erosion of the feature and precluding the encroachment of vegetation.

Figure 4-10. Diversity of wetland and upland communities at Miller Sands Island in the lower Columbia River near Astoria, Oregon.



Streaked horned larks have successfully nested on the northern spit of Miller Sands (Pearson et al. 2005), leading the US Fish and Wildlife Service (USFWS) to designate 50 ha of critical habitat on the northern spit of the island for this federally threatened species (USFWS 2013). The 2019 survey did not detect any streaked horned larks, focusing instead on assessing conditions where the majority of previous historic data were collected as reported by Landin, Webb, and Knutson (1989). As a result, only limited surveys were conducted on the northern side of the island, where the best habitat for streaked horned larks is located. Nonetheless,

continual placement of dredged material in the vicinity of the Miller Sands habitat improvement project and other islands in the lower Columbia River continues to play a pivotal role in restoring populations of this threatened species.

Bald eagles were observed nesting at the habitat improvement site, with one chick visible in the nest. The 2019 survey also detected several other bald eagles either perched or soaring over the project area. The lower Columbia River currently supports a healthy breeding population that has increased exponentially since the late 1970s (Isaacs and Anthony 2011). The Miller Sands project also supports several regional species of conservation concern that likely breed on the island, including willow flycatcher, rufous hummingbird, and purple finch (Table 4-14). Caspian terns do not breed on the island but may periodically use the exposed beaches on the north spit of the island for resting.

Table 4-14. All species observed at the Miller Sands Island restoration site that either appeared to be using the site or only passing over during avian surveys 6–7 June 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
American white pelican	140	140	Swainson's thrush	4	4
Canada goose	95	95	Black-capped chickadee	3	3
Mallard	93	86	Black-headed grosbeak	3	3
Tree swallow	93	52	Common merganser	3	3
Yellow warbler	67	67	European starling	3	3
Double-crested cormorant	44	42	Wilson's warbler	3	3
American crow	43	41	Killdeer	2	2
White-crowned sparrow	33	33	Northern rough-winged swallow	2	2
Song sparrow	30	30	Ring-billed gull	2	2
American robin	27	27	Hutton's vireo	1	1
Cedar waxwing	15	15	Marsh wren	1	1
Bald eagle†	13	10	Northern flicker	1	1

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Willow flycatcher†	10	10	Osprey	1	0
Great blue heron	9	7	Pacific wren	1	1
Rufous hummingbird†	7	7	Purple finch†	1	1
American goldfinch	5	5	Red-tailed hawk	1	1
Gadwall	5	5	Ruby-crowned kinglet	1	1
Bewick's wren	4	4	Turkey vulture	1	0
Caspian tern	4	2	Violet-green swallow	1	1
Red-winged blackbird	4	4			

The Snag Island reference area is located just to the east of the Miller Sands habitat improvement site. The island was generally uniform in marsh vegetation, consisting mostly of reed canary grass, cattail, sedge, and spike rush, and lacking woody vegetation (Figure 4-11). The lack of elevational gradients and diverse habitat types was reflected in the avian community, and most individuals detected appeared to be using the island for either loafing or feeding, as the island can be inundated during high tide. The 2019 survey detected only a few red-winged blackbirds and did not detect any marsh wrens or clapper rails; however, suitable nesting habitat was observed at the site. Breeding potential for other species that do not build nests aboveground in marsh vegetation is very low because of frequent inundation. The fringes of the island are exposed sand and mudflats that provide habitat for birds foraging or resting during low tidal periods, as was the case with cormorants, ducks, geese, gulls, and pelicans (Table 4-15). The lack of habitat diversity and inundation patterns limits the species composition at the Snag Island reference area, resulting in lower species richness and abundance compared with the Miller Sands habitat improvement site.

Table 4-15. All species observed at the Snag Island reference site that either appeared to be using the site or only passing over during avian surveys on 7 June 2019. Species denoted with † are considered species of conservation concern for this region (USFWS 2008).

Species	Total abundance including flyovers	Total abundance excluding flyovers	Species	Total abundance including flyovers	Total abundance excluding flyovers
Double-crested cormorant	50	50	American crow	2	0
Mallard	30	30	Bald eagle†	2	2
Canada goose	20	20	Gadwall	2	2
Larus spp.	20	20	Ring-billed gull	2	2
American white pelican	7	7	Turkey vulture	2	0
Cliff swallow	6	6	Barn swallow	1	1
Tree swallow	6	6	California gull	1	0
Red-winged blackbird	3	3	Caspian tern	1	0

Figure 4-11. Snag Island reference site near Astoria, Oregon.



4.10 Avian community assessment summary

The habitat improvement projects implemented by USACE continue to serve as important habitat for a diversity of avian communities since their creation over 40 years ago. Restoration of vegetation communities ranging from coastal salt marshes to upland habitats support a wide range of bird species, including numerous Species of Conservation Concern (USFWS 2008). While the habitat improvement sites continue to support abundant populations of birds, the 2019 survey did observe differences in species assemblages and abundances when comparing the assessment data with both previous survey efforts and results collected at reference areas.

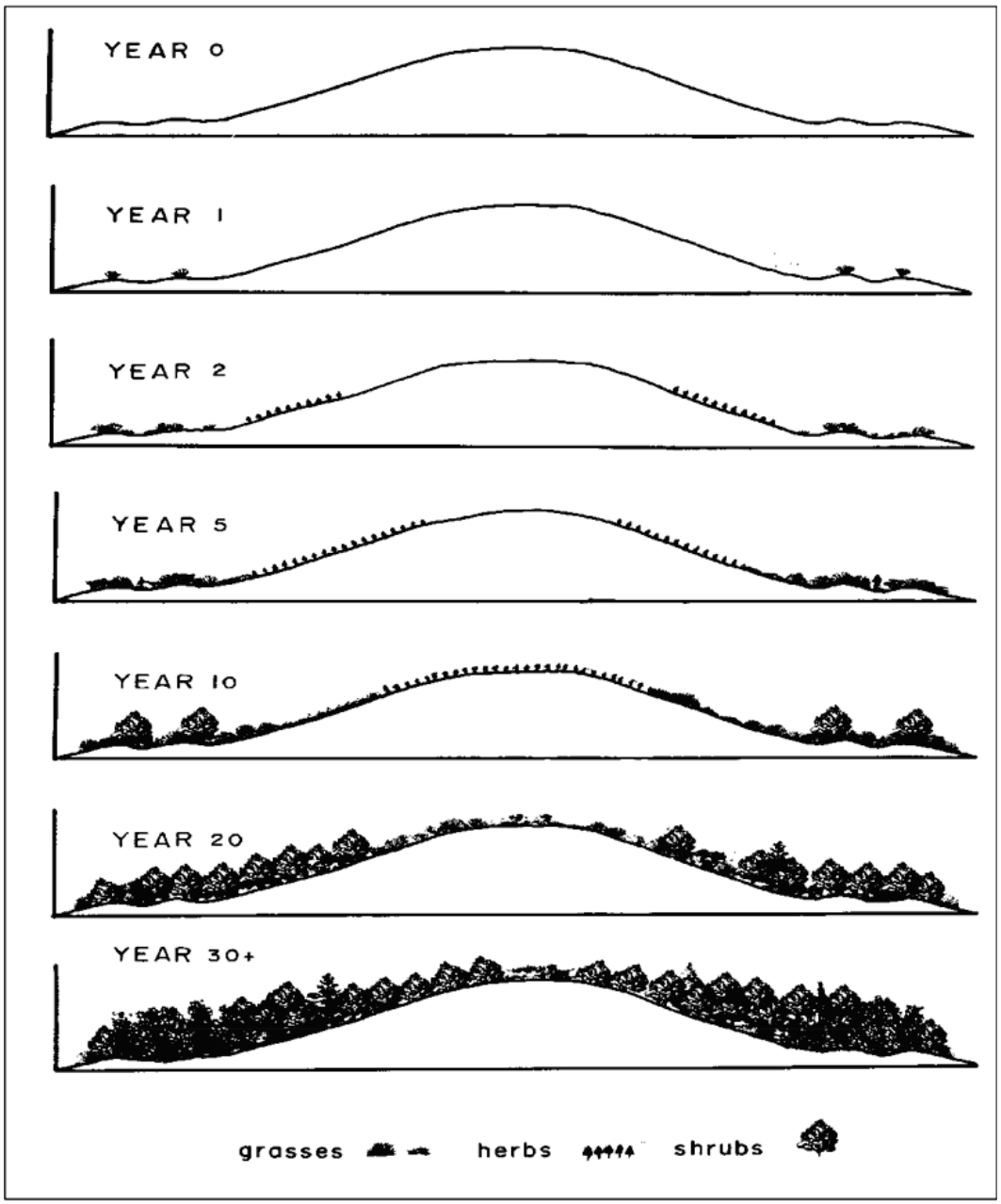
In general, restoration sites had higher species richness compared to reference sites due to a greater diversity of habitats. Other studies have reported successful establishment of avian populations following habitat improvement efforts, including rates of bird usage that exceed undisturbed reference areas (Warren et al. 2002). The intentional placement and manipulation of dredged materials to yield gradients of elevation, soil conditions, and hydrologic regime resulted in the development of a wider range of target habitat types compared to reference sites. Studies have shown that a diversity of habitats is more attractive to nesting and foraging birds compared to homogenous expanses of a single habitat type (Weller 1974; Harris et al. 1983; Rafe et al. 1985).

Melvin and Webb (1998) previously attributed the observed differences in bird communities between the habitat improvement sites and reference areas to (1) a lower abundance of tidal creeks and edge habitat, (2) higher elevations and decreased tidal fluctuation, (3) and steeper slopes. Data from the 2019 surveys demonstrates that differences in species assemblages persist several decades after project construction and the early monitoring activities, although to a lesser degree. However, it is important to note that the differences in species composition we observed are more closely linked to broad habitat type effects (for example, marsh, scrub-shrub, forest) than microclimate conditions within a particular habitat (for example, lack of tidal creeks in salt marshes). Additionally, some of the habitat improvement projects displayed different, but more diverse avian communities as a result of more habitat complexity compared with the reference areas. This suggests that future projects that seek to maximize avian community diversity should focus on creating a variety of appropriate target habitats as opposed to mimicking the landforms observed at reference areas.

We also observed differences in species assemblages between 2019 surveys and previous surveys described in Landin, Webb, and Knutson (1989). In the years immediately following construction of the habitat improvement sites numerous shorebirds, terns, and skimmers were documented using unvegetated or sparsely vegetated sandy dredge material deposits. However, with the exception of American White Pelicans on the persistent sand spit at Miller Sands, beach-nesting habitat is no longer available after more than four decades of ecological succession to support this community of waterbirds. This is not unexpected considering the duration of time since construction activities occurred. Areas that receive dredged placement

material undergo a series of plant succession that eventually results in the development of either shrub-scrub or forested community in areas not subject to frequent inundation or intermittent patterns of disturbance (Figure 4-12). Since >40 years has passed since the construction of the habitat improvement projects, many communities observed have reached these later stages of succession in areas where additional dredged material placement or other disturbance regimes have not occurred.

Figure 4-12. Plant succession on undiked dredged-material islands (Soots and Parnell 1975, 23).



One of the initial objectives of this study was to make comparisons between habitat use by birds following restoration of vegetation on beneficial use sites by Landin et al (1989) and what currently exists >40 years later. Several challenges prevented direct comparisons between the two survey periods. The data collected during the postconstruction period appears to have been collected by a number of different researchers within USACE, universities, and contracting firms. Unfortunately, those individuals used different sampling methodologies (for example, point counts versus line transects) across space and time, reported survey results using a variety of parameters (for example, abundance, diversity, or species richness), and failed to provide detailed information on sampling locations and information that would support a more reproducible study. In many cases, the 2019 study was unable to replicate more than a species list for comparison, as abundance per unit of effort was lacking. Therefore, even determining which species were most common compared to those rarely observed proved difficult. These limitations highlight the need for better documentation of sampling methodologies and the metadata required to replicate study results across time. In response, this report provides detailed information on the sampling locations, results, and other information in the appendices to support future assessment activities at the habitat improvement locations.

In summary, the 2019 observations at the habitat improvement sites documents the persistence of moderate to high levels of avian community diversity and abundance throughout the study period. Over the past 40 years, vegetative communities have established on dredged placement material, resulting in a series of plant successions. As these habitat changes occur, so too do the associated bird communities. One of the largest differences between Landin, Webb, and Knutson (1989) and the current study was the presence of beach-nesting birds such as terns, skimmers, and other shorebirds. Unfortunately, this type of habitat is now one that is very limited on the landscape; therefore, many of these species are in a population decline. Islands and other constructed features off the mainland are often more successful for reproduction because they lack mammalian predators in comparison to landscape features connected to the mainland. As a result, the placement of additional dredged materials or the maintenance of woody vegetation in the vicinity of the habitat improvement projects represents potential management activities that would increase habitat for that group of species (Guilfoyle et al. 2019). While the habitat improvement locations differ from reference areas and

have evolved over the >40 year assessment period, they continue to provide valuable habitat and also represent opportunities for future management actions to maximize environmental benefits while ensuring the sustainability of the navigation program.

5 Assessment of Soil Conditions

5.1 Introduction

Soils and sediment characteristics play a key role in determining ecological and engineering outcomes following the implementation of dredged material beneficial use and habitat improvement projects (Muñoz-Rojas 2018). These materials provide the physical substrate supporting the restored habitat and may also supply seed sources, nutrients, and organic matter to initiate plant establishment and succession (Abella et al. 2020; VanZomeren at al. 2018). However, soils can limit or postpone the success of habitat improvement projects when soil conditions and characteristics are not adequately considered (Eviner and Hawkes 2008). Common soil parameters limiting habitat improvement include high salinity, low nutrient or organic matter content, bulk densities too low to support plant establishment or too high (compaction) to promote root penetration, and the alteration of soil structure during project construction (Mendes et al. 2019; He et al. 2014). Additionally, soils in restored areas often exhibit textures, microbial and fungal communities, and other characteristics that differ from reference conditions (Bach et al. 2010; Banning et al. 2011). These factors influence soil-plant interactions, and, although soils generally become more similar to natural substrates over time, the differences in soil characteristics can persist for several decades or even centuries after the implementation of a project (Kindscher and Tieszen 1998; Craft et al. 2002). In response, the following section investigates changes in soil conditions >40 years after the implementation of the habitat improvement projects and provides a discussion of the trajectory of soil resources in comparison to observations made in natural reference areas.

5.2 Methods—soil physicochemical characteristics

During the 2019 assessment, triplicate 5 cm soil cores were collected from the surface horizons within habitat improvement project locations and at the associated reference areas. No soils were collected at the Pointe Mouillee habitat improvement site or the Cat Point reference area. Soils were stored in coolers and returned to the laboratory, where they were homogenized and prepared for analysis. Soil samples were analyzed for moisture content (MC); bulk density (BD); loss on ignition for percent

organic matter (LOI); pH; salinity; extractable ammonium (NH_4+),[5] nitrate (NO_3–), and soluble reactive phosphorus (SRP); and total carbon (TC), nitrogen (TN), and phosphorus (TP). Triplicate 10 cm soil were also collected from each sample location for belowground biomass (BGB) determinations. Soil samples were processed following the same methods used during the 1970s assessment period to the extent possible.

Field moist soil was homogenized, and 30 g subsamples were dried at 105°C until constant weight. Soil moisture content was calculated using the wet and dry weight of each subsample. Dry-weight soil bulk density was determined by dividing the total dry mass of soil in each core by the core's volume. Dried soil was ground using a ball mill grinder, homogenized, and combusted at 550°C for 4 h to measure percent organic matter using the LOI method.

Extractable NH_4+, NO_3–, and SRP was determined by 2M KCL extraction of field moist soil and subsequent filtration of extractant through a 0.45 µm Supor-450 membrane filter, acidification to a pH < 2, and storage at 4°C until analysis. Inorganic nutrients were analyzed calorimetrically using a Seal AQ2 Automated Discrete Analyzer with methods detection limits of 0.04 mg N/L, 0.015 N mg/L, and 0.04 P mg/L for NH_4+, NO_3–, and SRP, respectively (SEAL Analytical, Mequon, Wisconsin; Methods 350.1, 353.2, and 365.1, respectively, USEPA 1993). For the determination of total C and N, dried soil was weighed in tin capsules, sent to the Wetland Biogeochemistry Analytical Services Laboratory at Louisiana State University, and analyzed using an elemental combustion system (Costech 1040 CHNOS, Valencia, California) with method detection limits of 0.005 g C/kg and 0.005 g N/kg for C and N, respectively. Total P was determined using the ashing-digestion method (Anderson 1976) and analyzed calorimetrically as described above with a method detection limit of 0.006 mg P/L (Method 365.1, USEPA 1993). Soil pH and salinity was measured by creating a 1:1 soil slurry of field moist soil and deionized water following the methods described by Reddy et al. (2013). Soil samples for BGB were rinsed through a 2 mm sieve, and remaining roots plus rhizomes (dead plus live) were dried at 105°C for 24 h. Biomass was calculated by dividing the weight of the dried BGB by total core area. Because of the lack of replication during the historic assessment efforts

5. For a full list of the spelled-out forms of the chemical elements used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 265, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

and the paucity of data available on sampling locations, no statistical comparisons were made.

5.3 Bolivar Peninsula

The Bolivar Peninsula habitat improvement site was developed on an unconfined dredged material placement site adjacent to the Gulf Intercoastal Waterway in Galveston Bay, Texas. Loamy, clay-textured dredged materials were deposited at the site, which initially supported almost no vegetation (Newling and Landin 1985). The dredged sediments were graded to provide a variety of target habitats according to differences in elevation and patterns of inundation as described in section 2.0, and a temporary dike was constructed to promote establishment of low marsh habitat, allowing for protection from wave-driven erosion during consolidation of the dredged sediments.

The 2019 assessment confirmed that over four decades after construction the substrate at Bolivar Peninsula exhibits loamy clays surface horizons underlain by sandy deposits. The depth of the loamy clay materials varied across elevation gradients, with lower-elevation areas generally containing deeper deposits of fine-textured soils, presumably related to tide-driven sediment deposition (Reed et al. 1999). Organic matter has accumulated in the near surface soil horizons, especially in the low marsh landscape positions (Figure 5-1). Fine, sandy soil horizons occur deeper in the soil profile and, in some cases, as thin lenses (that is, stratified layers) within the soil profile. Field indicators of hydric soils were observed in the low-marsh, high-marsh, and transitional shrub-scrub habitats but were absent from the highest-elevation portions of the project location dominated by woody vegetation (no soil chemical analysis available). Specifically, F2—Loamy Gleyed Matrix was documented in the marsh soils, and F3—Depleted Matrix occurred in both marsh and transitional shrub-scrub habitats. The soils at the Pepper Grove reference area were composed of organic materials >40 cm deep, with many coarse living and dead roots intermixed with loamy, clayey soils. Field indicators of hydric soils in the reference area included A1—Histosol, F2—Loamy Gleyed Matrix, and F3—Depleted Matrix. Table 5-1 reports the findings of the 2019 soils analysis of Bolivar Peninsula and at the nearby Pepper Grove reference area.

Table 5-1. Soil data from 2019 assessment of the Bolivar Peninsula habitat improvement site and the Pepper Grove reference area. The 2019 data represent near-surface (0–5 cm) conditions. (*n* = number of samples, BD = bulk density; BGB = below ground biomass)

Parameter	Bolivar Peninsula			Pepper Grove
	Low marsh	High marsh	Shrub-scrub	Low marsh
n	3	3	3	2
BD (g/cm^3)	1.26±0.12	1.40±0.02	1.31±0.04	0.60±0.19
pH	7.72±0.27	8.15±0.11	8.02±0.61	7.12±0.09
Salinity (ppt)	1.43±0.15	1.17±0.03	0.03±0.03	1.70±0.30
BGB (g/m^2)	54±13	38±10	40±18	292±62
NO_3- (mg/kg)	1.78±0.07	3.78±1.73	4.70±0.32	7.64±2.23
NH_4+ (mg/kg)	7.29±2.98	2.70±1.23	4.88±0.83	11.71±8.6
SRP (mg/kg)	0.63±0.32	1.02±0.66	0.32±0.32	0.27±0.27
LOI	3.82±0.59	2.34±0.28	3.2±1.0	10.4±3.6
TC (%)	1.3±0.3	0.67±0.08	1.15±0.41	3.87±1.62
TN (%)	0.09±0.02	0.05±0	0.11±0.03	0.3±0.11
TP (mg/g)	286±54	221±62	185±36	397±24

After more than 40 years of ecological succession, soil characteristics at the habitat improvement site continue to differ from the reference area (Figure 5-2). Notably, the soils at the Bolivar Peninsula display higher bulk density, higher pH, and lower salinity than the Pepper Grove marsh. These findings are related to the presence of more mineral soil components and lower organic soil contents, higher elevation, and shorter tidal inundation periods at Bolivar Peninsula compared with Pepper Grove. Additionally, the habitat improvement project exhibited much lower (<20%) below ground biomass, organic matter content, and total carbon than the reference area. Given the carbon contents of the soils at Bolivar Peninsula, it is not unexpected that the plant available N, TN, and TP also remain lower than those observed at Pepper Grove.

In comparison to initial monitoring data, improvements in the soil conditions at Bolivar Peninsula have occurred since the project was constructed. The soil pH has declined in each habitat type from historic values >8.0 and as high as 8.9 in the postconstruction period, trending towards the zone of maximum nutrient availability (Havlin et al. 2016). Additionally, soil salinity has declined across each habitat type from an estimated high of 5.9 ppt during the postconstruction period. Organic matter has increased over time from near zero values (0.0–0.266%) after

initial construction activities in 1976. For example, in the low marsh, soil organic matter has increased to 0.40±0.16% by the late 1970s and is currently 3.82±0.59%. The soil has also seen two- to three-fold increases in extractable nitrate, reported at <0.60 mg/kg in the low marsh, 0.95±0.40 mg/kg in the high marsh, and 2.05±0.51 in the transitional areas during 1977. BGB was reported in in the early studies, ranging from 40 to 158 g/m² in 1978; however, the lack of detailed methodology information prevents a direct comparison with the 2019 data.

Figure 5-1. Soil morphology within the Bolivar Peninsula habitat restoration sites differed across the elevation gradient as the plant communities changed from low-marsh (left) into sapling-shrub (right) habitats.



Figure 5-2. Soil-core samples from the Pepper Grove reference area were characterized by high concentrations of dark organic matter (left); subsoils from both the Bolivar Peninsula habitat improvement site and the Pepper Grove reference area exhibited depleted matrices and many prominent redoximorphic features (right).



5.4 Buttermilk Sound

The Buttermilk Sound habitat improvement project was initiated in 1975 to create an intertidal salt marsh adjacent to the Altamaha River near Brunswick, Georgia. A 3 ha sandy, unvegetated historic dredged material deposition area was recontoured to decrease the slope and lower the elevation of the area to establish tidal connectivity. Salt-meadow and smooth cordgrass were planted and fertilized following construction (Landin, Webb, and Knutson 1989). After initial plantings, the cordgrass spread rapidly, leading Newling and Landin (1985) to suggest that the inclusion of fertilizers in the restoration design increased growth rates and resulted in a high degree of silt trapping (5–25 cm across the site) within four years of construction. By 1979 the habitat improvement area exhibited similar aboveground biomass as nearby reference areas, although aboveground biomass remained <50% of observations made in nearby unaltered reference wetlands.

After more than four decades of development, the soils at the constructed Buttermilk Sound marsh consisted of 10–25 cm of loamy clay materials overlying sandy textured materials (Figure 5-3). The field indicator of hydric soils, F3—Depleted Matrix, occurred in surface soils, which exhibited 15%–20% prominent redoximorphic features, and was observed in the low-marsh habitat. Soils at the Hardhead Island reference site exhibited peat or loamy clay materials or both at the surface and throughout the upper soil profile, with dark soil colors and organic matter accumulation in surface soil layers. Field indicators of hydric soils in the reference area included A2—Histic Epipedon and F3—Depleted Matrix.

Table 5-2 reports the findings of the 2019 soils analysis of Buttermilk Sound habitat improvement site and at the nearby Hardhead Island reference area; available data from previous soil analysis conducted in 1979 are also provided.

Table 5-2. Soil data from 2019 assessment of the Buttermilk Sound low-marsh habitat improvement site and the Hardhead Island reference area. The 2019 data represents near surface (0–5 cm) conditions. Available historical data from Buttermilk Sound is also provided. (*n* = number of samples)

	Buttermilk Sound (2019)	Hardhead Island (2019)	Buttermilk Sound (1979)
n	3	4	N/A
BD (g/cm^3)	0.49±0.40	0.37±0.04	N/A
pH	6.5±0.08	6.26±0.25	6.9–7.2
Salinity (ppt)	0.23±0.04	1.4±0.12	N/A
BGB (g/m^2)	188±96	191±86	>1290[a]
NO_3- (mg/kg)	1.86±1.75	3.3±0.74	0.1–0.75
NH_4+ (mg/kg)	24.4±14.5	4.92±0.98	8.7–12.2
SRP (mg/kg)	0.33±0.12	0.35±0.12	3.6–11.3[a]
LOI (%)	13.7±4.5	18.4±2.7	<5.5
TC (%)	5.76±1.9	6.72±1.37	N/A
TN (%)	0.45±0.14	0.54±0.06	0.1–0.97
TP (mg/g)	543±102	938±73	<10.4

a. The P extraction and BGB methods used in 1979 are unknown, so results cannot be directly compared with the 2019 data.

The surface soils in the Buttermilk Sound habitat improvement area showed many similarities to the Hardhead Island reference area, including similar bulk density, pH, aboveground biomass, organic matter content, SRP, TC, and TN. The similarities in surface-soil properties at the habitat improvement area and the reference area suggest the constructed marsh was, at least in part, successful in achieving the geomorphology required to establish and sustain the marsh. However, after 40 years of soil development, differences in soil morphology and a subset of physicochemical characteristics persist (Figure 5-3). For example, salinity and TP remained lower in the constructed marsh than in the reference area, while extractable ammonium was substantially higher. The lower salinity is not unexpected, because the reference area has less topographic relief than the constructed marsh, which displays an elevation gradient from the tidally inundated marsh to woody uplands composed of sandy dredged materials. The observed differences in some soil nutrients may be

related to the complex interactions of inundation, oxidation-reduction potentials, and plant species composition that determine nutrient uptake (Morris 1984). Additionally, while the amount of organic matter in the surface-soil horizons at the habitat improvement site were similar to the reference area, the subsurface layers displayed coarser-textured materials characterized by much lower organic matter contents according to visual assessments (Figure 5-3).

The available historical data from 1979 suggest the surface soils at the Buttermilk Sound restoration project have evolved towards conditions observed at the reference area, yet continue to exhibit several differences. The soil pH declined, and the concentration of soil organic matter and most soil nutrients increased. It is unclear whether the fertilizer treatments had any long-term effects on the project, but early observations suggest fertilization resulted in rapid plant establishment, which stabilizes the substrate, encourages sediment deposition and capture, and supports the natural succession of plant communities (Newling and Landin 1985). Both BGB and aboveground biomass are lower than the 1979 data, which could be related to fertilizer effects, but the lack of a formal methodology associated with the previous studies precludes the ability to draw strong conclusions. Notably, the historical BGB data is also ~6× higher than observations made at the reference area, suggesting the 1979 data should not be directly compared with the current data set. The TP concentrations increased with age but remain lower than observations at the reference location.

Figure 5-3. Soil profiles at Buttermilk Sound continue to be characterized by sandy subsurface materials underlying a thin, organic-rich surface horizon (left) and Hardhead Island (right). Note the darker colors and higher organic matter content readily observable in the Hardhead Island site, as evidenced by the surface layers of peat and subsurface organic streaking observed at Hardhead Island.



5.5 Drake Wilson Island

The Drake Wilson Island habitat improvement site established an intertidal salt marsh in a shallow bay adjacent to the Gulf Intercoastal Waterway navigation channel near Apalachicola, Florida. The habitat improvement site was constructed by introducing silty dredged material from the navigation channel that was planted with both smooth and salt-meadow cordgrass. Soils on the island are currently composed of descending layers of peat, dredged material (silt) or loamy clay, and sand (Figure 5-4). Several of the study locations at Drake Wilson Island displayed buried soil horizons indicative of sediment deposition during storm events. Soils within the project area exhibited field indicators of hydric soils, including A2—Histic Epipedon, A5—Stratified Layers, A1—Depleted Below Dark Surface, and F3—Depleted Matrix. No soil data was available within the reference area associated with the habitat improvement project.

There are very limited soils data from the historical monitoring efforts. However, the available data suggest pH has declined by an order of

magnitude, and salinity has undergone a dramatic reduction from >10 ppt to values near 1.0 ppt.

Soil organic matter has increased by a factor of two- to three-fold over the study period (Table 5-3). Other studies have documented the capacity of created wetlands to sequester soil organic matter, sometimes at rates exceeding natural wetlands (Bernal and Mitsch 2013). However, the total amount of soil carbon observed in created wetlands often remains lower than values reported at unaltered reference locations even several decades after project implementation (Yu et al. 2017). The current results align with these findings, suggesting soil organic matter remains depressed well beyond the period when other created wetland characteristics (that is, habitat, vegetation composition) have display significant similarities with undisturbed natural areas.

Table 5-3. Soil data from 2019 assessment of the Drake Wilson Island habitat improvement site. Note, no data were available for the Cat Point reference area. The available historical data are also included from the 1979 assessment. (*n* = number of samples)

	2019		1979
	Low marsh	High marsh	Low marsh
n	4	4	N/A
BD (g/cm^3)	0.37±0.04	0.66±0.15	N/A
pH	6.47±0.1	6.33±0.14	7.88–8.21
Salinity (ppt)	1.05±0.09	0.75±0.02	10–18
BGB (g/m^2)	446±64	355±32	N/A
NO_3- (mg/kg)	1.37±0.26	1.45±0.67	N/A
NH_4+ (mg/kg)	6±0.65	6.38±2.23	N/A
SRP (mg/kg)	0.18±0.1	0.01±0.01	N/A
LOI (%)	19.8±2.14	11.7±3.48	4.53–6.10
TC (%)	8.32±0.97	5.3±1.55	N/A
TN (%)	0.49±0.054	0.33±0.098	N/A
TP (mg/g)	421±46.5	324±122	N/A

Figure 5-4. Diversity of soil profiles within Drake Wilson in Apalachicola Bay, Florida. Note, each soil profile exhibits organic matter accumulation, and in several cases, evidence of over-wash and sediment-deposition events can be readily observed.



5.6 Nott Island

The habitat improvement project at Nott Island was designed to provide a 3.2 ha freshwater meadow on the Connecticut River. The project incorporated silts into a matrix of sandy dredged material. The site was graded to create a gently sloping (<5%) meadow to support habitat for wildlife communities by improving the conditions for vegetation establishment and growth (Barry et al. 1978). Although little soil data are available for the historic conditions, early monitoring results suggested dredged sediment initially exhibited high salinity from the tidal influence by Long Island Sound, and researchers noted concerns that vegetation establishment and survival would be hindered by the presence of salts (Newling and Landin 1985). Most of the site was planted with clover and tall fescue, but initial plant succession was slow. In response, all-purpose fertilizer and lime was applied to improve soil fertility (Newling and Landin 1985).

The habitat restoration site is now fully vegetated, with herbaceous plants growing on a substrate of loamy soils underlain by layers of sandy dredged deposits (Figure 5-5). There were little data provided about initial soil conditions in Nott Island, with only salinity and BGB having reportable data. Nott Island was initially reported to have high salinity levels following creation of the habitat improvement area, but any salinity limitations have

been alleviated by precipitation-driven leaching over the last four decades. BGB increased from an average of 7.4 g/m² in the years following project implementation to 48.5 g/m² currently (Barry et al. 1978). The significant increase in BGB observed in Nott Island is likely a result of improvements in soil conditions, as soil carbon and nutrients have been incorporated, and relief from salinity stressors on soil fertility over time. The colors of the surface horizons currently observable within the project area (Munsell value ≤3; chroma ≤2) indicate soil organic matter has accumulated within the surface-soil layers, which were originally composed of high Munsell-value sands lacking soil organic matter.

Nott Island and the Eustasia Island reference site displayed similar soil morphologies and properties, with the exception of bioavailable ammonium, which was ~60% higher in the reference area than in the constructed upland meadow (Table 5-4). This result is not unexpected, since the reference location is at a lower elevation and maintains a water table much closer to the surface than the well-drained habitat improvement project site at Nott Island.

Table 5-4. Soil data from 2019 assessment of the Nott Island habitat improvement site and the Eustasia Island reference area. (*n* = number of samples)

	Nott Island	Eustasia Island
	Meadow	Meadow
n	3	3
BD (g/cm³)	1.11±0.15	0.98±0.06
pH	5.99±0.19	5.29±0.27
Salinity (ppt)	0	0
BGB (g/m²)	48±18	43±18
NO_3– (mg/kg)	7.02±4.94	8.1±2.36
NH_4+ (mg/kg)	2.57±0.3	6.13±0.82
SRP (mg/kg)	0.17±0.11	0
LOI	4.8±1.77	5.16±0.46
TC (%)	2.05±0.91	2.45±0.23
TN (%)	0.15±0.058	0.2±0.009
TP (mg/g)	908±248	636±34.8

Figure 5-5. Soil profile from the created meadow feature at the Nott Island habitat improvement site. Note the darker color of the surface horizon, indicating soil organic matter accumulation over time.



5.7 Miller Sands

The Miller Sands habitat improvement site was established on a 162 ha dredged material island located on the Columbia River, where sandy substrates were contoured and supplemented with additional dredged materials to create an elevation gradient that changed from marsh habitat at the lowest elevation to an upland meadow in the higher elevations. Early monitoring efforts reported the dredge material deposition locations had low fertility prior to restoration and remained largely unvegetated prior to project implementation. The entire site was planted and fertilized following the recontouring efforts, and the island is now fully vegetated.

The soils at the Miller Sands habitat improvement site currently consist of fine materials overlying sandy deposits. Wetland areas at the habitat improvement site exhibited field indicators of hydric including S5—Sandy Redox, F3—Depleted Matrix, and F6—Redox Dark Surface. Soils at the nearby Snag Island reference area are composed entirely of loamy clay soil materials and included both the F3—Depleted Matrix and F2—Loamy Gleyed Matrix field indicators of hydric soils (Figure 5-6).

Soil characteristics at the Miller Sands habitat improvement marsh site share several similarities with the Snag Island reference area, including

BGB and most nutrient concentrations. However, several differences in both soil morphology and chemical properties persist (Table 5-5). Examining the available historic monitoring data, soil conditions within the habitat improvement project have improved over the past four decades, especially with regards to the concentrations of nitrate and a >10-fold increase in soil organic matter.

Table 5-5. Soil data from 2019 assessment of the Miller Sands habitat improvement site and the Snag Island reference area. Available historic soil data for the Miller Sands marsh are also included. (*n*= number of samples)

	Miller Sands (2019)		Snag Island (2019	Miller Sands (1979)
	Low marsh	Meadow	Low marsh	Low marsh
n	6	6	3	N/A
BD (g/cm^3)	0.98±0.04	1.03±0.1	0.73±0.1	N/A
pH	5.55±0.13	6.89±0.04	6.76±0.23	7
Salinity (ppt)	0.01±0.01	0	0.03±0.03	N/A
BGB (g/m^2)	104±20	25±3	106±28	128
NO_3–(mg/kg)	4.92±1.01	3.58±0.33	7.3±3.23	<1.1
NH_4+ (mg/kg)	2.71±0.67	5.6±3.74	20.4±15.3	5–12
SRP (mg/kg)	0.88±0.09	0.86±0.1	0.43±0.26	N/A
LOI	4.87±0.61	3.4±0.52	5.57±1.36	0.32
TC (%)	2.77±0.49	1.25±0.26	2.55±0.62	N/A
TN (%)	0.21±0.034	0.13±0.023	0.22±0.041	N/A
TP (mg/g)	551±15.2	608±46.5	667±129	N/A

Figure 5-6. Soil profiles in the upland meadow at the Miller Sands habitat restoration project (left) and examples of the gleyed soil materials observed in the marsh habitats at Miller Sands habitat improvement site (center) and the Snag Island reference area (right).



5.8 Soils assessment summary and discussion

Each of the habitat improvement projects displayed improvements in soil physicochemical properties with age, including increasing nutrient contents and improved physical structure. For example, the LOI data, which are both a measure of organic matter content and a proxy for organic carbon, increased over time and in most cases approached the values observed in reference locations. This trend demonstrates carbon is accumulating in the restored sites, supporting increases in water-holding capacity and decreases in bulk density required to support plant communities. Extractable NO_3- and NH_4+ also increased over time, further indicating that enhanced nutrient cycling is occurring at each habitat improvement location. Notably, after 40 years, the study locations display the ability to sustain the soil physical substrate needed to support the growth of robust rooted vegetation communities and as a result are performing the ecological functions associated with each target habitat type. These benefits have been achieved without the need for further management or intervention.

Not only were restored sites successful in development relative to initial postconstruction conditions, they also display a number of similarities with their natural counterparts. Only one site, Bolivar Peninsula, had more than 3 of 12 soil properties measured differ from its reference site, and

most of that variation resulted from the heterogeneity of vegetation communities present at the habitat improvement project compared with its unaltered reference study location. Bulk density, moisture content, and TP were the only soil parameters that were significantly different between treatments in more than one site. Belowground biomass often differed from reference conditions, as expected, but increases in this parameter were proportional and correlated to increases in soil organic and TC and TN measurements, suggesting vegetation biomass drives much of the nutrient data observed and site conditions will continue to improve over time. Vegetation composition and abundance directly influence soil conditions through bioavailable nutrient uptake and by increasing aboveground accumulation and litter deposition, contributing to organic carbon and long-term nutrient storage (TC, TN, and TP) while decreasing bulk density. Soils in the created sites continue to benefit from vegetation inputs into the system and are anticipated to do so in the future.

The paucity of available historical data represents a limitation of the study for several reasons. First, measurements of the dredged material physicochemical properties were not conducted at the time of project initiation, making it difficult to determine whether the results reported in the historical monitoring documents reflect initial sediment properties associated with the dredged material, the initial site substrate at the time of construction, or the result of experimental treatments. In addition, historical soil data were either incomplete or ineffectively described for many of the analyses reported within the historical monitoring documentation, making it challenging to develop direct comparisons between initial soil properties and the current data set. Further, while the impacts of site fertilization are no longer detectable, the type and amount of fertilizer in each site was not specified in the available historic reports; the available historical data suggest soil phosphorus, BGB, and other parameters may have been elevated as a result of fertilization during measurements conducted shortly after construction.

Despite these limitations, the available data allow for general comparisons across time and, most importantly, the identification of trends over the >40 year study period. Each habitat improvement site resulted in soil conditions have trended toward reference conditions over time, despite the persistence of differences in some parameters at a subset of study locations (that is, TC content). In particular, several of the habitat improvement sites failed to approach the soil carbon contents and BGB

levels observed in reference areas across the >40 year study period. This finding aligns with the results of other studies, including the recently published work of Abbott et al. (2019), who report carbon accumulation and content was significantly lower in marshes created using dredged materials across a 32-year chronosequence than in natural marshes.

In summary, the degree that each study location achieved reference conditions varied with creation-restoration technique, the extent of manipulation applied (for example, contouring; vegetation planting and fertilization), landscape setting, and the target habitats identified in the project objectives. These findings further support the conclusion that the projects successfully obtained the target habitat types, although the sites remain on trajectories that do not mimic unaltered reference conditions—especially with regard to some soil properties, which require additional time to reach their ecological equilibria in comparison with the establishment of vegetation and select faunal communities.

6 Linking Beneficial Use Project Ecological Functional Responses with Engineering Benefits to Maximize Project Outcomes

6.1 Approach

The habitat improvement projects constructed in the 1970s did not consider engineering benefits during project design and implementation, and the engineering benefits of the projects were neither evaluated nor discussed during the historical monitoring activities conducted through the mid-1980s. This focus on habitat aligned with the prevailing view at the time of project construction that ecological outcomes were separate, and in some cases antithetical, to the objectives of the dredging and navigation programs of the day. Based upon the available data, the authors of the historical studies viewed the pre-construction dredged material management sites as poor habitat that could be improved by initiating grading to achieve target habitat elevations, amending the dredged sediments to promote plant establishment, and introducing vegetation through plantings and seeding activities. This approach to improving habitat at dredged material deposition locations clearly has merit, as evidenced by the successful establishment of a wide array of habitat types. These habitats have generally persisted in the absence of additional construction or maintenance requirements for more than four decades, providing a number of ecological functions to various degrees determined by the target habitat type and local conditions. However, the prior studies failed to recognize another set of benefits associated with engineering outcomes that also resulted from project implementation.

More recently, a paradigm shift has elevated the concept that beneficial use projects can deliberately align the objectives of the engineering and environmental stewardship missions to maximize outcomes for both navigation and the ecosystem (Bridges et al. 2014). This concept has been incorporated into the Engineering With Nature® initiative currently being implemented through a variety of USACE projects and programs. In support of this effort, the following section provides a qualitative assessment of the engineering benefits associated with the six habitat improvement projects described herein. The intent of this assessment is to highlight the engineering benefits provided by each project and develop a conceptual framework integrating the ecological functions identified

during this study with associated engineering benefits that can be operationalized through project design and management.

6.2 Placing engineering benefits within an ecological context

Ecological functions have been defined as things ecosystems do, such as provide habitat for flora and fauna, floodwater detention, and nutrient cycling (Novitski et al. 1996). These ecological functions also benefit society, providing opportunities to harvest fish or other materials supported by the habitat function, reducing flood risk to infrastructure, and improving water quality. Notably, ecosystem functions occur regardless of anthropogenic need, while humans rely on the benefits and services associated with ecological functions for survival (Daily et al. 2000). As such, ecosystems can be thought of as capital assets, whose benefits and services can be assessed and quantified in a variety of frameworks, including economic and engineering contexts.

Many studies have evaluated the complex ecological functions and benefits associated with different habitat types and landscape conditions have been published, forming a robust source of available literature linking ecosystem form, function, and benefits. An array of approaches to assess these functions and benefits have been applied across the United States and internationally (De Groot et al. 2002; Oliver et al. 2015). This array includes the early work of Smith et al. (1995), who linked geomorphology, hydrology, hydrodynamics, and structural components (for example, vegetative strata) to develop a framework for describing and quantifying ecological functions in support of management initiatives.

The engineering benefits and project objectives associated with the beneficial use of dredged materials can be coupled with established ecosystem functions, yet few studies effectively link these two approaches. In one exception, Foran et al. (2018) provide an example of this approach by linking ecological functions with navigation project objectives at a dredged material beneficial use site in the Atchafalaya Basin, Louisiana.

To further promote this concept within a dredged material beneficial use context, the following section provides several examples of these coupled ecological function–engineering benefit relationships to highlight the interplay between ecological functions and engineering outcomes. For example, wetlands provide ecosystem functions that dissipate wave energy and retain sediment, which are related to engineering benefits associated

with shoreline stabilization and the maintenance of navigation channels. These functional outcomes work in concert to sustain the physical substrate on which flora and fauna can thrive (ecological functions) while promoting improvements in water quality (engineering benefits) (Steinmuller et al. 2020; Berkowitz et al. 2017).

The capacity of a wetland system to decrease wave energy and retain sediment remains closely linked with the type and abundance and vegetative structures present to reduce flow velocities (ecological functions), which in turn helps to maintain the elevation required to sustain projects and decrease flood impacts to adjacent communities (engineering benefits) (Smith and Klimas 2002). Also, biogeochemical processes provide the nutrients supporting the structural complexity and composition of the vegetation communities that dictate the distribution of habitat types occurring on the landscape, providing effective traps for sediment, decreasing sediment transport to open-water systems, and reducing future dredging requirements (Gleason et al. 1979; Reddy and DeLaune 2008). As such, the engineering benefits associated with the maintenance of navigation channels and the sustainability of landscape features can be coupled with sediment retention and biogeochemical cycling ecological functions.

Notably, these concepts not only highlight the engineering benefits that can be associated with (or are derived from) select ecological functions but also support the intentional and deliberate incorporation of engineering project objectives within the ecological functional framework. As such, the following discussion seeks to encourage the integration of ecological functions into the design and operation of beneficial use projects in order to achieve and maximize targeted engineering benefits and outcomes during the implementation of beneficial use projects.

Tables 6-1 and 6-2 describe a subset of ecological functions and associated engineering benefits, respectively, and Figure 6-1 establishes linkages between select ecological functions and engineering outcomes. Note, the items included are not designed to be comprehensive and are restricted to the major ecological functions and engineering benefits associated with the habitat improvement sites evaluated herein.

Table 6-1. Ecological functions associated with dredged material beneficial use projects. Each function is defined, dominant drivers of the function are provided, and examples of common landscape features providing the function are detailed below. Several of the ecological function definitions are adapted from Smith and Klimas (2002).

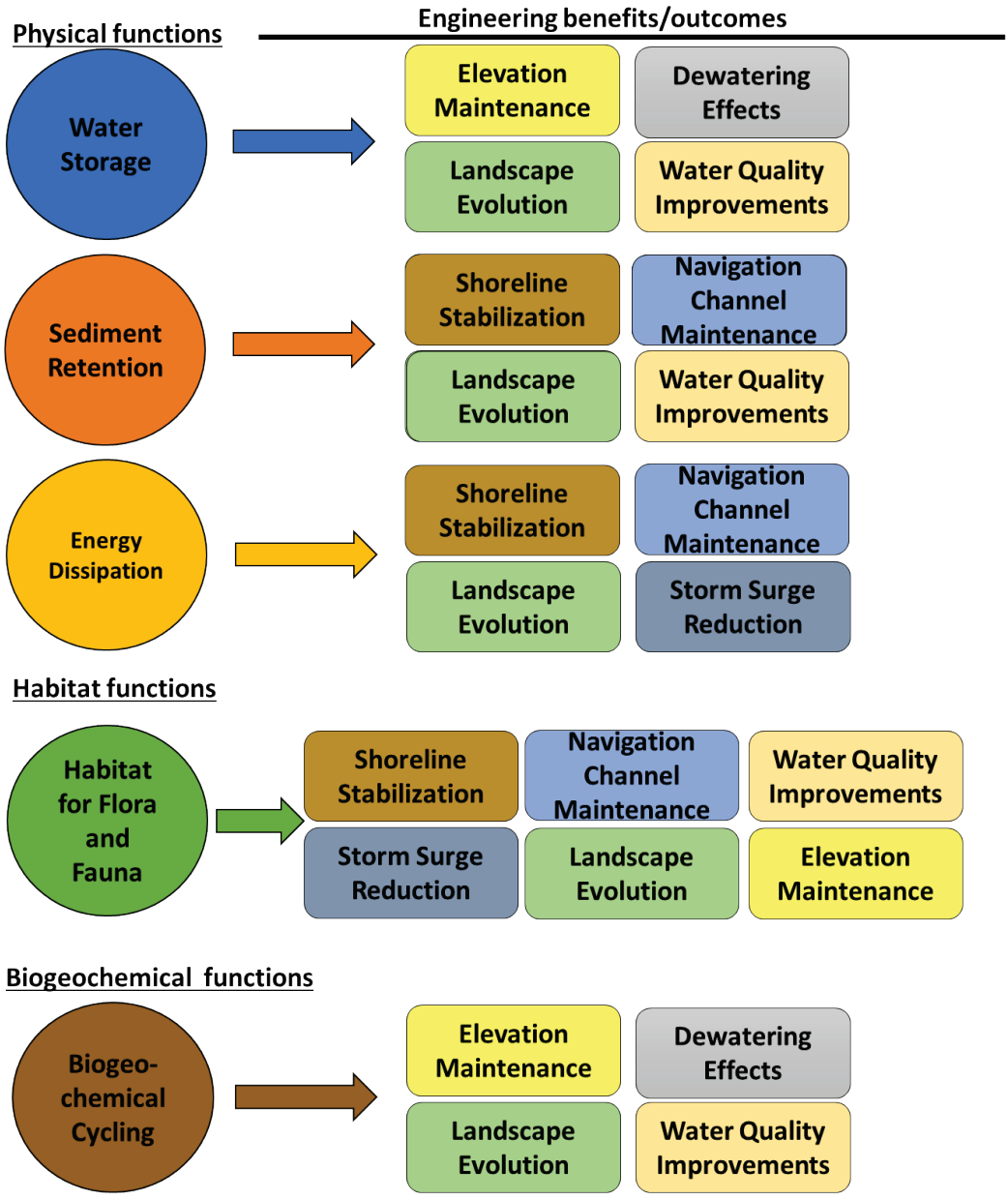
Ecological functions	
Water storage—the ability of the ecosystem to store, convey, and deliver water to down-gradient areas or recharge groundwater	
Functional drivers—inundation frequency, soil porosity, microtopography	Examples—floodplains, estuaries, coastal marshes, depressional areas
Sediment retention—the ability of the ecosystem to permanently remove or temporarily immobilize sediments and other materials that are imported to the system from various sources, but primarily via flooding	
Functional drivers—flood frequency and sediment content, surface roughness	Examples—floodplains, estuaries, coastal marshes, forested wetlands
Energy dissipation—the ability of the ecosystem to attenuate and decrease energy during periods of flooding and inundation	
Functional drivers—inundation frequency, vegetation structure, surface roughness	Examples—floodplains, estuaries, coastal marshes, forested wetlands
Habitat for flora and fauna—the capacity of an ecosystem to provide the environment necessary for a characteristic plant community to develop and be maintained and to support the fish and wildlife species that use wetlands during some part of their life cycles	
Functional drivers—hydropattern, substrate characteristics, land use and connectivity with other suitable habitats, disturbance regime	Examples—all landforms provide habitat functions to varying degrees, although many wetlands display high biodiversity and productivity compared with other ecosystems
Biogeochemical cycling—the ability of the ecosystem to convert nutrients and other materials from inorganic forms to organic forms and back through a variety of processes such as photosynthesis, microbial decomposition, and carbon sequestration	
Functional drivers—primary productivity, vegetation species, microbial activity	Examples—wetlands, lakes, rivers, estuaries, nearshore areas

Table 6-2. Engineering benefits and objectives associated with ecosystem functions that can be used to maximize dredged material beneficial use project outcomes. Each benefit is described, associated ecological functions are provided, and examples of design and management operations that can be used to maximize project outcomes are detailed below.

Engineering benefits and objectives	
Shoreline stabilization—the capacity of an ecosystem or project to maintain grade and avoid edge erosion or failure at the interface of aquatic and terrestrial systems	
Associated functions—energy dissipation, habitat for flora and fauna	Design—decrease fetch, follow natural contours to avoid abrupt edge effects
	Operations—establish plant communities or use soil amendments to improve soil shear strength
Elevation maintenance—the capacity of an ecosystem or project to aggrade at a rate equal or greater than rates of erosion or subsidence relative to surrounding water bodies	
Associated functions—sediment retention, biogeochemical cycling, water storage, habitat for flora and fauna	Design—ensure connectivity with sediment sources, target elevation to promote tidal exchange and flooding
	Operations—establish plant communities to trap sediments, deposit nearshore sediments
Navigation channel maintenance—the capacity of an ecosystem or project to prevent sediment transport to open-water areas and transit routes	
Associated functions—energy dissipation, sediment retention, habitat for flora and fauna	Design—locate projects to increase flow velocities in adjacent channels by decreasing the cross-sectional area of the waterway
	Operations—establish plant communities to prevent erosion, use strategic sediment placement to expand project footprints
Storm surge reduction—the capacity of an ecosystem or project to reduce the velocity of floodwater as it moves through the system	
Associated functions—energy dissipation, habitat for flora and fauna, water storage	Design—locate projects in adjacent to vulnerable infrastructure or other assets, contour areas to increase microtopographic relief and storage capacity
	Operations—decrease flow velocities through the introduction of downed wood or other natural materials to increase roughness, maintain plant communities
Landscape Evolution—ecosystem components in high energy environments, including riverine and coastal settings, undergo natural geomorphologic changes in response to environmental forcing. This benefit or objective is characterized as the capacity of an ecosystem or project to undergo periodic geomorphological transformations (for example, tidal creek evolution, distributary channel meander) while maintaining a sustainable trajectory towards the dynamic equilibrium characteristic of the system.	

Engineering benefits and objectives	
Associated functions—water storage, wave energy attenuation, biogeochemical cycling, sediment retention, habitat for flora and fauna	Design—incorporate tolerances for geomorphological changes into design success criteria, ensure adequate tidal exchange and flooding will occur according to target elevations to drive these changes
	Operations—manage stakeholder expectations, use strategic sediment placement and contouring to guide geomorphic trajectories
Water-quality improvements—the capacity of an ecosystem or project to permanently remove, temporarily sequester, or transform nutrients, metals, and other elements and compounds in ways that reduce pollution and the transport of undesirable materials to downstream environments	
Associated functions—water storage, biogeochemical cycling, sediment retention, habitat for flora and fauna	Design—ensure frequent connectivity with water sources and sediments, promote increased water-retention times through inclusion of depressional features
	Operations—establish plant communities to trap sediment, amend soils to increase organic matter content and accumulation
Dewatering effects—the capacity of an ecosystem or project to reduce the water content and salinity of dredged sediments to prepare them for other uses or decrease volume	
Associated functions—water storage, biogeochemical cycling	Design—promote drainage and exposure to precipitation to promote leaching, test sediments for acid-generation potential
	Operations—manage plant communities using the project objectives

Figure 6-1. Relationship between select ecological functions (circles) and engineering benefits and outcomes (rectangles) associated with the beneficial use projects examined during this study. Note, the ecological functions have been grouped into categories that can inform the timescales and trajectories associated with each function or benefit within a beneficial use context.



6.3 Ecological functions and engineering benefits associated with the historic habitat improvement projects

The six habitat improvement projects evaluated in this study provide a number of ecological functions and associated ecological benefits and outcomes (Table 6-3). Because the study applied herein was designed to

mimic the methodologies and measurements used during the historic monitoring efforts, the current analysis was inherently biased towards a subset of ecosystem functions. This bias results from availability of historic data, which evaluated vegetation communities and avian habitat that infers habitat functions and, to a lesser extent, soil properties linked with biogeochemical processes (for example, nutrient cycling, carbon accumulation), the retention of sediment, and several other physical functions (Figure 6-1). As a result, a qualitative analysis of engineering benefits is provided to promote the incorporation of both ecological and engineering assessments into studies evaluating beneficial use activities. Additional research will be required to quantify and monetize these engineering benefits.

Previous efforts have investigated mechanisms to translate ecological functions, benefits, and services into economic terms, but few studies have specifically evaluated engineering benefits in this way (see Gómez-Baggethun et al. 2010 for a survey of this literature). For example, Jenkins et al. (2010) successfully estimated the monetary value of restoring wetland habitats in the Mississippi River Valley, focusing on greenhouse gas reductions, water-quality improvements, and recreation. However, that study did not consider other functions and benefits, such as flood risk reduction, sediment retention, or other benefits more closely aligned with engineering objectives.

Table 6-3. Summary of habitat improvement project outcomes, including the success of target habitat types and associated capacity of each habitat type to provide ecological functions and engineering benefits and outcomes. Ecological functions include HA = habitat for flora and fauna; WS = water storage; ED = energy dissipation; SR = sediment retention; BC = biogeochemical cycling. Engineering benefits and outcomes include SS = storm-surge reduction; ST = shoreline stabilization; EM = elevation maintenance; NC = navigation channel maintenance; DE = dewatering effects; LE = landscape evolution; WQ = water-quality improvement.

Location	Target habitat type	Habitat sustained >40 years?	Ecological functional capacity	Engineering benefit or objective capacity	Challenges to achieving or sustaining habitat and function	Management opportunities
Bolivar Peninsula	Low marsh	No	HA WS ED SR BC	ST EM NC SS LE WQ	Erosion	Sediment placement to establish low marsh
	High marsh	Yes	HA WS ED SR BC	ST EM NC SS LE WQ	None	None
	Herbaceous upland	Yes	HA	DE NC	Undesirable species	Selective species control
	Woody upland	Yes	HA	DE NC	Planted some species outside of native range, poor survival	Selective species control
Drake Wilson Island	Low marsh	Yes	HA WS ED SR BC	ST EM NC SS LE WQ	Decreasing land area	Sediment placement
	High marsh	Yes	HA WS ED SR BC	ST EM NC SS LE WQ	Decreasing land area	Sediment placement
	Woody upland	Yes	HA	DE NC	None	None
Buttermilk Sound	Low marsh	Yes	HA WS ED SR BC	ST EM NC SS LE WQ	None	None
	High marsh	Yes	HA WS ED SR BC	ST EM NC SS LE WQ	None	None
	Unvegetated upland	No	HA	DE NC	Woody species encroachment	Selective species control
Nott Island	Upland meadow	Yes	HA	DE NC	Undesirable species, poor soil quality	Selective species control, soil amendments
Pointe Mouillee	Freshwater marsh	Yes	HA WS ED SR BC	ST EM NC SS LE WQ DE	Woody species encroachment	Selective species control

Location	Target habitat type	Habitat sustained >40 years?	Ecological functional capacity	Engineering benefit or objective capacity	Challenges to achieving or sustaining habitat and function	Management opportunities
Miller Sands	Upland meadow	Yes	HA	DE NC	Undesirable species, poor soil quality	Selective species control, soil amendments
	Tidal marsh	Yes	HA WS ED SR BC	ST EM NC SS LE WQ	Undesirable species, erosion	Selective species control, sediment placement
	Dune	Yes	HA ED SR	ST EM NC SS LE DE WQ	Erosion, Sediment supply	Sediment placement

The habitat improvement projects were very successful from an ecological-functional standpoint, achieving levels of habitat and biogeochemical cycling that rival reference areas in many instances while providing for more habitat complexity due to more heterogeneity in both geomorphology and habitat type. Notably, most of the study locations provided few habitat and biogeochemical cycling functions prior to project construction, so the functional lift (that is, increases in ecological functions compared with a no-action alternative) gained at each location was extensive.

Additionally, evidence of physically derived ecological functions was observed during site visits, including the dissipation of energy and retention of sediment functions observed through observations of buried soil horizons and soil pedogenesis resulting in the development of stratified layers (Figure 5-4). Water storage functions were clearly occurring at every habitat improvement project and every project site displayed field indicators of hydric soils that only develop in response to extended periods of saturation persisting long enough to induce anaerobic conditions in the upper part of the soil profile (except the upland meadow at Nott Island, which benefited from water-storage functions through the observed decrease in soil salinity) (USDA-NRCS 2018). These soil morphological features provide further evidence that biogeochemical cycling and the subset of ecological functions driven by physical processes is occurring at the beneficial use project locations.

Importantly, the capacity of the habitat improvement projects to deliver ecological functions has increased over time. This increased capacity is evident through the increase in vegetative cover at the study sites and increases in the footprint of some study locations resulting from sediment retention that expanded the extent of the project area beyond its original footprint (Figures 6-2–6-7). Sections 3.0 through 5.0 provide details on improvements in vegetative community composition, avian species assemblages and use, and soil conditions as the habitat improvement projects have matured.

Figure 6-8 presents a summary of landcover trends using aerial photography analysis at a decadal scale, where available, to evaluate temporal changes resulting from the restoration efforts in each project area. The images used in the analysis were derived from Earth Explorer engine (https://explorer.earthengine.google.com), the National Agriculture Imagery Program

(https://gis.apfo.usda.gov/arcgis/rest/services), and the University of Connecticut, Air Photo Archive (https://connecticut.maps.arcgis.com). Each image was rectified using ArcGIS Pro software and categorized into three classes—water, vegetation, and barren—using the Environment for Visualizing Images (ENVI) feature extraction method. The water class was comprised of open water, channels, rivers, and aquatic vegetation features, while the vegetation class included marsh, grasses, shrubs, and trees. The barren class included the remaining areas, such as sand, mud flats, and nonvegetated areas. Finally, each classified image was converted to polygons where area statistics (in hectares) were generated using the ArcGIS Calculate Geometry tool.

Several trends emerge when examining these landcover data to inform the analysis of ecological functions and engineering benefits presented in Table 6-3. First, the majority (13 of 15) of target habitats types were successfully established, and those habitat features have persisted for several decades after project construction. Exceptions include the low-marsh habitat at Bolivar Peninsula, which changed to high marsh because of elevation and soil inundation constraints, and the unvegetated upland habitat at Buttermilk Sound, which has experienced woody vegetation encroachment. The successful establishment and sustainability of the habitat improvement projects is of note, as these represent some of the oldest dredged material beneficial use projects in the United States for which early monitoring data are available.

The project implementation activities resulted in landscape features that in most cases display more topographic relief and habitat heterogeneity than the associated reference locations, which resulted in increased vegetation and avian species richness compared with unaltered study locations (see sections 3.0 and 4.0). These findings are not intended to suggest the habitat improvement projects resulted in ecological conditions that are better than their unaltered counterparts but rather highlight that, while the habitat improvement areas have trended towards reference site conditions in many ways, they display distinct characteristics that have persisted over the past four decades.

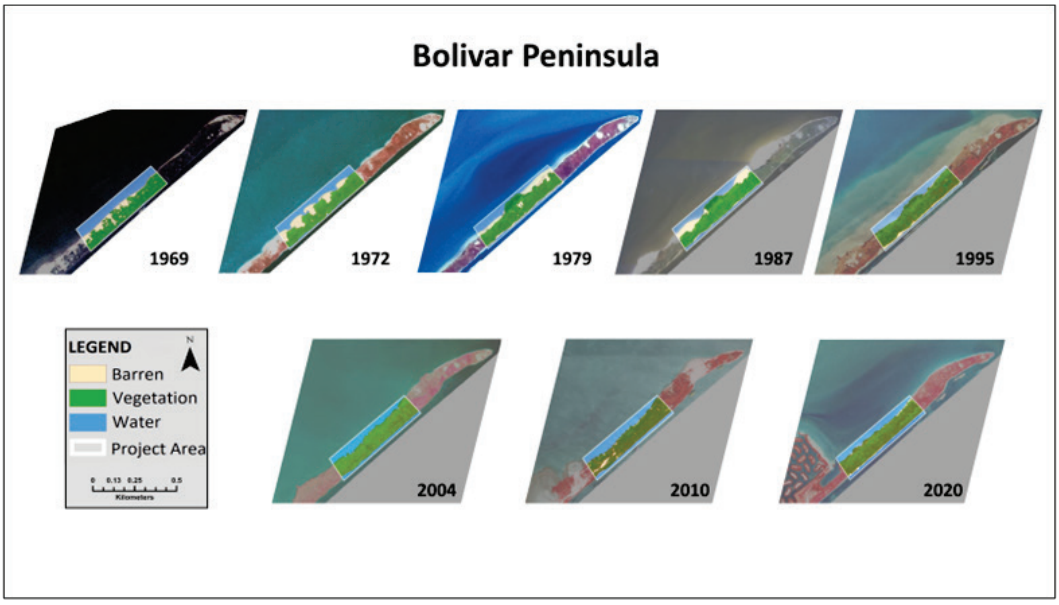
Similarly, the ecological functions provided by the habitat improvement sites reflect conditions observed in unaltered landscape features in many ways, but the magnitude and distribution of the functional capacities delivered by the constructed sites will likely continue to diverge from

natural systems in several ways. For example, the greater topographic heterogeneity associated with the habitat improvement project areas such as Bolivar Peninsula and Buttermilk Sound results in more diverse habitat assemblages, which in turn induces a wider range of ecological functions and engineering benefits provided (for example, dewatering effects) compared with reference areas. Additionally, some of the habitat improvement areas provide a subset of ecological functions and engineering benefits at a lower or higher magnitude than natural reference areas. For example, the Pointe Mouillee study area was constructed specifically to reduce energy and shoreline erosion to protect the degraded freshwater marsh adjacent to the project. This erosion reduction was accomplished by orienting the project in a configuration that would dissipate the energy associated with the prevailing winds and waves. While this required the selective use of armoring on the outer edge of the project, the project has resulted not only in the delivery of habitat and other ecological functions within the project footprint but has also resulted in the resurgence of the degraded marshlands that eroded prior to project implementation (Figure 6-6). This additional positive outcome highlights the importance of placing beneficial use projects within a regional or landscape-scale context, because while the habitat quality of the Pointe Mouillee project remains limited by woody vegetation encroachment and other stressors, researchers noted that the adjacent resurgent marsh (now protected by the beneficial use project) provides ideal habitat for a wide variety of avian species (see section 4.0).

As previously discussed, ecological functions can be linked with engineering benefits and outcomes that benefit society (Table 6-2; Figure 6-1). Within this context, the habitat improvement projects provide a variety of ecological benefits that have persisted over the period of analysis. Table 6-3 outlines the engineering benefits associated with each target habitat type, and the paragraphs below detail the engineering functions delivered on site specific basis. Additionally, Table 6-3 identifies management activities to address potential challenges to the sustainability or functional capacity of the habitat improvement projects identified during field assessments conducted in 2019. Potential management activities to improve ecological function include selective species control or removal, strategic placement of additional sediment, and soil amendments. This combination of incorporating the recognition of engineering benefits and potential management activities within an ecological functional framework provides a mechanism to maximize

positive outcomes in beneficial use projects. Significantly, the habitat improvement projects were not designed or implemented to maximize engineering benefits, because the focus of these early beneficial use efforts remained on habitat outcomes. Yet engineering benefits have certainly been generated for multiple decades as a result of project implementation. These unplanned positive results suggest that project outcomes can be further enhanced if a combination of ecological functions and engineering benefits can be incorporated into the design, execution, and management phases of a project's life cycle.

Figure 6-2. Time-series images of the Bolivar Peninsula habitat improvement study location, initiated in 1976. Note, vegetation cover increases over time, and the area retains its physical footprint over the study period.



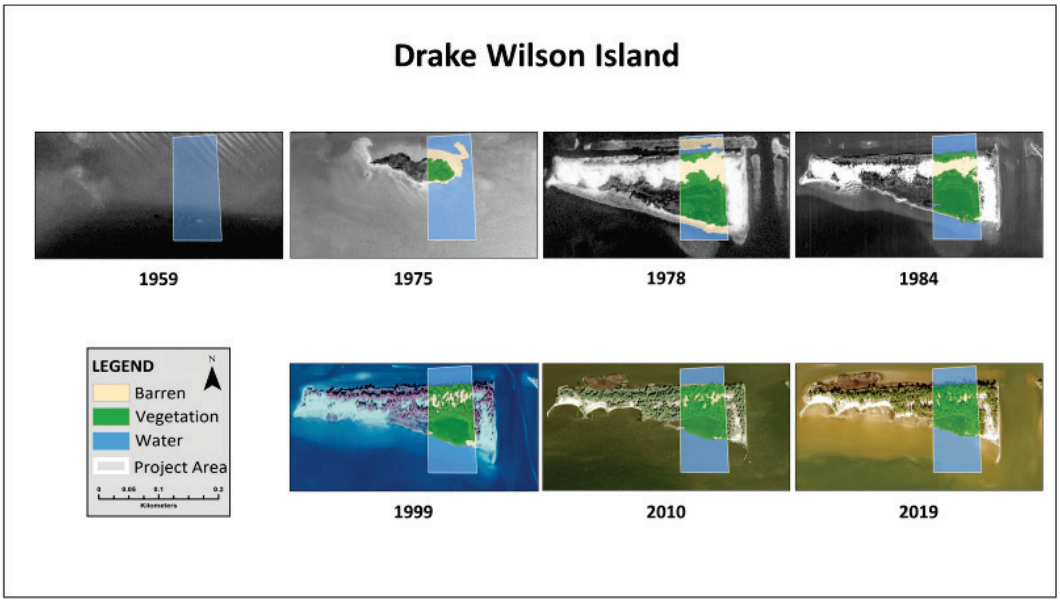
The Bolivar Peninsula study location provides a wide array of engineering benefits including shoreline stabilization, elevation maintenance, navigation channel maintenance, storm-surge reduction, landscape evolution, water quality improvements, and dewatering effects. The variety of engineering benefits observed within the site are derived from the diverse assemblages of habitats present, ranging from wetland marshes to woody uplands. Additionally, the landscape setting provides ample opportunities for the delivery of engineering benefits. For example, the project site is located adjacent to the navigation channel which provides access to dredged materials for navigation channel maintenance. Additionally, the persistence of the site over time suggests that the project protects the navigation channel from sediment accumulation. The study location also includes a gradient of elevations, allowing for dewatering

effects to occur in higher elevation upland areas. The position of the project site adjacent to Galveston Bay, a system with abundant fine-grained sediments that are readily mobilized by wind and wave energy promotes both elevation maintenance and landscape evolution benefits through the retention of sediments during periods of inundation or storm events. Further, the daily inundation that occurs in the lower elevation marsh portions of the project area support water quality improvements through denitrification and the sequestration/transformation of elements and compounds.

Wetlands within the Bolivar Peninsula project area exhibit more categories of engineering benefits (shoreline stabilization, elevation maintenance, navigation channel maintenance, storm-surge reduction, landscape evolution, water quality improvements) than transitional or upland landscape features (dewatering effects, navigation channel maintenance). This occurs because wetlands and aquatic environments are more frequently inundated, providing more opportunities to yield a subset of engineering benefits relative to non-wetlands. For example, daily patterns of inundation within the marsh habitat facilitates the retention of sediment from the water column, which supports elevation maintenance and other engineering benefits. Similarly, marsh and other wetland vegetation within the project area occurs at higher densities than observed in upland habitats; resulting in increased shoreline stabilization and storm-surge reduction engineering benefits compared with the upland areas.

The differences in the number or magnitude of engineering benefits should not be interpreted to suggest that the wetlands are 'better' than the upland areas in terms of project outcomes, but instead highlights the fact that recognizing how engineering benefits differ across the landscape can inform project design and management. For example, the results of the assessment at Bolivar Peninsula indicates that projects incorporating a variety of landscape features promotes a higher diversity of engineering benefits than projects that only contain a single geomorphological feature. This also corresponds with the wide range of vegetation and avian habitats described in other sections of this report, yielding a wide variety of ecological functions.

Figure 6-3. Time-series images of the Drake Wilson Island habitat improvement study location, initiated in 1976. Note, vegetation cover increases over time and, despite small declines in total land area, the project has largely retained its physical footprint over the study period.



The Drake Wilson Island study location provides a similar set of engineering benefits to those observed within the Bolivar Peninsula project area including shoreline stabilization, elevation maintenance, navigation channel maintenance, storm-surge reduction, landscape evolution, water quality improvements, and dewatering effects. The similarities to the Bolivar Peninsula site results from Drake Wilson Island exhibiting the same general set of habitats/landforms, comparable tidal regimes, and the fact that both locations occur adjacent to large open bodies of water with substantial fetch.

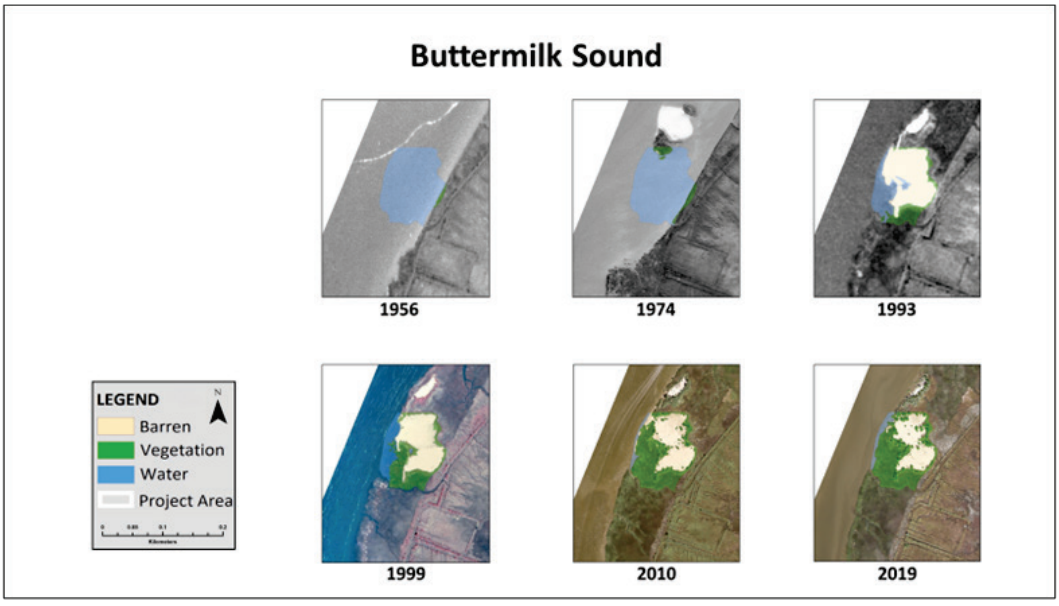
The variety of engineering benefits observed within the site are derived from the diverse assemblages of habitats present, which result from the incorporation of an elevation gradient into the project design. The landscape setting, adjacent to the intercoastal waterway and open to the Gulf coast of Florida provides ample opportunities for the delivery of engineering benefits. The proximity to the project site to the intercoastal waterway allows for maintenance of the navigation channel. This has been documented in other beneficial use contexts, such as the Horseshoe Bend Island project in Louisiana, where the establishment of landforms created using dredged materials decreased the need for maintenance dredging as a result of improved hydrodynamics that increase flow velocities and

decreased sediment accumulation within the navigation channel (Foran et al., 2018).

The position of the project, which faces the open Gulf of Mexico promotes elevation maintenance through sediment capture during storm events, as observed in the soil samples collected during site visits, which displayed clear evidence of periodic sediment deposition resulting in the formation of stratified layers (Figure 5-4). Additionally, the location of the Drake Wilson Island beneficial use site in front of the mainland provides opportunities for shoreline stabilization, and storm surge reduction. Anecdotal observations made during 2019 following hurricane Michael suggest that less erosion and damage to docks and other infrastructure occurred in areas located behind the beneficial use feature relative to unprotected areas. However, additional research will be required to quantify this subset of engineering benefits.

The sandy uplands that were incorporated into the project design highlight the capacity of the project to promote dewatering effects. Finally, the evidence of anaerobic conditions observed through soil morphological characteristics provide evidence that the wetland marshes associated with the project are active sites of denitrification and other processes that improve water quality.

Figure 6-4. Time series images of the Buttermilk Sound habitat improvement study location, initiated in 1975. Note, vegetation cover increases over time, and the area has expanded the physical footprint of marshes adjacent to the project area over the study period.



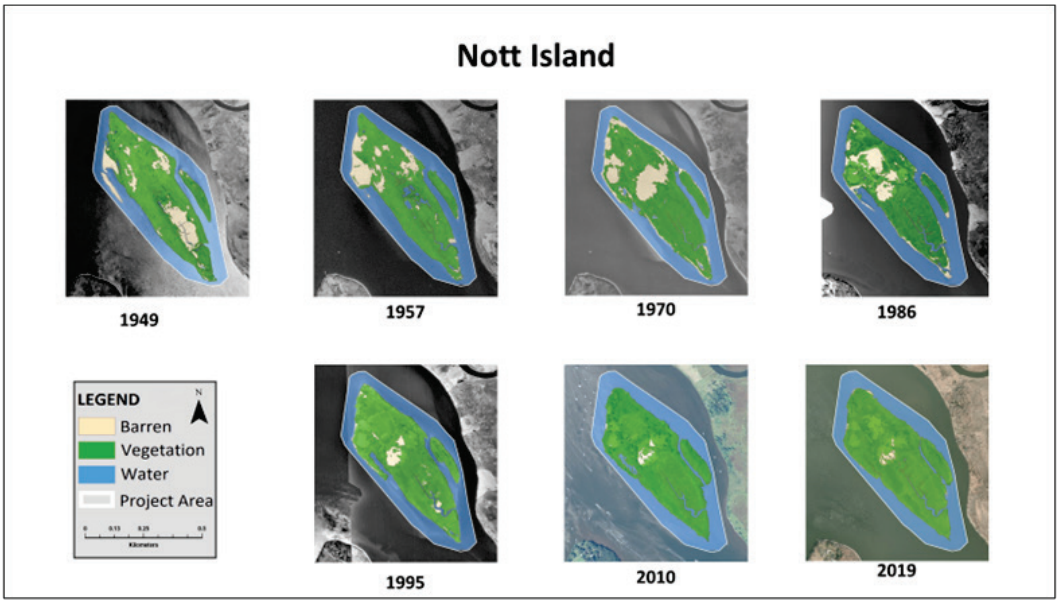
The Buttermilk Sound study location provides a similar set of engineering benefits to those observed within the Bolivar Peninsula and Drake Wilson Island project areas including shoreline stabilization, elevation maintenance, navigation channel maintenance, storm-surge reduction, landscape evolution, water quality improvements, and dewatering effects. However, the magnitude of the engineering benefits likely differs from those locations due to a combination of environmental and landscape factors. These include differences in tidal rescheme (micro- vs. meso-tidal) and landscape positions (adjacent to large expanses of open water vs. riverine). The potential differences between engineering benefits across diverse landscape settings and ecological conditions could be elucidated with additional research, but the following discussion serves as a conceptual comparison across study sites. The more robust tidal prism and riverine setting likely provide a more constant supply of sediment at Buttermilk Sound than at the Bolivar Peninsula or Drake Wilson Island sites. Further, while all three areas are subject to storm driven inundation and sediment inflows, the effect at Buttermilk Sound may be buffered by its location relative to the Bolivar Peninsula and Drake Wilson Island sites which are both directly exposed to wave and wind energy from long fetches associated with Galveston Bay and the Gulf of Mexico respectively.

The landscape evolution engineering benefits provided at the Buttermilk Sound site are highlighted in Figure 6-4. The time series analysis suggests that following project construction, the beneficial use project area expanded as more sediments were trapped within and adjacent to the project area (i.e., highlighted area). This resulted in the expansion of the tidal marsh habitats well beyond the sediment placement area. The conversion of the un-vegetated sandy dredged material deposits to a variety of vegetated habitats through ecological succession is also evident in the time series images. The observed landscape evolution benefits provide an example of the capacity for the geomorphology of beneficial use projects to respond to environmental gradients when projects are constructed without the use of restrictive hardened infrastructure. Project managers and stakeholders should prepare for and accommodate changes in project geomorphology as an appropriate and valuable component of beneficial use activities. The landscape evolution benefits are closely aligned with the elevation maintenance, storm-surge reduction, and shoreline stabilization benefits as they occur in response to the energy reduction and sediment retention functions discussed above. Data from soil descriptions suggests that the project area has accumulated between

10 and 25 cm of fine- grained sediments since project implementation within the marsh habitats observed within the project area.

The Buttermilk Sound project site also displays the capacity to improve water quality as indicated by the predominance of depleted soil matrices that result from prolonged periods of soil inundation and anaerobic conditions. The water quality engineering benefits are extremely valuable in riverine systems subject to excess nitrogen or other nutrient inputs from agricultural and urban sources, which can be decreased through denitrification and the sequestration, retention, and/or transformation of other compounds. The remaining sandy upland habitat at Buttermilk Sound indicates that dewatering effects have been provided at this location, and further management activities such as additional sediment placement or the selective removal of vegetation within the existing upland areas would improve habitat for ground nesting shorebirds in conjunction with the delivery of additional engineering benefits.

Figure 6-5. Time series images of the Nott Island habitat improvement study location, initiated in 1974. Note, vegetation cover increases over time, and the area has expanded its physical footprint over the study period.



The Nott Island habitat improvement project resulted in the establishment of an upland meadow through the grading and manipulation of high elevation, unproductive sandy dredged deposits adjacent to the Connecticut River. Within the framework described above, the project provides navigation channel maintenance and dewatering effects engineering benefits. The channel maintenance benefits are derived from

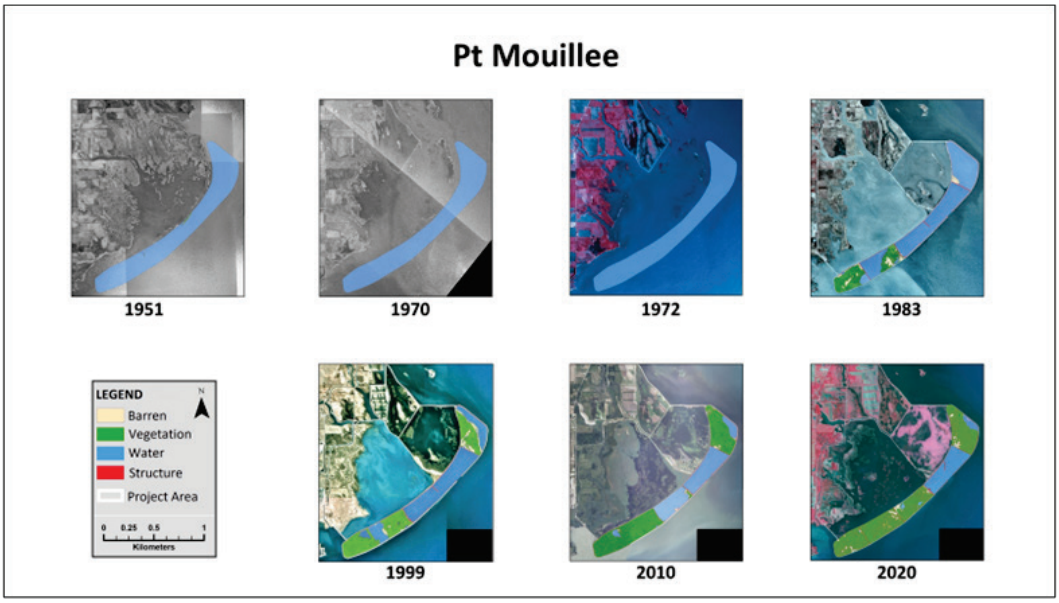
the location of the project site adjacent to the navigation channel, which allows for the efficient placement of dredged materials in an upland location that precludes re-introduction of the sediments into the channel. The high elevation and well drained conditions at the project site also provide an ideal location for dewatering which is likely expedited by the course texture of the materials within the project site as well as the geomorphology of the site which promotes rapid leaching.

While the entire island includes wetland marshes and other habitats that are frequently inundated, the habitat improvement project site is limited to the upland meadow. As a result, the Nott Island project sites provides a smaller number of engineering benefits than the study locations discussed above. This occurs because many of the engineering benefits assessed herein require frequent or periodic contact with water and/or sediment to deliver ecological functions (e.g., energy dissipation) and associated engineering benefits (e.g., storm surge reduction). The absence of a direct connection between the upland project area and the surrounding river floodplain precludes many of these types of interactions. However, the fact that the Nott Island project site provides a smaller number of engineering benefits than other study areas does not suggest that the project failed to achieve its objectives, which focused on the successful establishment of upland meadow habitat.

The distribution engineering benefits observed across the six study locations highlights the importance of understanding the interactions between geomorphology and the capacity to deliver ecological functions and associated engineering benefits. As such, projects intending to maximize delivery of multiple engineering benefits should incorporate design features that support a variety of ecosystem functions. For example, this could include the development of project features that integrate a variety of habitat types and morphologic features, yielding opportunities for effective interactions with water and sediment for storm surge reduction and shoreline stabilization, but also upland features to support navigation channel maintenance and dewatering effects. Alternatively, in cases where ecological constraints or other factors limit the capacity to deliver multiple engineering benefits, the subset of achievable engineering benefits can be maximized within the project area through design and management. For example, the presence of existing infrastructure (e.g., roads, buildings) may preclude the direct connection of the project to the sources of water and sediment. In such cases, engineering benefits that do

not require a direct physical connection between the project site and water/sediment inputs (e.g., dewatering effects) can be maximized during design and implementation.

Figure 6-6. Time-series images of the Pointe Mouillee habitat improvement study location, initiated in 1976. Note, vegetation cover increases over time, and the area has expanded its physical footprint over the study period as additional dredged sediments were introduced into the project area.

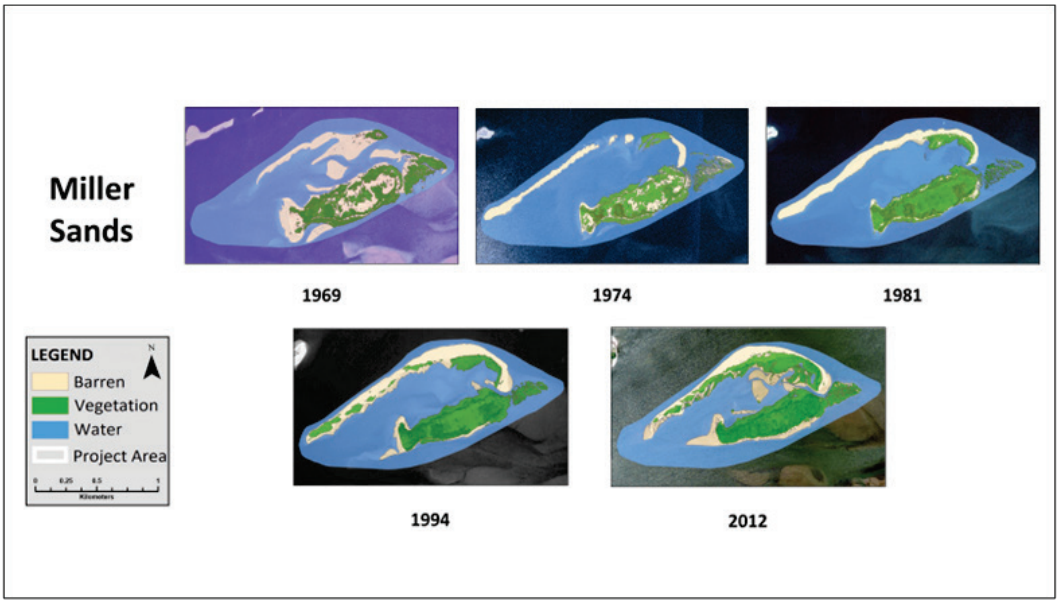


The Pointe Mouillee study location provides the full array of engineering benefits evaluated in this assessment including shoreline stabilization, elevation maintenance, navigation channel maintenance, storm-surge reduction, landscape evolution, water quality improvements, and dewatering effects. The project is unique amongst the six habitat improvement sites examined because it has been actively managed and includes the use of hard infrastructure. The active management includes the periodic delivery and manipulation of dredged materials from the Detroit River and surrounding waterways. A series of five dredged material containment cells facilitates sediment management within the site, which was designed to both provide containment for dredged materials and protection for the degraded marshlands to the west of the study area. The hard infrastructure within the project site includes large rip-rap dikes and a maintenance road encircling each dredged material containment cell. The use of these materials was required to protect the project site and the adjacent marsh habitat from wind and wave energy generated within the western Lake Erie basin.

The operations at Pointe Mouillee highlight opportunities to maximize some engineering benefits through active management while allowing natural processes to delivery other engineering benefits. For example, the use of rip rap along the boundary of the project site has effectively reduced storm surges and stabilized the shoreline, allowing for recovery of the adjacent degraded marsh in accordance with the project objectives, while also providing navigation channel maintenance. Additionally, manipulation of dredged materials via diching and other actions promotes dewatering effects within the active containment cells, and the intentional periodic delivery of sediment to the cells results in elevation maintenance benefits.

These desirable outcomes occur in combination with other engineering benefits derived from natural, passive processes. For example, the habitats that have developed through ecological succession indicates that the beneficial use site is delivering landscape evolution benefits (Figure 6-8), and the resultant wetlands (which are frequently inundated) display the ability to provide water quality improvements via denitrification and the transformation of elements and compounds. The resultant combination of engineering benefits, derived from both active management and natural passive processes, can inform the design and management of future beneficial use projects. Understanding the need to maximize particular engineering benefits through management based on project objectives or environmental constraints in conjunction with allowing natural processes to yield engineering benefits where possible likely represents the best path forward for many future beneficial use projects. The Pointe Mouillee habitat improvement project provides a valuable example of how active management and natural, passive processes can be integrated to facilitate delivery of a diverse array of engineering benefits.

Figure 6-7. Time series images of the Miller Sands habitat improvement study location, initiated in 1974. Note, vegetation cover increases over time, and the feature has persisted despite changes in the geomorphology of the island across the study period in response to sediment retention and erosion.



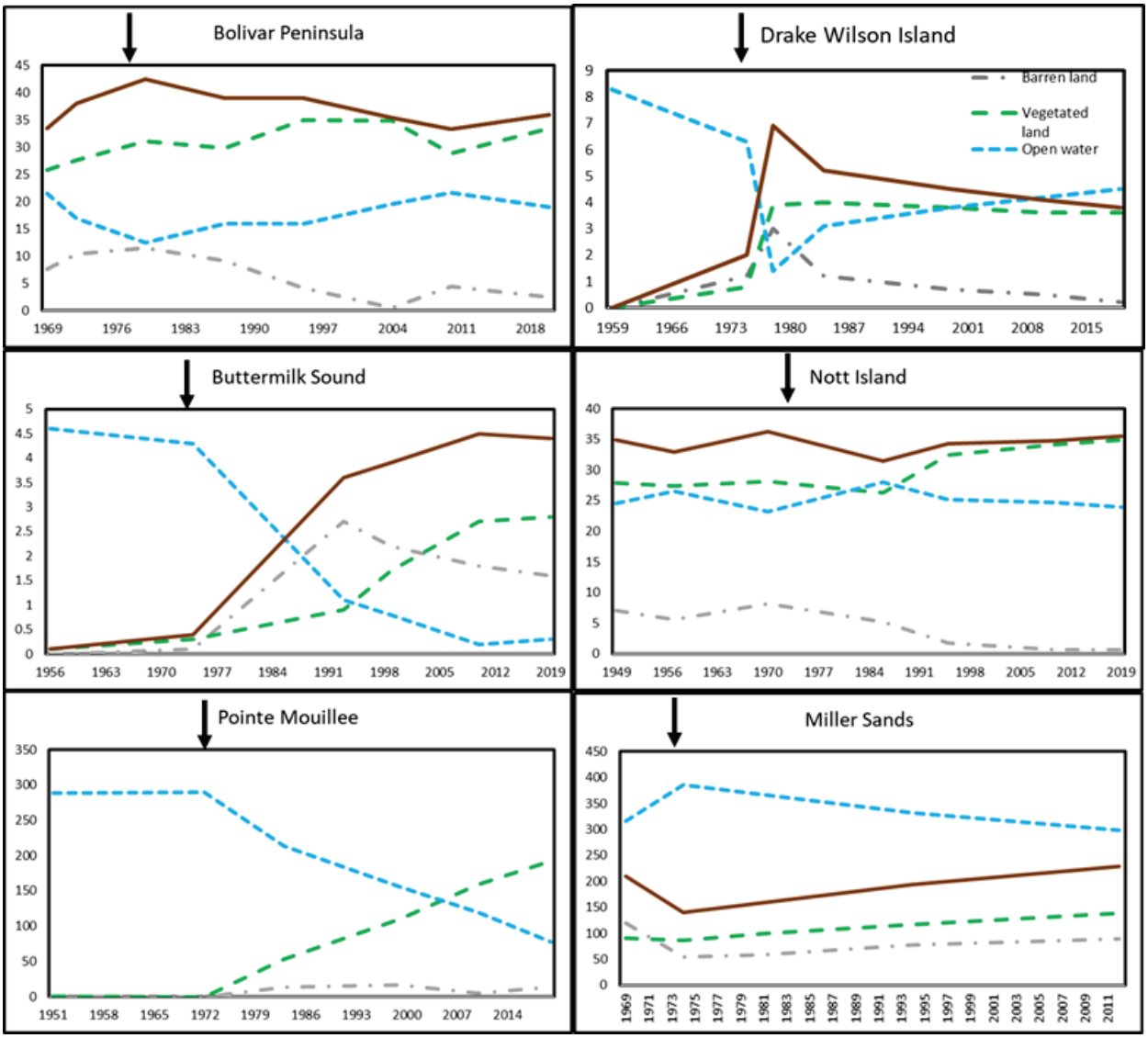
Similar to the Pointe Mouillee study location, the Miller Sands habitat improvement project delivers the full range of engineering benefits included in the current analysis. However, the site has not required active management to deliver the shoreline stabilization, elevation maintenance, navigation channel maintenance, storm-surge reduction, landscape evolution, water quality improvements, and dewatering effects evident in the project area.

As observed in several of the other project areas, the variety of engineering benefits provided at Miller Sands is closely linked with the diversity of elevation gradients, salinity, and associated habitat types at the study location. Notably, the engineering benefits result from the project design, which intentionally incorporated multiple project elements and target habitats. For example, the upland meadow provides an ideal location for dewatering effects due to its elevation, well drained soils, and topography. The dune features also supports dewatering in addition to navigation channel maintenance, especially since additional dredged sediment placement can occur on or adjacent to the dune without damaging well established vegetation communities. The time series images (Figure 6-7, 6-8) demonstrate that the landscape evolution and elevation maintenance engineering benefits are occurring as additional sediments are retained, expanding the footprint of the beneficial use feature. The marsh and dune

features of the project promote shoreline stability, storm surge reduction, and water quality improvements due to frequent inundation and contact with sediments during tidal cycles and storm events.

Given its location in the Columbia River, the Miller Sands project site is located within the highest tidal range of any of the habitat improvement projects examined and the highest energy landscape setting evaluated. High energy environments are more likely to introduce water, sediment, and other materials into a project area, yielding additional opportunities for the delivery of some engineering benefits. This has important implications for the magnitude of engineering benefits provided by projects, which can be quantified with additional research. Qualitatively, the Miller Sands beneficial use project likely yields several engineering benefits at higher magnitudes and frequencies than other projects due to the increased opportunities for ecological functions (e.g., energy dissipation) and associated engineering benefits (e.g., storm surge reduction) to occur. As such, Miller Sands represents a useful location to further explore engineering benefits within high energy environments.

Figure 6-8. Landcover change at habitat improvement project study locations. The *y*-axis represents the area of each cover type (in hectares), and the black arrows indicate when each project was initiated. Note, project implementation increased the total land cover at most study locations, and the proportion of vegetated lands increased following project construction. The total land category is not shown for the Pointe Mouillee study location because the site has been managed as an active CDF, which includes some structural features.



6.4 Beneficial use project trajectories for delivering ecological functions and engineering outcomes

Ecological functions and associated engineering benefits have been shown to respond to ecosystem perturbations and restoration activities at different rates according to the type and magnitude of the change. For example, Hunter et al. (2008) investigated the impact of restoring wetland hydrology on increasing biogeochemical cycling functions and water-

quality improvements during restoration activities. Berkowitz (2013) used data from a wetland restoration chronosequence to categorize ecosystem functional components into rapid-response, response, and stable groups, providing a framework for developing ecological response trajectories. Those findings, along with a subsequent study, reported that ecosystem functions driven by physical and hydrologic factors yield a moderate level of functions in the first few years after restoration has been initiated, then increase to provide high levels of function at intermediate and long-term intervals (Berkowitz 2019). This pattern (Figure 6-9) results from the initial improvements in ecological conditions unrelated to biological factors, followed by further enhancements that occur in response to biological maturation of the restored habitat. For example, energy dissipation is a physically driven process by which impediments to the transport of water decreases flow velocities. Unvegetated substrates have the capacity to dissipate energy immediately following project execution. However, the dissipation of energy is enhanced when vegetation becomes established, because it increases resistance within the water column, generates additional surface roughness, and increases soil shear stress. As a result, the initial degree of energy dissipation increases at intermediate time steps, and restored environments continue to deliver high levels of this function as restoration projects reach maturity. A similar pattern can be applied to water-storage and sediment-retention functions.

The physical and hydrology-driven functions are often limited by landscape-scale factors, such as elevation that can affect access to waters and sediments, retention times, and other factors. As a result, this subset of functions and associated engineering benefits should be maximized during project design and implementation. For example, water-storage functions can be increased by incorporating depressional areas and microtopographic relief into project designs, and sediment retention can be enhanced by designing projects to experience longer holding times and more frequent periods of inundation. Maximizing these functions promotes shoreline stabilization, storm-surge reduction, and navigation channel maintenance early within the project life cycle, yielding benefits immediately or very shortly after construction has been completed. These physically and hydrologically derived functions (and associated engineering benefits) have the highest capacity to deliver project benefits immediately after an action has been executed—especially in landscapes providing low levels of engineering benefits in an unaltered condition.

Berkowitz (2018) suggested biologically mediated functions often lag behind physically derived processes. For example, biogeochemical cycling requires time for microbial communities (which mediate biogeochemical activity) to adjust to site conditions and for deliver labile sources of carbon, nutrients, and other elements and compounds to accumulate within the system. The rate of biogeochemical cycles varies substantially, with processes such as denitrification occurring fairly quickly, although often at lower rates than observed in reference areas. For example, Bruland et al. (2006) measured denitrification activity in three- to six-year-old restored and created wetlands, reporting the wetlands were yielding substantial water-quality benefits. Other biogeochemical cycling processes, including carbon accumulation, require additional time to equilibrate, and as seen in this technical report (and others), may not reach reference levels several decades after restoration or creation. This effect is captured by the decrease in the rate of functional gains associated with the biogeochemical cycling functions depicted in Figure 6-9 at mid- to long-term intervals. The nonlinearity of increasing functional capacity has been noted elsewhere and aligns with biologically mediated processes, which often follow logarithmic (or in some cases exponential) growth patterns (Kentula 1996). This effect has important implications for engineering benefits and outcomes, since sufficient vegetative litter production is required to maintain elevation through organic matter deposition, and many water-quality improvements result from microbial transformation of nutrients and other compounds that require organic matter as a reactive substrate.

Habitat functions often remain depressed relative to physically and biogeochemically driven processes immediately after project execution because of the time required for soil nutrients to become available to support vegetative growth and for food sources, vegetative structures, and other life requirements to develop in support of faunal community colonization. Notably, the rate of habitat functional increases is often subject to thresholds that, once exceeded, induce rapid changes in ecological productivity. For example, the effect of canopy closure on vegetative species composition and structure is a major driver of habitat functions in forested systems (Berkowitz 2013). This dynamic results in functional response rates that increase or decrease throughout the succession and maturation process. Canopy closure induces a reduction in the density of shrubs and herbaceous vegetation, then subsequent self-

thinning processes open canopy gaps that stimulate new growth and sustain mature forests.

Of course, the functional trajectories of floral and faunal communities differ across time and space, as do the life requirements for individual species. As a result, the habitat pattern depicted in Figure 6-9 only represents one potential trajectory for habitat functions. However, this example provides a relative measure of functional responses to ecosystem restoration and beneficial use within the context of the current study. Because habitat functions influence a large number of engineering benefits (six of the seven evaluated here), appropriately identifying target habitat types, selecting species of interest, and designing restoration and beneficial use projects for maximum engineering gain is essential. For example, Table 6-3 indicates that within the current data set, coastal marshes provided the greatest variety of engineering benefits or outcomes. This result stems from the connectivity between marshes and water, which provides opportunities to improve water quality, reduce storm surge, trap sediment that may otherwise enter navigation channels, and other benefits. The available evidence suggests that, through design, engineers can maximize select benefits of interest. For example, if project objectives include water-quality improvement, wetland habitat features that are frequently inundated and support a robust assemblage of floating and rooted vegetation will yield the most benefits (Berkowitz et al. 2017).

In addition to the differences between types of functions (for example, physical versus habitat), the time frames during which ecosystem functional milestones are reached depends on the ecological setting being considered. For example, data from this study report that coastal marshes may be fully vegetated within 1–2 years of construction, especially when plantings and soil amendments are included in beneficial use project designs, and reached their climax vegetative community in less than 10 years according to the available historical species data from the habitat improvement sites. However, forested systems may require more than 80 years to reach maturity and yield the full suite of habitat functions. These time factors have important implications for the delivery and quantification of engineering benefits. For example, the establishment of early successional species can stabilize soil to reduce storm surge, trap sediment, and help maintain elevation. However, development of more robust vegetative structures with time likely provides greater storm-surge

reduction and produces better outcomes for navigation channel maintenance.

The trajectory of engineering benefits and outcomes can also be generated from the ecological functional curves. Figure 6-10 provides a conceptual example of this approach. Each engineering benefit curve was developed using the relative proportion of functional drivers depicted in Figure 6-9. For example, the shoreline stabilization benefit reflects the relative increases predicted for the sediment retention, energy dissipation, and habitat for flora and fauna functions. While conceptionally derived in this study, these curves can help practitioners understand how a given project design feature or operational initiative will influence one or more engineering outcomes. Additionally, these figures provide a mechanism to link ecological functions and engineering benefits in a systematic way that can further promote a given project objective, support alternatives analysis, and guide messaging in relation to likely project outcomes.

Note that none of the engineering benefits or outcomes receives a low rating at the immediate or rapid time step. This occurs because each engineering benefit is at least partially derived from the physical functions discussed above, which yield moderate level of function shortly after project implementation (Figure 6-9). This approach provides a relative scale to estimate and communicate with stakeholders when, and to what extent, engineering outcomes are likely to be realized. In other words, engineering benefits associated with multiple physically derived ecological functions (that is, shoreline stabilization) are likely to yield benefits more rapidly and to a greater extent than engineering outcomes driven by habitat and biogeochemical functions (that is, elevation maintenance) (Figure 6-11). Understanding and communicating these effects to practitioners and stakeholder groups can improve the perception of beneficial use projects by coupling ecological processes with engineering outcomes.

Figure 6-9. Conceptual increases in ecological functions over time following ecosystem restoration. Note that physical and hydrologically driven functions (for example, water storage, sediment retention, and energy dissipation) yield moderate levels of function at short timescales, while biogeochemical cycling and habitat functions require additional time to increase because they are biologically mediated processes.

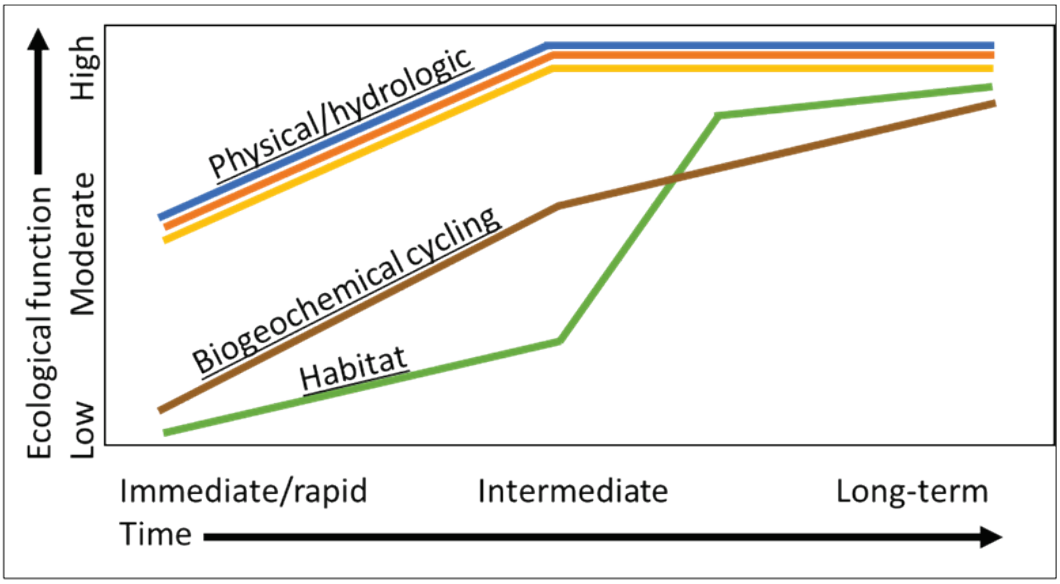


Figure 6-10. Conceptualized engineering benefit and outcome trajectory curves for the seven benefit categories investigated in the current study. Each engineering benefit curve was developed using the relative proportion of functional drivers depicted in Figure 6-9.

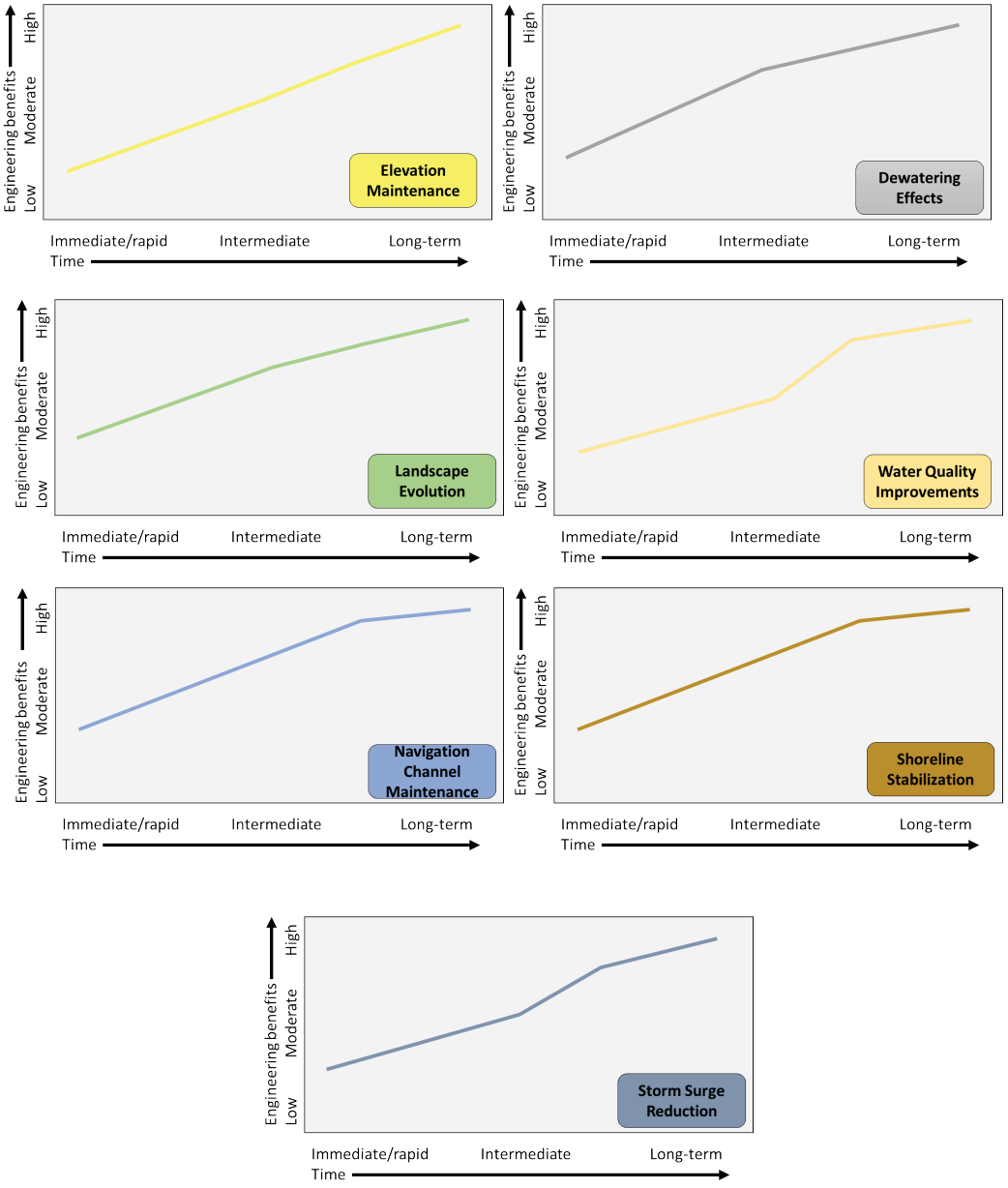
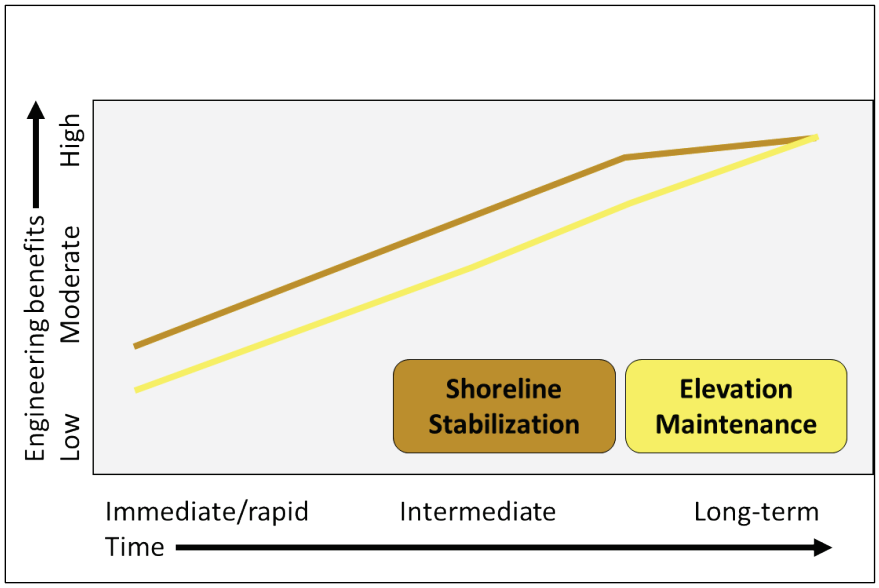


Figure 6-11. Comparison of conceptual trajectory curves for shoreline stabilization and elevation maintenance, demonstrating shoreline stabilization engineering benefits are likely to yield positive outcomes sooner and to a greater extent than elevation maintenance. This difference occurs because shoreline stabilization benefits are derived from more physically driven ecological functions, while elevation maintenance requires substantial inputs from habitat and biogeochemical functions (Figure 6-1).



6.5 Summary of ecological functions and engineering benefits and outcomes

Each of the habitat improvement projects created through the beneficial use of dredged materials continues to provide a variety of ecological functions and engineering benefits more than 40 years after construction was completed. The ecological functions include a suite of physical and hydrologic, habitat, and biogeochemical functions that have helped to sustain the projects over time. This analysis is one of the first to link ecological functions with engineering benefits and to develop a framework for communicating these linkages across multiple disciplines. Additionally, the quantitative and qualitative data presented herein supports the construction of functional trajectory curves that can be translated into predictive engineering benefit curves that can help drive project design, implementation, and management. For example, practitioners can use these curves to estimate the relative effect of a design feature, management action, or alternatives analysis on ecological functions and the engineering outcomes associated with those functions. As a result, this study provides additional tools for users seeking to incorporate engineering benefits into

project life-cycle analysis. This research also provides a framework to better monetize and operationalize beneficial use initiatives within a functions and benefits context.

7 Summary and Conclusions

7.1 Vegetation habitat assessment

The vegetation community data collected during the 2019 survey demonstrates that the habitat improvement projects continue to provide a variety of habitat functions important to ecological processes along with associated engineering benefits. In general, the projects achieved the target habitat types, and those features have been sustained for more than four decades. Notably, the spatial extent of habitat components or the suite of vegetation species, or both, present today differs from the conditions observed during postconstruction and early monitoring surveys at some study locations. The shift in species composition following construction is not unanticipated, as ecological succession occurs in response to biotic and abiotic factors that drive the success of individual species and plant communities over time. In some cases, the disconnect between project designs and steady-state conditions can be attributed to inappropriate species selection, including the planting of some species outside of their native ranges. At other habitat improvement project locations, target communities may not be sustainable without further interventions to maintain favorable conditions. For example, additional periodic sediment placement may be required to maintain low-marsh communities (Bolivar Peninsula), woody plant removal would help sustain open, sandy habitats (Buttermilk Sound), and soil amendments would help improve the conditions for vegetative growth in areas subject to nutrient limitations (Miller Sands). Additionally, nuisance, invasive, and non-native species continue to pose a significant challenge at several study locations. In general, the number of undesirable species and their abundance has increased throughout the postconstruction period.

The available data suggest that in some instances, initial planting efforts had limited effects on the occurrence and distribution of plant species after 40 years of ecological succession, and other studies have inferred that in areas with rapid natural recruitment, post restoration plantings may not be necessary. However, establishing appropriate species provides advantages even if those plant communities do not persist, as they can stabilize soils and sediments, accelerate dewatering, provide habitat, help prevent or decrease the establishment of undesirable plant species, and improve soil health.

Despite the shifts in vegetation community composition since construction, several trends emerge across the monitoring period. First, the overall complexity of study location generally increased as plant communities adjusted to local conditions and succession occurred. Observed increases in species richness and complexity are not expected to continue indefinitely as the habitat improvement sites reach maturity. These changes reflect natural and anthropogenic drivers occurring in both habitat improvement locations and reference communities.

The vegetation community assemblages observed in the habitat improvement sites were more ecologically complex than the reference areas, with the exception of the Drake Wilson Island study location. The increased complexity results from a combination of factors, including the wider variety of topography within the constructed project areas relative to the reference areas. This finding may seem counterintuitive, as other studies have identified the lack of topographic heterogeneity (for example, microtopographic relief) as a limitation on many restoration projects (see section 3 for additional discussion). However, within the sample locations examined, one of the driving factors behind the restoration design was to create appropriate ecological gradients that would support a variety of habitats. The habitat improvement projects have reached a moderate level of maturity, yet they do not directly mimic the plant community assemblages of reference areas.

Finally, both habitat improvement locations and reference areas appear to be responding to environmental conditions in similar ways despite the observed differences in species composition and structural complexity. This similarity in trend and function further suggests that the vegetation communities at habitat improvement locations are exhibiting the same responses to changing environmental conditions that affect plant distribution and growth at reference areas.

In summary, these findings suggest that the vegetation communities established at the habitat improvement sites generally reflect the conditions at reference areas but do not replicate the species composition and distribution observed in un-engineered systems. However, the study locations are effectively providing habitat for a variety of species and provide stable features that will persist into the future. Results also indicate additional management activities could further improve site conditions, especially with regard to selective species management, and in some cases

the implementation of periodic disturbance regimes (for example, additional sediment deposition) may improve the sustainability of some landscape features, including low marshes and coastal-fringe wetlands.

7.2 Avian habitat assessment

The habitat improvement projects continue to serve as important habitat for a diversity of avian communities since their creation over 40 years ago. Restoration of vegetation communities ranging from coastal salt marshes to upland habitats support a wide range of bird species, including numerous USFWS Species of Conservation Concern. However, differences in species assemblages and abundances exist between the current data set and both previous survey efforts and results from reference areas.

In general, restoration sites had higher species richness compared to reference sites because of a greater diversity of habitats. The intentional placement and manipulation of dredged materials resulted in the development of a wider range of target habitat types compared to reference sites. A diversity of habitats is more attractive to nesting and foraging birds compared to homogenous expanses of a single habitat type (see section 4.0). The differences in species composition are more closely linked to broad habitat-type effects (for example, marsh, scrub-shrub, forest) than microclimate conditions within a particular habitat (for example, lack of tidal creeks in salt marshes). Additionally, some of the habitat improvement projects displayed different, but more diverse, avian communities as a result of more habitat complexity compared with the reference areas. Future projects that seek to maximize avian community diversity should focus on creating a variety of appropriate target habitats as opposed to mimicking the landforms observed at reference areas.

This study also observed differences in species assemblages between 2019 surveys and previous surveys. In the years immediately following construction of the habitat improvement sites, numerous shorebirds, terns, and skimmers were documented using unvegetated or sparsely vegetated sandy dredged material deposits. However, beach-nesting habitat is no longer available in areas not subject to frequent inundation or intermittent patterns of disturbance, and additional management activities would be required to sustain habitat for these species.

Observations at the habitat improvement sites document the persistence of moderate to high levels of avian community diversity and abundance

throughout the study period. As these habitats matured, the associated bird communities responded. This response included the loss of beach-nesting bird habitat and the expansion of habitat for forest- and shrub-nesting species. This shift has important implications for ecosystem functions and engineering benefits, which display trade-offs as site conditions change. For example, the loss of unvegetated areas reduces habitat for some species, but increased plant productivity contributes to biogeochemical cycling, energy dissipation, and other functions that may improve engineering outcomes. If project objectives include development of shorebird habitat, the placement of additional dredged materials or the maintenance of woody vegetation represent potential management activities that would increase habitat for those groups of species. In summary, the habitat improvement locations differ from reference areas and have evolved over the >40 year assessment period; they continue to provide valuable habitat and also represent opportunities for future management actions to maximize ecosystem functions and engineering benefits that help to ensure the sustainability of the navigation program.

7.3 Soils assessment

Each of the habitat improvement projects displayed improvements in soil physicochemical properties with age. After 40 years, the study locations exhibit the ability to sustain the soil physical substrate needed to support the growth of robust rooted vegetation communities and as a result are performing the ecological functions and associated engineering benefits within each target habitat type. These benefits have generally been achieved without the need for further management or intervention.

Not only are restored sites successful in development relative to initial post-construction conditions, they also display a number of similarities with their natural counterparts. Vegetation composition and abundance directly influences soil conditions through bioavailable nutrient uptake and increasing aboveground biomass accumulation and litter deposition, highlighting the interconnectivity that drives the ecological functions and engineering benefits provided by the study sites (see section 6.0).

The soil characteristics at each habitat improvement project site have trended toward reference conditions over time, despite the persistence of differences in some parameters at a subset of study locations. This finding aligns with the results of other studies, indicating that while some soil and biogeochemical processes are rapidly initiated after activities such as

dredged material placement other processes (including recalcitrant carbon accumulation) occur at much longer time intervals.

In summary, the soils assessment further supports the conclusion that the projects successfully obtained the target habitat types, although the sites remain on trajectories that do not mimic unaltered reference conditions. This success highlights the need to focus restoration objectives and milestones on developing highly functional projects that maximize engineering benefits and to avoid placing too much emphasis on mimicking reference conditions with respect to soil parameters.

7.4 Ecological function and engineering benefits and outcomes

The habitat improvement projects continue to provide a variety of ecological functions and engineering benefits after more than 40 years. This analysis links observed ecological functions with engineering benefits to communicate the long-term outcomes of historic dredged material beneficial use projects to a variety of stakeholders. The results of this study promote project design, construction, and management based on anticipated ecological functional trajectories that can be translated into predictive engineering benefit curves. Conceptual trajectory curves were developed for seven engineering benefits and outcomes including: shoreline stabilization, storm surge reduction, navigation channel maintenance, dewatering effects, elevation maintenance, landscape evolution, and water quality improvements. Practitioners can use these curves to estimate the relative effect of a design feature, management action, or alternatives analysis on ecological functions that deliver beneficial engineering outcomes. As a result, this study provides tools to further incorporate engineering benefits into project life-cycle analysis. This research can also be expanded to better monetize and operationalize beneficial use initiatives within an ecosystem functions and engineering benefits context.

7.5 Opportunities for additional research

The habitat improvement projects represent unique opportunities to conduct manipulation studies because of the availability of existing historical data and the analysis reported herein. In many instances, beneficial use studies and management activities are conducted at relatively new project areas that have not undergone significant ecological succession or have limited information regarding project trajectory. As a

result, the habitat improvement areas, which have been self-sustaining for decades, can continue to inform beneficial use practices moving forward.

Because these study locations represent some of the oldest dredged material beneficial projects in the United States, they have the capacity to play a valuable role in the development of restoration chronosequences if they can be placed in a context with more recent beneficial use sites in their respective region. Berkowitz and Szimanski (2020) discuss opportunities for establishing beneficial use chronosequences according to geographic region, target habitat type, and other considerations. The availability of mature study sites is often a major limitation of chronosequence studies, and the projects investigated herein can play a valuable role for conducting retrospective studies when they can be combined with more recent beneficial use projects.

Finally, as mentioned elsewhere, there is a growing interest in improving project life-cycle analysis from a number of standpoints. The availability of these habitat improvement projects provides an outstanding opportunity to consider the annualized benefits and services provided within each project area. This analysis may include determinations of annual habitat units or valuation of ecological functions and engineering benefits related to water-quality improvements, navigation channel maintenance, or other factors. These historic beneficial use projects represent an asset for practitioners seeking to incorporate long-term perspectives into the determination of project costs, benefits, and sustainability.

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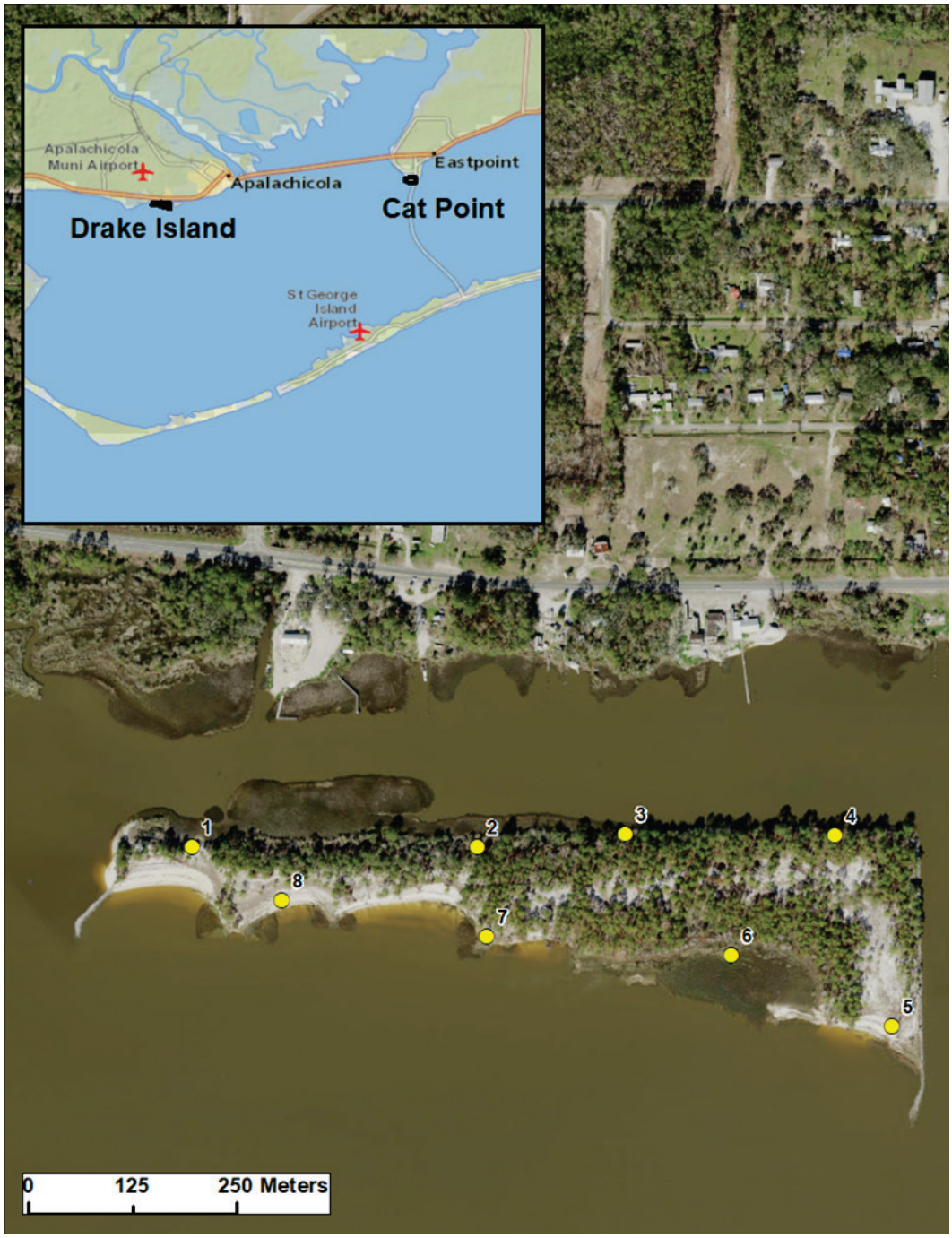
Appendix A: Figures of Field Site Locations and Avian Point Counts for Surveys Conducted During Spring 2019

Bolivar Peninsula Field Site

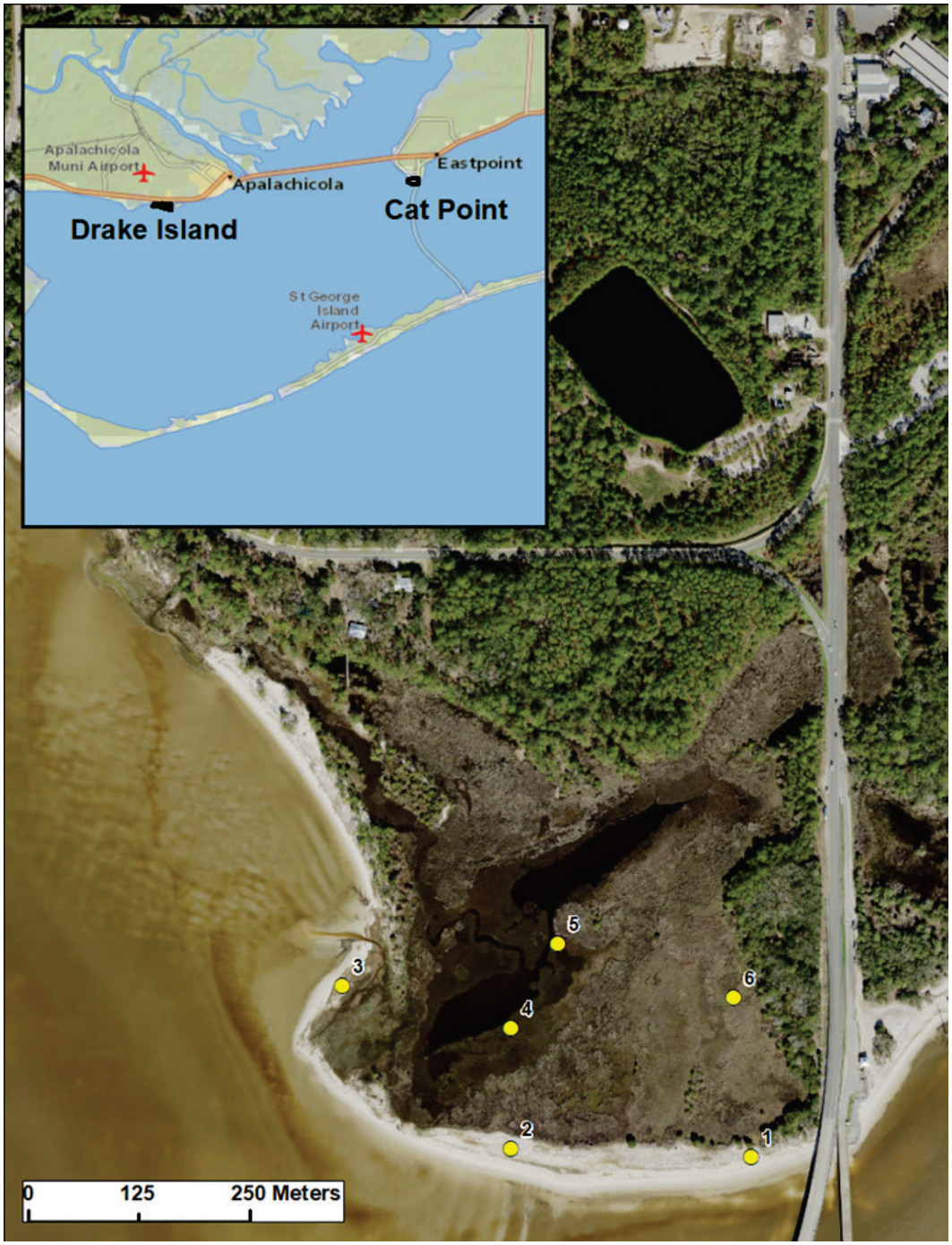



Badiff
San Leon
Pepper Grove
Bolivar Field Site
Texas City
Galveston
Scholes Intl At
Galveston Airport
1
2
3
4
5
6
0
250
500 Meters

Drake-Wilson Island



Cat Point Reference Site



Buttermilk Sound Field Site



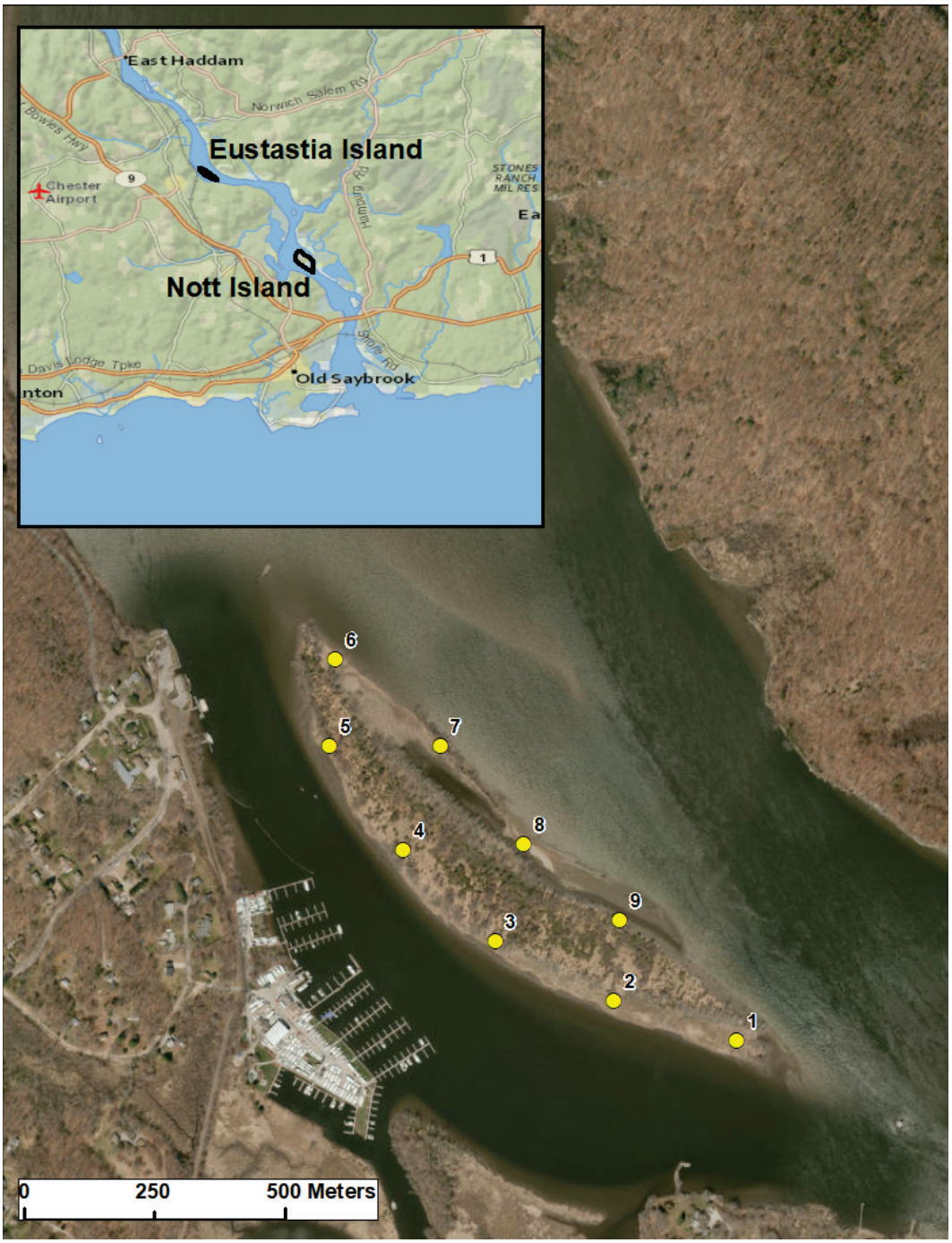
Hardhead Island Reference Site



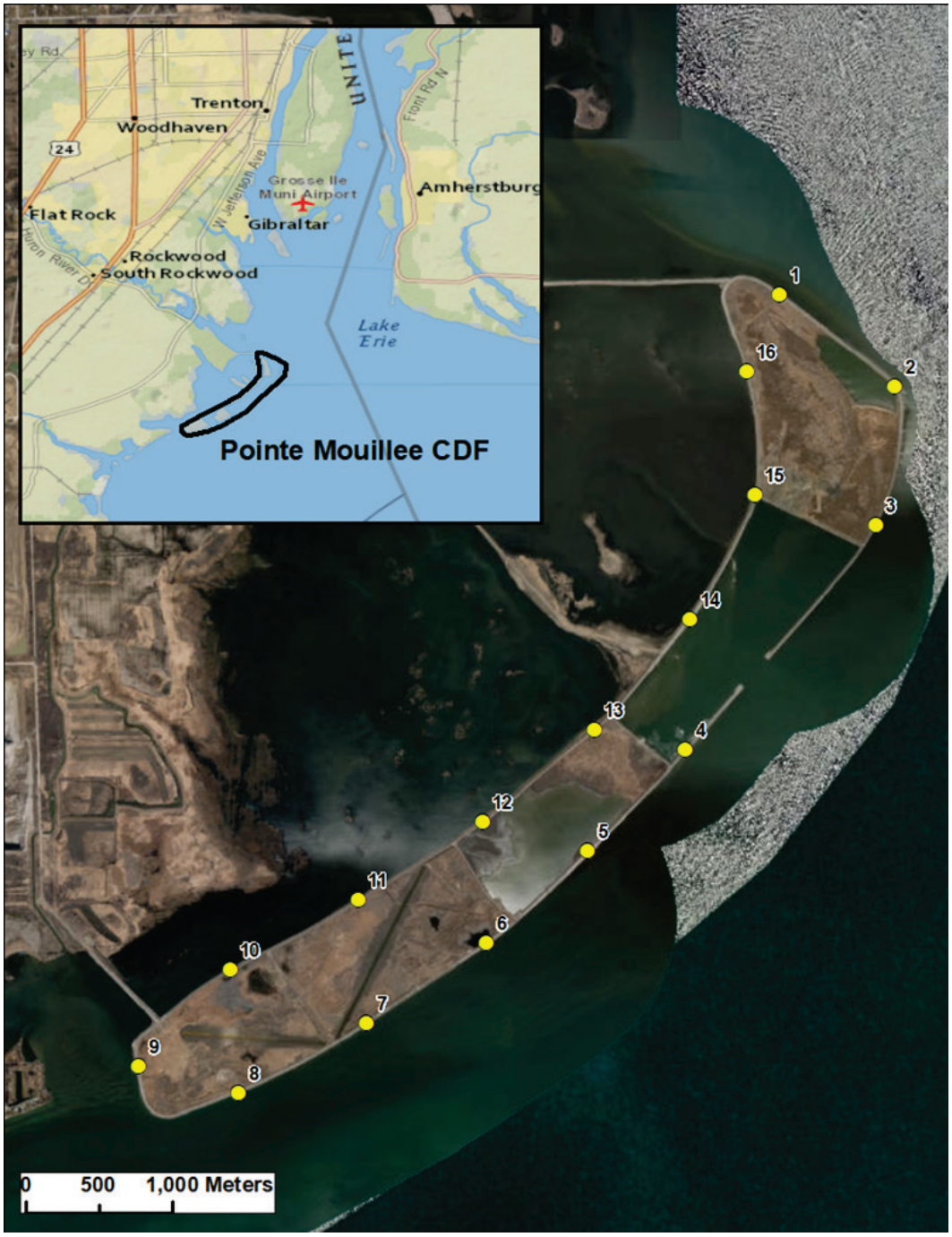
Nott Island


East Haddam
Norwich Salem Rd
Eustastia Island
Chester Airport
Hamburg Rd
Nott Island
Davis Lodge Tpke
Shore Rd
Old Saybrook
7
8
9
6
10
5
11
4
3
12
2
1
0
250
500 Meters

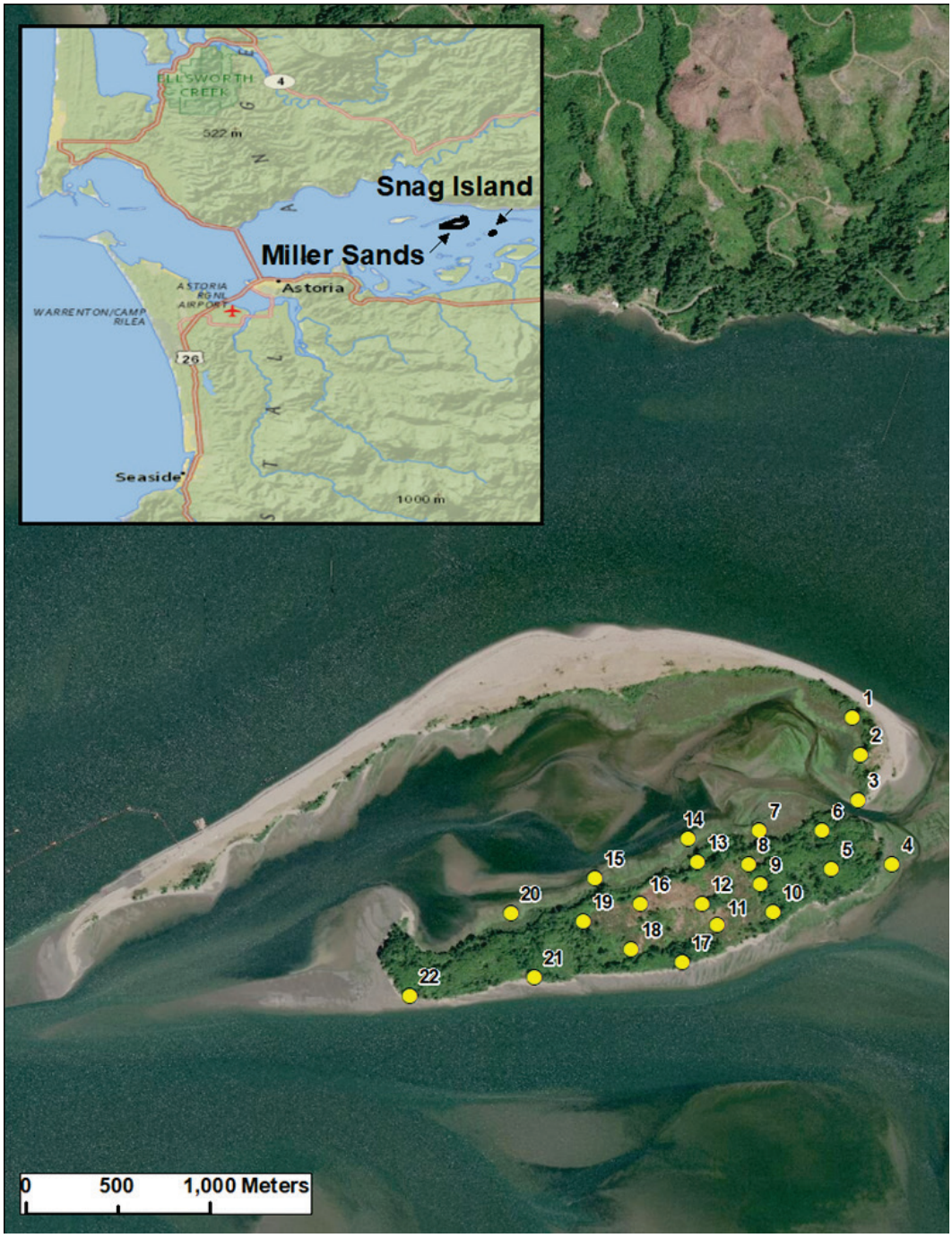
Eustasia Island Reference Site



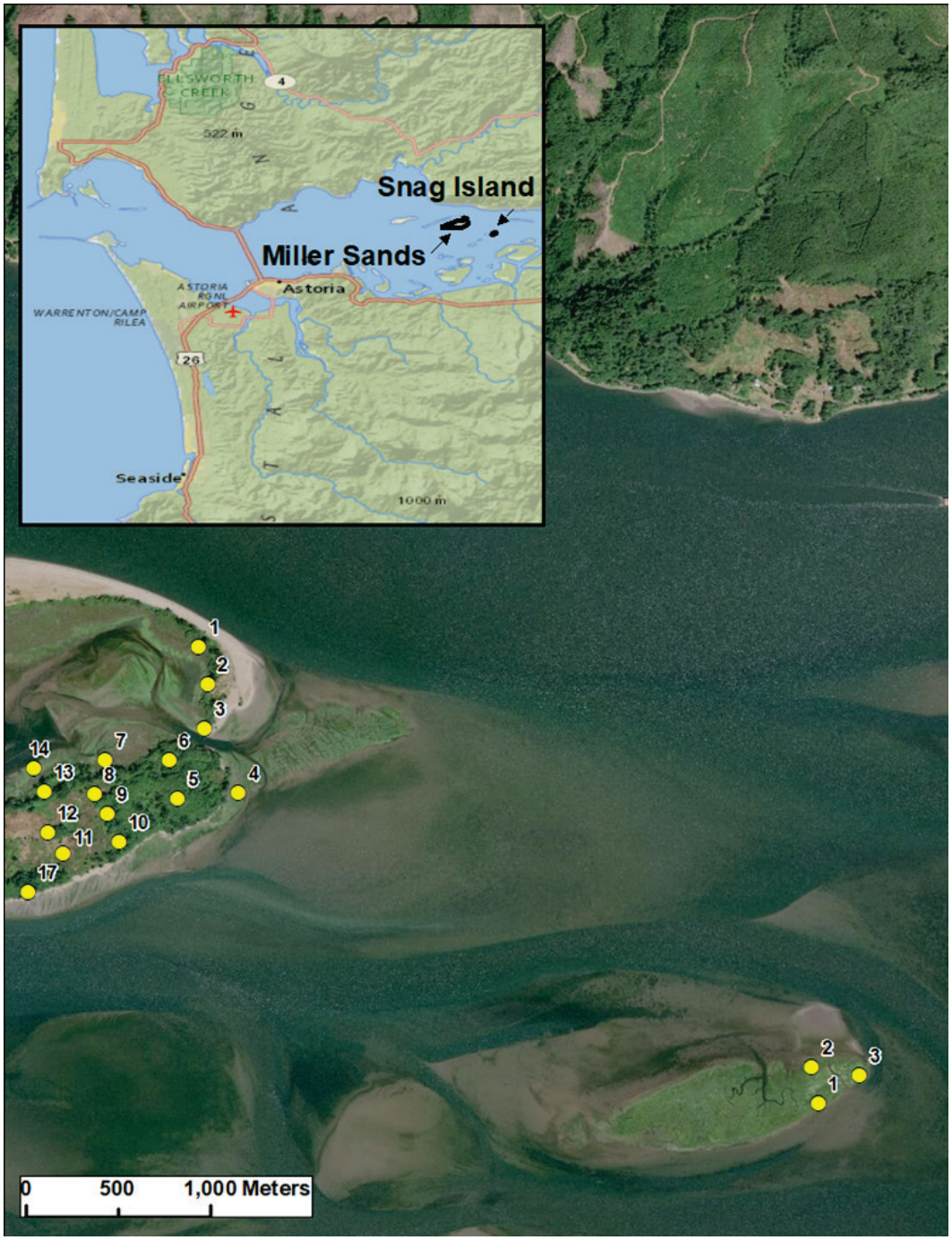
Pointe Mouillee



Miller Sands Island



Snag Island Reference Site



Appendix B: Coordinates for Avian Point Counts

Coordinates for avian point counts conducted during spring and early-summer 2019 at 6 study sites and 5 reference sites at dredged island sites within the contiguous US Site types included habitat improvement projects (HI) and reference areas (R).

Site	Location	Site Type	Point Number	Latitude	Longitude
Drake Wilson Island	Apalachicola Bay, FL	HI	1	29.7115	-85.0216
Drake Wilson Island	Apalachicola Bay, FL	HI	2	29.7115	-85.0185
Drake Wilson Island	Apalachicola Bay, FL	HI	3	29.7116	-85.0169
Drake Wilson Island	Apalachicola Bay, FL	HI	4	29.7116	-85.0147
Drake Wilson Island	Apalachicola Bay, FL	HI	5	29.7098	-85.0141
Drake Wilson Island	Apalachicola Bay, FL	HI	6	29.7105	-85.0158
Drake Wilson Island	Apalachicola Bay, FL	HI	7	29.7107	-85.0184
Drake Wilson Island	Apalachicola Bay, FL	HI	8	29.7110	-85.0206
Cat Point	Apalachicola Bay, FL	R	1	29.7226	-84.8888
Cat Point	Apalachicola Bay, FL	R	2	29.7227	-84.8912
Cat Point	Apalachicola Bay, FL	R	3	29.7241	-84.8930
Cat Point	Apalachicola Bay, FL	R	4	29.7238	-84.8912
Cat Point	Apalachicola Bay, FL	R	5	29.7245	-84.8908
Cat Point	Apalachicola Bay, FL	R	6	29.7240	-84.8890
Bolivar Field Site	Bolivar Peninsula, TX	HI	1	29.4266	-94.7208
Bolivar Field Site	Bolivar Peninsula, TX	HI	2	29.4250	-94.7219

Site	Location	Site Type	Point Number	Latitude	Longitude
Bolivar Field Site	Bolivar Peninsula, TX	HI	3	29.4235	-94.7236
Bolivar Field Site	Bolivar Peninsula, TX	HI	4	29.4222	-94.7253
Bolivar Field Site	Bolivar Peninsula, TX	HI	5	29.4208	-94.7268
Bolivar Field Site	Bolivar Peninsula, TX	HI	6	29.4193	-94.7288
Bolivar Field Site	Bolivar Peninsula, TX	HI	7	29.4182	-94.7302
Bolivar Field Site	Bolivar Peninsula, TX	HI	8	29.4169	-94.7320
Bolivar Field Site	Bolivar Peninsula, TX	HI	9	29.4156	-94.7337
Bolivar Field Site	Bolivar Peninsula, TX	HI	10	29.4132	-94.7365
Bolivar Field Site	Bolivar Peninsula, TX	HI	11	29.4132	-94.7384
Bolivar Field Site	Bolivar Peninsula, TX	HI	12	29.4146	-94.7368
Bolivar Field Site	Bolivar Peninsula, TX	HI	13	29.4162	-94.7362
Bolivar Field Site	Bolivar Peninsula, TX	HI	14	29.4174	-94.7344
Bolivar Field Site	Bolivar Peninsula, TX	HI	15	29.4187	-94.7327
Bolivar Field Site	Bolivar Peninsula, TX	HI	16	29.4200	-94.7309
Bolivar Field Site	Bolivar Peninsula, TX	HI	17	29.4213	-94.7292
Bolivar Field Site	Bolivar Peninsula, TX	HI	18	29.4228	-94.7278
Bolivar Field Site	Bolivar Peninsula, TX	HI	19	29.4243	-94.7264
Bolivar Field Site	Bolivar Peninsula, TX	HI	20	29.4258	-94.7250
Bolivar Field Site	Bolivar Peninsula, TX	HI	21	29.4274	-94.7235
Pepper Grove Island	Bolivar Peninsula, TX	R	1	29.4475	-94.6971
Pepper Grove Island	Bolivar Peninsula, TX	R	2	29.4496	-94.6941

Site	Location	Site Type	Point Number	Latitude	Longitude
Pepper Grove Island	Bolivar Peninsula, TX	R	3	29.4513	-94.6921
Pepper Grove Island	Bolivar Peninsula, TX	R	4	29.4529	-94.6903
Pepper Grove Island	Bolivar Peninsula, TX	R	5	29.4540	-94.6887
Pepper Grove Island	Bolivar Peninsula, TX	R	6	29.4552	-94.6872
Buttermilk Sound Field Site	Buttermilk Sound, GA	HI	1	31.3056	-81.3932
Buttermilk Sound Field Site	Buttermilk Sound, GA	HI	2	31.3048	-81.3938
Buttermilk Sound Field Site	Buttermilk Sound, GA	HI	3	31.3042	-81.3933
Buttermilk Sound Field Site	Buttermilk Sound, GA	HI	4	31.3028	-81.3928
Buttermilk Sound Field Site	Buttermilk Sound, GA	HI	5	31.3020	-81.3944
Buttermilk Sound Field Site	Buttermilk Sound, GA	HI	6	31.3031	-81.3947
Hardhead Island	Buttermilk Sound, GA	R	1	31.3298	-81.3438
Hardhead Island	Buttermilk Sound, GA	R	2	31.3306	-81.3459
Hardhead Island	Buttermilk Sound, GA	R	3	31.3312	-81.3468
Hardhead Island	Buttermilk Sound, GA	R	4	31.3319	-81.3475
Hardhead Island	Buttermilk Sound, GA	R	5	31.3321	-81.3464
Hardhead Island	Buttermilk Sound, GA	R	6	31.3320	-81.3451
Hardhead Island	Buttermilk Sound, GA	R	7	31.3315	-81.3405
Hardhead Island	Buttermilk Sound, GA	R	8	31.3311	-81.3362
Nott Island	Connecticut River, Old Lyme, CT	HI	1	41.3441	-72.3675
Nott Island	Connecticut River, Old Lyme, CT	HI	2	41.3452	-72.3693

Site	Location	Site Type	Point Number	Latitude	Longitude
Nott Island	Connecticut River, Old Lyme, CT	HI	3	41.3464	-72.3710
Nott Island	Connecticut River, Old Lyme, CT	HI	4	41.3477	-72.3725
Nott Island	Connecticut River, Old Lyme, CT	HI	5	41.3488	-72.3743
Nott Island	Connecticut River, Old Lyme, CT	HI	6	41.3505	-72.3750
Nott Island	Connecticut River, Old Lyme, CT	HI	7	41.3524	-72.3747
Nott Island	Connecticut River, Old Lyme, CT	HI	8	41.3518	-72.3727
Nott Island	Connecticut River, Old Lyme, CT	HI	9	41.3506	-72.3714
Nott Island	Connecticut River, Old Lyme, CT	HI	10	41.3492	-72.3702
Nott Island	Connecticut River, Old Lyme, CT	HI	11	41.3479	-72.3687
Nott Island	Connecticut River, Old Lyme, CT	HI	12	41.3463	-72.3678
Eustasia Island	Connecticut River, Old Lyme, CT	R	1	41.3906	-72.4168
Eustasia Island	Connecticut River, Old Lyme, CT	R	2	41.3911	-72.4190
Eustasia Island	Connecticut River, Old Lyme, CT	R	3	41.3919	-72.4210
Eustasia Island	Connecticut River, Old Lyme, CT	R	4	41.3930	-72.4226

Site	Location	Site Type	Point Number	Latitude	Longitude
Eustasia Island	Connecticut River, Old Lyme, CT	R	5	41.3944	-72.4239
Eustasia Island	Connecticut River, Old Lyme, CT	R	6	41.3955	-72.4238
Eustasia Island	Connecticut River, Old Lyme, CT	R	7	41.3944	-72.4220
Eustasia Island	Connecticut River, Old Lyme, CT	R	8	41.3931	-72.4205
Eustasia Island	Connecticut River, Old Lyme, CT	R	9	41.3921	-72.4188
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	1	46.2524	-123.6430
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	2	46.2512	-123.6430
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	3	46.2497	-123.6430
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	4	46.2475	-123.6410
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	5	46.2473	-123.6440
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	6	46.2486	-123.6440
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	7	46.2486	-123.6480

Site	Location	Site Type	Point Number	Latitude	Longitude
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	8	46.2475	-123.6480
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	9	46.2468	-123.6470
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	10	46.2459	-123.6470
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	11	46.2454	-123.6500
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	12	46.2462	-123.6500
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	13	46.2475	-123.6510
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	14	46.2483	-123.6510
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	15	46.2470	-123.6560
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	16	46.2461	-123.6530
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	17	46.2442	-123.6510
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	18	46.2446	-123.6540

Site	Location	Site Type	Point Number	Latitude	Longitude
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	19	46.2456	-123.6560
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	20	46.2458	-123.6600
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	21	46.2437	-123.6590
Miller Sands Island	Lower Columbia River, Astoria, OR	HI	22	46.2430	-123.6650
Snag Island	Lower Columbia River, Astoria, OR	R	1	46.2370	-123.6130
Snag Island	Lower Columbia River, Astoria, OR	R	2	46.2382	-123.6130
Snag Island	Lower Columbia River, Astoria, OR	R	3	46.2380	-123.6110
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	1	42.0260	-83.1785
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	2	42.0218	-83.1714
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	3	42.0155	-83.1726
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	4	42.0053	-83.1842
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	5	42.0006	-83.1903

Site	Location	Site Type	Point Number	Latitude	Longitude
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	6	41.9964	-83.1964
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	7	41.9928	-83.2038
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	8	41.9896	-83.2116
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	9	41.9909	-83.2178
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	10	41.9952	-83.2122
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	11	41.9984	-83.2043
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	12	42.0020	-83.1967
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	13	42.0062	-83.1898
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	14	42.0112	-83.1840
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	15	42.0168	-83.1800
Pointe Mouillee CDF	Pointe Mouillee CDF, Rockwood, MI	HI	16	42.0225	-83.1805

Appendix C: Avian Species Detected

Appendix C.1

Avian species detected at each point count station using the Bolivar Study Site and the Pepper Grove Reference Sites at Bolivar Peninsula, Texas, during early April 2019. Species not appearing to use the site, but simply flying over were not tallied in the table.

Bolivar restoration site			Pepper Grove reference site		
Station	Species	Abundance	Station	Species	Abundance
1	Unidentified warbler	1	1	Willet	1
1	Prothonotary warbler	1	1	Red-winged blackbird	3
1	Scissor-tailed flycatcher	1	1	Mourning dove	1
1	Yellow-rumped warbler	1	2	Royal tern	12
2	Tree swallow	7	2	American white pelican	9
2	Eastern meadowlark	1	2	Double-crested cormorant	2
2	Prothonotary warbler	1	2	White-faced ibis	1
2	Marsh wren	1	2	Little blue heron	1
2	Swamp sparrow	1	2	Boat-tailed grackle	4
3	Carolina wren	1	2	Red-winged blackbird	3
4	American oystercatcher	1	2	Swamp sparrow	1
4	Mottled duck	1	3	Double-crested cormorant	11
4	Prothonotary warbler	3	3	Snowy egret	3
4	Northern parula	1	3	Great blue heron	2
7	Northern harrier	1	3	Brown pelican	1
7	White-tailed kite	1	3	Boat-tailed grackle	23
7	Northern mockingbird	2	3	Red-winged blackbird	4
8	Forster's tern	4	3	Brown-headed cowbird	1
8	Indigo bunting	1	3	Savannah sparrow	1
9	Forster's tern	2	3	Yellow-rumped warbler	1
10	Laughing gull	31	4	Blue-winged teal	50
10	Royal tern	15	4	American coot	25
10	Ruddy turnstone	3	4	Least sandpiper	5
10	Black-necked stilt	3	4	Double-crested cormorant	4
10	Black-bellied plover	1	4	Black-necked stilt	3
10	Forster's tern	1	4	White-faced ibis	3
10	Gull-billed tern	1	4	Green-winged teal	2

Bolivar restoration site			Pepper Grove reference site		
Station	Species	Abundance	Station	Species	Abundance
10	Willet	1	4	Great blue heron	1
11	Willet	11	4	Lesser yellowlegs	1
11	Lesser scaup	10	4	Unidentified yellowlegs	1
11	Unidentified tern	4	4	Willet	1
11	Dunlin	3	4	Pied-billed grebe	1
11	Forster's tern	3	4	Tricolored heron	1
11	Black-necked stilt	2	4	Osprey	1
11	Sandwich tern	2	4	Boat-tailed grackle	10
11	Snowy egret	2	4	Red-winged blackbird	5
11	Marbled godwit	1	4	Song sparrow	3
11	Royal tern	1	4	Salt-marsh sparrow	1
11	Reddish egret	1	5	Unidentified peep	20
11	Tricolored heron	1	5	Western sandpiper	18
11	Eastern meadowlark	1	5	Willet	12
11	Palm warbler	1	5	Least sandpiper	10
11	Marsh wren	1	5	Short-billed dowitcher	5
12	Common tern	3	5	Pectoral sandpiper	3
12	Dunlin	3	5	Northern shoveler	2
12	American oystercatcher	1	5	Unidentified duck	2
12	Forster's tern	1	5	Semipalmated sandpiper	1
12	Gull-billed tern	1	5	Whimbrel	1
12	Willet	1	5	Snowy egret	1
12	Savannah sparrow	2	5	Sora	1
12	Boat-tailed grackle	1	5	Purple martin	2
13	Dunlin	6	5	Red-winged blackbird	15
13	Black-necked stilt	4	5	Boat-tailed grackle	6
13	Willet	2	5	Northern mockingbird	1
14	Dunlin	19	6	American coot	100
14	Black-bellied plover	15	6	Blue-winged teal	31
14	Least sandpiper	4	6	Unidentified dowitcher	30
14	Willet	4	6	Short-billed dowitcher	20
14	Unidentified dowitcher	3	6	Gadwall	17
14	Eastern meadowlark	1	6	Snowy egret	13
14	Palm warbler	1	6	Black-crowned night heron	5
14	Yellow-throated warbler	1	6	Long-billed dowitcher	5
14	Swamp sparrow	1	6	Black-bellied plover	4

Bolivar restoration site			Pepper Grove reference site		
Station	Species	Abundance	Station	Species	Abundance
15	Black-bellied plover	1	6	Lesser scaup	4
15	Dunlin	1	6	Northern shoveler	4
15	Whimbrel	1	6	Roseate spoonbill	4
15	Wilson's plover	1	6	American wigeon	3
15	Song sparrow	5	6	Western sandpiper	3
15	Red-winged blackbird	1	6	Double-crested cormorant	2
16	Willet	1	6	Forster's tern	2
16	Unidentified rail	1	6	Sandwich tern	2
16	White-tailed kite	1	6	Willet	2
16	Red-winged blackbird	1	6	Common gallinule	2
17	Willet	3	6	White-faced ibis	1
17	Red-tailed hawk	1	6	Yellow-crowned night heron	1
17	White-tailed kite	1	6	Clapper rail	1
18	Forster's tern	3	6	Great egret	1
18	Red-winged blackbird	2	6	Purple martin	4
18	Song sparrow	1	6	Tree swallow	3
18	Unidentified sparrow	1	6	Barn swallow	1
19	Willet	2	6	Turkey vulture	1
19	Wilson's plover	1	6	Boat-tailed grackle	8
19	Swamp sparrow	1	6	Red-winged blackbird	5
20	Forster's tern	2	6	Eastern kingbird	2
20	Wilson's plover	1	6	Northern mockingbird	2
21	Wilson's plover	1			
21	Barn swallow	3			
21	Mourning dove	3			
21	Prothonotary warbler	3			
21	Northern mockingbird	1			
21	Orange-crowned warbler	1			
21	Palm warbler	1			
21	Savannah sparrow	1			
21	Scissor-tailed flycatcher	1			
21	Yellow-throated warbler	1			

Appendix C.2

Avian species detected at each point count station using the Drake Wilson Island Restoration Site and the Cat Point Reference Sites at Apalachicola, Florida, during late April 2019. Species not appearing to use the site, but simply flying over were not tallied in the table.

Drake Wilson Island restoration site			Cat Point reference site		
Station	Species	Abundance	Station	Species	Abundance
1	Belted kingfisher	1	1	Red-winged blackbird	3
1	Green heron	1	1	Blue-gray gnatcatcher	2
1	Red-winged blackbird	3	1	Red-bellied woodpecker	1
1	Brown-headed nuthatch	2	1	Carolina wren	1
1	Great-crested flycatcher	1	1	Northern cardinal	1
1	Northern parula	1	2	Bobolink	3
1	Carolina wren	1	2	Red-winged blackbird	3
1	Mourning dove	1	2	Blue jay	1
1	Northern mockingbird	1	3	Semipalmated plover	2
1	Boat-tailed grackle	1	3	Least sandpiper	2
2	Red-winged blackbird	4	3	Ruddy turnstone	1
2	Blue jay	1	3	Black-bellied plover	1
2	Downy woodpecker	1	3	Clapper rail	1
2	Red-bellied woodpecker	1	3	Turkey vulture	3
2	Northern cardinal	1	3	Red-winged blackbird	4
2	Northern mockingbird	1	3	Red-bellied woodpecker	1
2	Boat-tailed grackle	1	3	Boat-tailed grackle	1
3	Brown-headed nuthatch	1	4	Osprey	1
3	Red-winged blackbird	1	4	Red-winged blackbird	6
4	Red-shouldered hawk	1	4	Bobolink	3
4	Blue jay	1	4	Eastern meadowlark	1
4	Carolina wren	1	4	Boat-tailed grackle	1
4	Northern cardinal	1	4	Marsh wren	1
4	Boat-tailed grackle	1	5	Pied-billed grebe	1
5	Bald eagle	1	5	Sora	1
5	Northern cardinal	2	5	Red-winged blackbird	4
5	Blue jay	1	5	Carolina wren	1
5	Brown-headed nuthatch	1	5	Boat-tailed grackle	1
5	Red-bellied woodpecker	1	5	Marsh wren	1
5	Carolina wren	1	6	Bobolink	2

Drake Wilson Island restoration site			Cat Point reference site		
Station	Species	Abundance	Station	Species	Abundance
5	Boat-tailed grackle	1	6	Northern cardinal	2
5	Red-winged blackbird	1	6	Red-winged blackbird	2
6	Caspian tern	1	6	Fish crow	1
6	Willet	1			
6	Clapper rail	1			
6	Great egret	1			
6	Blue jay	3			
6	Red-winged blackbird	3			
6	Blue-gray gnatcatcher	1			
6	Carolina wren	1			
6	Northern cardinal	1			
7	Spotted sandpiper	1			
7	Bald eagle	2			
7	Blue jay	1			
7	Downy woodpecker	1			
7	Great-crested flycatcher	1			
7	Carolina wren	1			
7	Eastern towhee	1			
7	Northern cardinal	1			
7	Marsh wren	1			
7	Red-winged blackbird	1			
8	Spotted sandpiper	1			
8	Blue jay	4			
8	Brown-headed nuthatch	2			
8	Northern cardinal	2			
8	Red-winged blackbird	2			
8	Great-crested flycatcher	1			
8	Red-bellied woodpecker	1			
8	Carolina wren	1			
8	Northern mockingbird	1			

Appendix C.3

Avian species detected at each point count station using the Buttermilk Sound Restoration Site and the Hardhead Island Reference Site in the Altamaha River near Brunswick, Georgia, during late April 2019. Species not appearing to use the site, but simply flying over were not tallied in the table.

Buttermilk Sound restoration site			Hardhead Island reference site		
Station	Species	Abundance	Station	Species	Abundance
1	Clapper rail	2	1	Clapper rail	1
1	Red-winged blackbird	5	1	Boat-tailed grackle	4
1	Boat-tailed grackle	3	1	Marsh Wren	3
1	Marsh wren	3	1	Red-winged blackbird	2
1	Common yellowthroat	1	2	Boat-tailed grackle	3
1	Northern cardinal	1	2	Marsh wren	3
2	Clapper rail	1	2	Red-winged blackbird	3
2	Barn swallow	2	3	Clapper rail	4
2	Red-winged blackbird	3	3	Boat-tailed grackle	2
2	Common yellowthroat	2	3	Marsh wren	2
2	Marsh wren	2	3	Red-winged blackbird	2
2	Blue-gray gnatcatcher	1	4	Clapper rail	2
2	Boat-tailed grackle	1	4	Boat-tailed grackle	3
3	Clapper rail	3	4	Marsh wren	2
3	Red-winged blackbird	4	4	Red-winged blackbird	1
3	Boat-tailed grackle	3	5	Red-winged blackbird	2
3	Common yellowthroat	2	5	Boat-tailed grackle	1
3	Marsh wren	2	5	Marsh wren	1
4	Clapper rail	4	6	Clapper rail	1
4	Red-winged blackbird	7	6	Boat-tailed grackle	3
4	Common yellowthroat	3	6	Marsh wren	2
4	Blue-gray gnatcatcher	2	6	Red-winged blackbird	1
4	Boat-tailed grackle	2	7	Clapper rail	1
4	Mourning dove	1	7	Marsh wren	4
5	Clapper rail	4	7	Boat-tailed grackle	1
5	Red-winged blackbird	7	7	Red-winged blackbird	1
5	Boat-tailed grackle	3	8	Great blue heron	1
5	American robin	1	8	Marsh wren	3
5	Common yellowthroat	1			

Buttermilk Sound restoration site			Hardhead Island reference site		
Station	Species	Abundance	Station	Species	Abundance
5	Northern cardinal	1			
6	Clapper rail	1			
6	Red-winged blackbird	9			
6	Boat-tailed grackle	2			
6	Blue-gray gnatcatcher	1			
6	Carolina wren	1			
6	Eastern towhee	1			
6	Northern cardinal	1			

Appendix C.4

Avian species detected at each point count station using the Nott Island Restoration Site and the Eustasia Island Reference Site in the Connecticut River near Old Lyme, Connecticut, during late May 2019. Species not appearing to use the site, but simply flying over were not tallied in the table.

Nott Island restoration site			Eustasia Island reference site		
Station	Species	Abundance	Station	Species	Abundance
1	Great egret	1	1	Red-winged blackbird	2
1	Snowy egret	1	1	Common yellowthroat	1
1	Red-winged blackbird	4	1	Song Sparrow	1
1	Marsh wren	2	1	Yellow warbler	1
1	Common yellowthroat	1	2	Common grackle	2
1	Song sparrow	1	2	Common yellowthroat	2
1	Willow flycatcher	1	2	Warbling vireo	2
1	Swamp sparrow	1	2	Red-winged blackbird	2
2	American goldfinch	2	2	Blue-winged warbler	1
2	Marsh wren	2	2	Carolina wren	1
2	American robin	1	2	Song sparrow	1
2	Gray catbird	1	2	Yellow warbler	1
2	Ruby-throated hummingbird	1	3	Song Sparrow	2
2	Song sparrow	1	3	Red-winged blackbird	2
2	Willow flycatcher	1	3	Carolina wren	1
2	Red-winged blackbird	1	3	Common yellowthroat	1
2	Yellow warbler	1	3	Northern cardinal	1
3	Mallard	1	3	Warbling Vireo	1

Nott Island restoration site			Eustasia Island reference site		
Station	Species	Abundance	Station	Species	Abundance
3	Mute swan	1	4	Mallard	2
3	Gray catbird	3	4	Common grackle	6
3	Yellow warbler	3	4	Yellow warbler	3
3	Red-winged blackbird	2	4	Northern cardinal	2
3	American goldfinch	1	4	Baltimore oriole	1
3	House finch	1	4	Blue-winged warbler	1
3	Indigo bunting	1	4	Black-capped chickadee	1
3	Ruby-throated hummingbird	1	4	Brown-headed cowbird	1
3	Song sparrow	1	4	Common yellowthroat	1
3	Marsh wren	1	4	House finch	1
4	Red-winged blackbird	4	4	Song Sparrow	1
4	Song sparrow	2	4	Tufted titmouse	1
4	Yellow warbler	2	4	Red-winged blackbird	1
4	American goldfinch	1	5	Canada goose	7
4	Common yellowthroat	1	5	American goldfinch	3
4	Gray catbird	1	5	Yellow warbler	3
4	Mourning dove	1	5	Song sparrow	2
4	Marsh wren	1	5	Red-winged blackbird	2
5	Cedar waxwing	12	5	Blue-winged warbler	1
5	Gray catbird	4	5	Brown-headed cowbird	1
5	Yellow warbler	3	5	Gray catbird	1
5	Mourning dove	2	5	Northern cardinal	1
5	Red-winged blackbird	2	5	Warbling Vireo	1
5	Blue jay	1	6	Bald eagle	2
5	Alder flycatcher	1	6	Red-winged blackbird	3
5	American goldfinch	1	6	Song sparrow	2
5	Carolina wren	1	6	Yellow warbler	2
5	Chestnut-sided warbler	1	6	American Crow	1
5	Song sparrow	1	6	American goldfinch	1
5	Tufted titmouse	1	6	American robin	1
6	American goldfinch	4	6	Brown-headed cowbird	1
6	Gray catbird	4	6	Warbling vireo	1
6	Carolina wren	2	7	Belted kingfisher	1
6	Red-eyed Vireo	1	7	Barn Swallow	2
6	Blue-gray Gnatcatcher	1	7	Song Sparrow	2
6	Northern cardinal	1	7	Red-winged blackbird	2

Nott Island restoration site			Eustasia Island reference site		
Station	Species	Abundance	Station	Species	Abundance
6	Tufted titmouse	1	7	Baltimore oriole	1
6	Red-winged blackbird	1	7	American goldfinch	1
6	Yellow warbler	1	7	Eastern kingbird	1
7	Gray catbird	3	7	House finch	1
7	American goldfinch	2	7	Warbling vireo	1
7	Cedar waxwing	1	7	Yellow warbler	1
7	Chestnut-sided warbler	1	8	Canada goose	13
7	Yellow warbler	1	8	Barn swallow	2
8	Canada goose	1	8	Tree swallow	1
8	Song sparrow	3	8	Brown-headed cowbird	2
8	American goldfinch	2	8	Yellow warbler	2
8	Gray catbird	2	8	Black-throated green warbler	1
8	Yellow warbler	2	8	Blue-winged warbler	1
8	Hooded warbler	1	8	Carolina wren	1
8	Mourning dove	1	8	Common yellowthroat	1
8	Willow flycatcher	1	8	House finch	1
9	Gray catbird	2	8	Song sparrow	1
9	Song sparrow	2	9	American goldfinch	2
9	Willow flycatcher	2	9	Yellow warbler	2
9	Yellow warbler	2	9	Song sparrow	1
9	American goldfinch	1			
9	Common yellowthroat	1			
10	Red-winged blackbird	3			
10	Yellow warbler	3			
10	American goldfinch	2			
10	Carolina wren	1			
10	Gray catbird	1			
10	Orchard oriole	1			
10	Song sparrow	1			
10	Willow flycatcher	1			
10	Marsh wren	1			
11	American goldfinch	2			
11	Marsh wren	2			
11	Red-winged blackbird	2			
11	Yellow warbler	2			
11	American crow	1			

Nott Island restoration site			Eustasia Island reference site		
Station	Species	Abundance	Station	Species	Abundance
11	Chestnut-sided warbler	1			
11	Common yellowthroat	1			
11	Gray catbird	1			
11	Orchard oriole	1			
11	Song sparrow	1			
11	Willow flycatcher	1			
12	Unidentified peep	10			
12	Semipalmated plover	3			
12	Greater yellowlegs	1			
12	Least sandpiper	1			
12	Barn swallow	2			
12	Red-winged blackbird	2			
12	Song sparrow	1			
12	Marsh wren	1			

Appendix C.5

Avian species detected at each point count station using the Pointe Mouillee Restoration Site on the western shore of Lake Erie near South Rockwood, Michigan, during late May 2019. Species not appearing to use the site, but simply flying over were not tallied in the table.

Pointe Mouillee restoration site		
Station	Species	Abundance
1	Mallard	3
1	Canada goose	1
1	Whimbrel	1
1	Pied-billed grebe	1
1	Barn swallow	1
1	Red-winged blackbird	20
1	Common grackle	2
1	Eastern kingbird	2
1	Yellow warbler	1
2	Double-crested cormorant	36
2	Mute swan	19
2	Great egret	19
2	Ruddy duck	9

Pointe Mouillee restoration site		
Station	Species	Abundance
2	American white pelican	8
2	Redhead	7
2	Common tern	6
2	Mallard	3
2	Common gallinule	3
2	Ring-billed gull	2
2	Canada goose	1
2	Great blue heron	1
2	Lesser scaup	1
2	Whimbrel	1
2	Wood duck	1
2	Common grackle	15
2	Red-winged blackbird	15
3	Canada goose	1
3	Common tern	1
3	Barn swallow	2
3	Red-winged blackbird	6
3	Yellow warbler	2
3	Common yellowthroat	1
4	Lesser scaup	20
4	Canada goose	2
4	Mallard	1
4	Red-breasted merganser	1
4	Osprey	1
4	Red-winged blackbird	30
4	Eastern kingbird	1
4	Yellow warbler	1
5	Mallard	3
5	Tree swallow	1
5	Red-winged blackbird	10
5	Eastern wood pewee	1
5	Red-eyed vireo	1
5	Alder flycatcher	1
5	American robin	1
5	Eastern kingbird	1
5	Indigo bunting	1

Pointe Mouillee restoration site		
Station	Species	Abundance
5	Magnolia warbler	1
5	Yellow warbler	1
6	Mallard	1
6	Osprey	1
6	Red-winged blackbird	15
6	European starling	3
6	Eastern kingbird	2
6	Yellow warbler	2
6	Common yellowthroat	1
7	Gadwall	2
7	Mallard	2
7	Great egret	2
7	Great blue heron	1
7	Tree swallow	1
7	Red-winged blackbird	15
7	Common yellowthroat	2
7	Carolina wren	1
7	Northern cardinal	1
8	Killdeer	2
8	Northern shoveler	2
8	Mallard	1
8	Red-winged blackbird	20
8	Common yellowthroat	3
8	Dickcissel	2
8	European starling	1
8	American robin	1
8	Common grackle	1
8	Eastern kingbird	1
8	Yellow warbler	1
9	Blue-winged teal	2
9	Mallard	2
9	Green heron	1
9	Red-winged blackbird	20
9	Common grackle	3
9	Common yellowthroat	2
9	Indigo bunting	1

Pointe Mouillee restoration site		
Station	Species	Abundance
10	Red-winged blackbird	20
10	Common grackle	3
10	Common yellowthroat	2
11	Common tern	10
11	Canada goose	1
11	American coot	1
11	Pied-billed grebe	1
11	Red-winged blackbird	25
11	Common yellowthroat	1
12	Mallard	2
12	Green heron	1
12	Red-winged blackbird	15
12	Common yellowthroat	2
12	Indigo bunting	2
12	Eastern wood pewee	1
12	Common grackle	1
12	Eastern kingbird	1
12	Northern cardinal	1
12	Yellow warbler	1
13	Mallard	2
13	Great blue heron	1
13	Killdeer	1
13	Pied-billed grebe	1
13	Tree swallow	1
13	Red-winged blackbird	20
13	Common grackle	3
13	American robin	1
13	Gray catbird	1
13	Indigo bunting	1
13	Northern cardinal	1
13	Song sparrow	1
13	Willow flycatcher	1
14	Ruddy turnstone	1
14	Red-winged blackbird	5
15	Canada goose	9
15	Killdeer	1

Pointe Mouillee restoration site		
Station	Species	Abundance
15	Lesser scaup	1
15	Osprey	2
15	Red-winged blackbird	10
15	Common yellowthroat	1
16	Red-winged blackbird	10
16	Common yellowthroat	1
16	Indigo bunting	1
16	Yellow warbler	1

Appendix C.6

Avian species detected at each point count station using the Miller Sands Island Restoration Site and the Snag Island Reference Site in the Lower Columbia River near Astoria, Oregon, during early June 2019. Species not appearing to use the site, but simply flying over were not tallied in the table.

Miller Sands Island restoration site			Snag Island reference site		
Station	Species	Abundance	Station	Species	Abundance
1	Mallard	3	1	Cliff swallow	5
1	Canada goose	1	1	Tree swallow	3
1	Yellow warbler	5	1	Bald eagle	1
1	Song sparrow	2	2	Double-crested cormorant	50
1	American crow	1	2	Mallard	30
1	American robin	1	2	Canada goose	20
1	Marsh wren	1	2	Larus spp.	20
1	Swainson's thrush	1	2	Gadwall	2
2	Canada goose	14	2	Red-winged blackbird	1
2	Gadwall	2	3	American white pelican	7
2	Great blue heron	1	3	Tree swallow	3
2	Killdeer	1	3	Barn swallow	1
2	Violet-green swallow	1	3	Cliff swallow	1
2	Yellow warbler	2	3	Bald eagle	1
2	American crow	1	3	Red-winged blackbird	2
2	American robin	1			
2	European starling	1			
2	Red-winged blackbird	1			

Miller Sands Island restoration site			Snag Island reference site		
Station	Species	Abundance	Station	Species	Abundance
2	Song sparrow	1			
3	Mallard	1			
3	Bald eagle	1			
3	Yellow warbler	3			
3	American crow	2			
3	American robin	1			
3	European starling	1			
3	Red-winged Blackbird	1			
3	Song sparrow	1			
3	Willow flycatcher	1			
4	Canada goose	15			
4	Mallard	8			
4	Great blue heron	1			
4	Tree swallow	15			
4	Bald eagle	1			
4	American crow	3			
4	White-crowned sparrow	3			
4	Song sparrow	2			
4	Willow flycatcher	2			
4	Wilson's warbler	2			
4	Yellow warbler	2			
4	Rufous hummingbird	1			
5	Great blue heron	2			
5	Bald eagle	3			
5	American crow	3			
5	Black-headed grosbeak	1			
5	Pacific wren	1			
5	Ruby-crowned kinglet	1			
5	Song sparrow	1			
5	Yellow warbler	1			
6	Great blue heron	2			
6	Canada goose	1			
6	Tree swallow	1			
6	Cedar waxwing	4			
6	American crow	3			
6	Yellow warbler	3			

Miller Sands Island restoration site			Snag Island reference site		
Station	Species	Abundance	Station	Species	Abundance
6	Black-headed Grosbeak	1			
6	Song sparrow	1			
6	White-crowned sparrow	1			
7	American white pelican	40			
7	Double-crested Cormorant	40			
7	Mallard	20			
7	Caspian tern	2			
7	Gadwall	2			
7	Canada goose	1			
7	Great blue heron	1			
7	Tree swallow	5			
7	Bald eagle	4			
7	American crow	6			
7	American robin	2			
7	Red-winged Blackbird	2			
7	Yellow warbler	2			
7	Black-capped Chickadee	1			
7	Song sparrow	1			
8	Cedar waxwing	3			
8	Yellow warbler	3			
8	Song sparrow	2			
8	White-crowned Sparrow	2			
8	Bewick's wren	1			
8	European starling	1			
9	Yellow warbler	4			
9	White-crowned Sparrow	3			
9	Song sparrow	2			
9	Willow flycatcher	2			
9	American robin	1			
9	Rufous hummingbird	1			
10	Red-tailed Hawk	1			
10	White-crowned Sparrow	3			
10	Song sparrow	2			
10	Yellow warbler	2			

Miller Sands Island restoration site			Snag Island reference site		
Station	Species	Abundance	Station	Species	Abundance
10	Rufous hummingbird	1			
10	Willow flycatcher	1			
11	Killdeer	1			
11	White-crowned Sparrow	4			
11	Yellow warbler	4			
11	American robin	2			
11	Rufous hummingbird	1			
11	Song sparrow	1			
12	Canada goose	55			
12	Tree swallow	6			
12	Yellow warbler	5			
12	White-crowned Sparrow	4			
12	Willow flycatcher	2			
12	American crow	1			
12	American robin	1			
12	Cedar waxwing	1			
12	Purple finch	1			
12	Swainson's thrush	1			
13	Tree swallow	1			
13	Yellow warbler	4			
13	American goldfinch	3			
13	American robin	3			
13	Cedar waxwing	3			
13	Rufous hummingbird	2			
13	Song sparrow	2			
14	Mallard	10			
14	Canada goose	6			
14	Common merganser	3			
14	Double-crested Cormorant	1			
14	Gadwall	1			
14	Ring-billed Gull	1			
14	Tree swallow	4			
14	Northern Rough-winged Swallow	2			
14	American robin	3			

Miller Sands Island restoration site			Snag Island reference site		
Station	Species	Abundance	Station	Species	Abundance
14	Song sparrow	2			
14	Yellow warbler	2			
14	Northern flicker	1			
15	Mallard	10			
15	Canada goose	2			
15	Tree swallow	3			
15	Bald eagle	1			
15	American robin	4			
15	Cedar waxwing	3			
15	Yellow warbler	3			
15	American crow	2			
15	Rufous hummingbird	1			
16	Tree swallow	7			
16	White-crowned Sparrow	6			
16	Yellow warbler	4			
16	American robin	3			
16	American crow	1			
16	Song sparrow	1			
16	Willow flycatcher	1			
17	Yellow warbler	4			
17	American robin	2			
17	Song sparrow	1			
17	Wilson's warbler	1			
18	White-crowned Sparrow	4			
18	American goldfinch	2			
18	American robin	2			
18	Yellow warbler	2			
18	Song sparrow	1			
18	Swainson's thrush	1			
19	Yellow warbler	3			
19	Song sparrow	2			
19	White-crowned Sparrow	2			
19	Black-capped Chickadee	1			
19	Black-headed Grosbeak	1			

Miller Sands Island restoration site			Snag Island reference site		
Station	Species	Abundance	Station	Species	Abundance
19	Cedar waxwing	1			
19	Willow flycatcher	1			
20	American white pelican	100			
20	Mallard	34			
20	Double-crested Cormorant	1			
20	Ring-billed Gull	1			
20	Tree swallow	10			
20	American crow	17			
20	Yellow warbler	4			
20	Song sparrow	2			
21	Yellow warbler	3			
21	Song sparrow	2			
21	American crow	1			
21	American robin	1			
21	Bewick's wren	1			
21	Black-capped Chickadee	1			
21	Swainson's thrush	1			
21	White-crowned Sparrow	1			
22	Bewick's wren	2			
22	Yellow warbler	2			
22	Hutton's vireo	1			
22	Song sparrow	1			

Appendix D: Comparison of Birds Detected During Previous Surveys

Appendix D.1

Comparison of birds detected during previous surveys conducted during the late 1970s to mid-1980s as reported by Landin, Webb, and Knutson (1989) to those conducted during a one-time visit of the current study on 2–3 April 2019 at Bolivar Peninsula, Texas. Only species that are likely to occur during the winter or spring seasons according to current range maps are reported.

Species	Bird type	Landin, Webb, and Knutson 1989	Bolivar Peninsula 2 April 2019	Pepper Grove 3 April 2019
American avocet	Waterbird	X		
American coot	Waterbird	X		X
American kestrel	Raptor	X		
American oystercatcher	Waterbird	X	X	
American pipit	Land bird	X		
American redstart	Land bird	X		
American robin	Land bird	X		
American white pelican	Waterbird	X		X
American wigeon	Waterbird			X
Baltimore oriole	Land bird	X		
Bank swallow	Swallow	X		X
Barn swallow	Swallow	X	X	
Belted kingfisher	Waterbird	X		
Black skimmer	Waterbird	X		
Black tern	Waterbird	X		
Black-and-white warbler	Land bird	X		
Black-bellied plover	Waterbird	X	X	X
Black-crowned night heron	Waterbird	X		X
Black-necked stilt	Waterbird	X	X	X
Blackpoll warbler	Land bird	X		
Black-throated gray warbler	Land bird	X		
Blue grosbeak	Land bird	X		
Blue jay	Land bird	X		

Species	Bird type	Landin, Webb, and Knutson 1989	Bolivar Peninsula 2 April 2019	Pepper Grove 3 April 2019
Blue-gray gnatcatcher	Land bird	X		
Blue-winged teal	Waterbird	X		X
Boat-tailed grackle	Land bird		X	X
Brown pelican	Waterbird		X	X
Brown-headed cowbird	Land bird	X		X
Canvasback	Waterbird	X		
Carolina wren	Land bird		X	
Caspian tern	Waterbird	X		
Cattle egret	Waterbird	X	X	
Chimney swift	Swallow	X		
Clapper rail	Waterbird	X		X
Common gallinule	Waterbird			X
Common grackle	Land bird	X		
Common nighthawk	Nightjar	X		
Common tern	Waterbird	X	X	
Common yellowthroat	Land bird	X		
Dark-eyed junco	Land bird	X		
Double-crested cormorant	Waterbird	X	X	X
Dunlin	Waterbird	X	X	
Eared grebe	Waterbird	X		
Eastern kingbird	Land bird	X		X
Eastern meadowlark	Land bird	X	X	
Eastern phoebe	Land bird	X		
Eastern wood pewee	Land bird	X		
Field sparrow	Land bird	X		
Forster's tern	Waterbird	X	X	X
Gadwall	Waterbird			X
Gray catbird	Land bird	X		
Great blue heron	Waterbird	X	X	X
Great egret	Waterbird	X	X	X
Greater yellowlegs	Waterbird	X		
Great-tailed grackle	Land bird	X		
Green heron	Waterbird	X		
Green-winged teal	Waterbird			X
Gull-billed tern	Waterbird	X	X	X

Species	Bird type	Landin, Webb, and Knutson 1989	Bolivar Peninsula 2 April 2019	Pepper Grove 3 April 2019
Hermit thrush	Land bird	X		
Herring gull	Waterbird	X	X	
Hooded warbler	Land bird	X		
Horned lark	Land bird	X		
House wren	Land bird	X		
Indigo bunting	Land bird	X	X	
Killdeer	Waterbird	X		
Laughing gull	Waterbird	X	X	X
Least sandpiper	Waterbird	X	X	
Least tern	Waterbird	X	X	X
Leconte's sparrow	Land bird	X		
Lesser scaup	Waterbird		X	X
Lesser yellowlegs	Waterbird	X		X
Little blue heron	Waterbird			X
Loggerhead shrike	Land bird	X		
Long-billed curlew	Waterbird	X		
Long-billed dowitcher	Waterbird	X		X
Magnificent frigatebird	Waterbird	X		
Magnolia warbler	Land bird	X		
Marbled godwit	Waterbird	X	X	
Marsh wren	Land bird	X	X	
Mottled duck	Waterbird	X	X	
Mourning dove	Land bird	X	X	X
Neotropical cormorant	Waterbird	X		
Northern cardinal	Land bird	X		
Northern flicker	Land bird	X		
Northern harrier	Raptor	X	X	
Northern mockingbird	Land bird	X	X	X
Northern parula	Land bird		X	
Northern rough-winged swallow	Swallow	X	X	
Northern shoveler	Waterbird	X		X
Northern waterthrush	Land bird	X		
Orange-crowned warbler	Land bird	X	X	
Orchard oriole	Land bird	X		

Species	Bird type	Landin, Webb, and Knutson 1989	Bolivar Peninsula 2 April 2019	Pepper Grove 3 April 2019
Osprey	Raptor	X	X	X
Ovenbird	Land bird	X		
Painted bunting	Land bird	X		
Palm warbler	Land bird	X	X	
Pectoral sandpiper	Waterbird	X		X
Pied-billed grebe	Waterbird			X
Piping plover	Waterbird	X		
Prothonotary warbler	Land bird	X	X	
Purple martin	Swallow	X		X
Red knot	Waterbird	X		
Red-breasted merganser	Waterbird	X	X	
Reddish egret	Waterbird	X	X	
Red-eyed vireo	Land bird	X		
Red-tailed hawk	Raptor	X	X	
Red-winged blackbird	Land bird	X	X	X
Ring-billed gull	Waterbird	X		
Roseate spoonbill	Waterbird	X	X	X
Rose-breasted grosbeak	Land bird	X		
Royal tern	Waterbird	X	X	X
Ruby-crowned kinglet	Land bird	X		
Ruby-throated hummingbird	Land bird	X		
Ruddy turnstone	Waterbird	X	X	
Sanderling	Waterbird	X		
Sandwich tern	Waterbird	X	X	X
Savannah sparrow	Land bird	X	X	X
Scissor-tailed flycatcher	Land bird	X	X	
Semipalmated plover	Waterbird	X		
Semipalmated sandpiper	Waterbird			X
Short-billed dowitcher	Waterbird			X
Short-eared owl	Raptor	X		
Snow goose	Waterbird	X		
Snowy egret	Waterbird	X	X	X
Solitary sandpiper	Waterbird	X		
Song sparrow	Land bird	X	X	X
Sooty tern	Waterbird	X		

Species	Bird type	Landin, Webb, and Knutson 1989	Bolivar Peninsula 2 April 2019	Pepper Grove 3 April 2019
Spotted sandpiper	Waterbird	X		
Swainson's thrush	Land bird	X		
Swamp sparrow	Land bird	X	X	
Tennessee warbler	Land bird	X		
Tree swallow	Swallow	X	X	X
Tricolored heron	Waterbird	X	X	X
Turkey vulture	Raptor			X
Veery	Land bird	X		
Western sandpiper	Waterbird	X		X
Whimbrel	Waterbird	X	X	X
White ibis	Waterbird	X	X	X
White-eyed vireo	Land bird	X		
White-faced ibis	Waterbird	X		X
White-rumped sandpiper	Waterbird	X		
White-tailed kite	Raptor	X	X	
Willet	Waterbird	X	X	X
Wilson's plover	Waterbird	X	X	
Worm-eating warbler	Land bird	X		
Yellow warbler	Land bird	X		
Yellow-billed cuckoo	Land bird	X		
Yellow-breasted chat	Land bird	X		
Yellow-crowned night heron	Waterbird			X
Yellow-rumped warbler	Land bird	X	X	
Yellow-rumped warbler	Land bird			X
Yellow-throated warbler	Land bird	X	X	

Appendix D.2

Comparison of birds detected during previous surveys conducted during the late 1970s to mid-1980s as reported by Landin, Webb, and Knutson (1989) to those conducted during a one-time visit of the current study on 29–30 April 2019 at Apalachicola Bay, Florida. Only species that are likely to occur during the breeding season according to current range maps are reported.

Species	Bird type	Landin, Webb, and Knutson 1989	Drake Wilson Island 29 April 2019	Cat Point 30 April 2019
American coot	Waterbird	X		
American crow	Land bird	X		
American oystercatcher	Waterbird	X		X
American robin	Land bird	X		
Bald eagle	Raptor		X	X
Barn swallow	Swallow	X	X	
Belted kingfisher	Waterbird	X	X	
Black vulture	Raptor	X		
Black-crowned night heron	Waterbird	X		
Blue jay	Land bird	X	X	X
Blue-gray gnatcatcher	Land bird	X	X	X
Boat-tailed grackle	Land bird	X	X	
Brown pelican	Waterbird	X	X	X
Brown thrasher	Land bird	X		
Brown-headed cowbird	Land bird	X		
Brown-headed nuthatch	Land bird		X	
Carolina chickadee	Land bird	X		
Carolina wren	Land bird		X	X
Caspian tern	Waterbird	X	X	X
Cattle egret	Waterbird	X		
Clapper rail	Waterbird	X	X	
Common grackle	Land bird	X		
Common nighthawk	Nightjar	X		
Common yellowthroat	Land bird	X		
Double-crested cormorant	Waterbird	X		

Species	Bird type	Landin, Webb, and Knutson 1989	Drake Wilson Island 29 April 2019	Cat Point 30 April 2019
Downy woodpecker	Land bird		X	
Eastern meadowlark	Land bird			X
Eastern towhee	Land bird		X	
European starling	Land bird	X		
Fish crow	Land bird	X		X
Gray catbird	Land bird	X		
Great blue heron	Waterbird	X		
Great egret	Waterbird	X	X	
Great-crested flycatcher	Land bird		X	
Green heron	Waterbird	X	X	
Gull-billed tern	Waterbird	X		
House sparrow	Land bird	X		
Killdeer	Waterbird	X		
Laughing gull	Waterbird	X	X	X
Least tern	Waterbird	X	X	X
Little blue heron	Waterbird	X		
Mallard	Waterbird	X		
Marsh wren	Land bird	X	X	X
Mourning dove	Land bird	X	X	
Northern cardinal	Land bird		X	X
Northern flicker	Land bird	X		
Northern mockingbird	Land bird	X	X	
Northern parula	Land bird		X	
Northern rough-winged swallow	Swallow	X	X	
Osprey	Raptor		X	X
Pied-billed grebe	Waterbird			X
Purple martin	Swallow	X		
Red-bellied woodpecker	Land bird		X	X
Red-shouldered hawk	Raptor		X	
Red-tailed hawk	Raptor	X		
Red-winged blackbird	Land bird	X	X	X
Royal tern	Waterbird	X	X	
Ruby-throated hummingbird	Land bird	X		

Species	Bird type	Landin, Webb, and Knutson 1989	Drake Wilson Island 29 April 2019	Cat Point 30 April 2019
Sandwich tern	Waterbird	X		
Seaside sparrow	Land bird	X		
Snowy egret	Waterbird	X		
Tricolored heron	Waterbird	X		X
Turkey vulture	Raptor			X
White ibis	Waterbird	X		
Willet	Waterbird	X	X	
Yellow-crowned night heron	Waterbird	X		

Appendix D.3

Comparison of birds detected during previous surveys conducted during the late 1970s to mid-1980s as reported by Landin, Webb, and Knutson (1989) to those conducted during a one-time visit of the current study 1–2 May 2019 at Buttermilk Sound, Georgia. Only species that are likely to occur during the breeding season according to current range maps are reported.

Species	Bird type	Landin, Webb, and Knutson 1989	Buttermilk Sound 1 May 2019	Hardhead Island 2 May 2019
American crow	Land bird	X		
American oystercatcher	Waterbird	X		
American robin	Land bird		X	
Barn swallow	Swallow		X	
Black skimmer	Waterbird	X		
Black-crowned night heron	Waterbird	X	X	
Blue-gray gnatcatcher	Land bird		X	
Boat-tailed grackle	Land bird	X	X	X
Carolina wren	Land bird		X	
Caspian tern	Waterbird	X		X
Clapper rail	Waterbird	X	X	X
Common yellowthroat	Land bird		X	
Double-crested cormorant	Waterbird			X
Eastern towhee	Land bird		X	
Fish crow	Land bird	X		
Great blue heron	Waterbird	X		X
Great egret	Waterbird	X		
Green heron	Waterbird	X		
Laughing gull	Waterbird	X		
Least tern	Waterbird	X		
Little blue heron	Waterbird	X		
Marsh wren	Land bird	X	X	X
Mourning dove	Land bird	X	X	
Northern cardinal	Land bird		X	
Osprey	Raptor	X	X	
Pied-billed grebe	Waterbird	X		
Red-winged blackbird	Land bird	X	X	X

Royal tern	Waterbird	X		X
Sandwich tern	Waterbird	X		
Snowy egret	Waterbird	X		
Willet	Waterbird	X		
Wood stork	Waterbird			X
Yellow-crowned night heron	Waterbird	X		

Appendix D.4

Comparison of birds detected during previous surveys conducted during the late 1970s to mid-1980s as reported by Landin, Webb, and Knutson (1989) to those conducted during a one-time visit of the current study on 23–24 May 2019, at the Connecticut River near Olde Lyme, Connecticut. Only species that are likely to occur during the breeding season according to current range maps are reported.

Species	Bird type	Landin, Webb, and Knutson 1989	Buttermilk Sound 1 May 2019	Hardhead Island 2 May 2019
Alder flycatcher	Land bird	X	X	
American crow	Land bird	X	X	X
American goldfinch	Land bird	X	X	X
American kestrel	Raptor	X		
American robin	Land bird	X	X	X
Bald eagle	Raptor		X	X
Baltimore oriole	Land bird			X
Bank swallow	Swallow	X		
Barn swallow	Swallow	X	X	X
Belted kingfisher	Waterbird	X		X
Black duck	Waterbird	X		
Black-capped chickadee	Land bird	X		X
Black-throated green warbler	Land bird			X
Blue jay	Land bird	X	X	
Blue-gray gnatcatcher	Land bird		X	
Blue-winged warbler	Land bird			X
Brown thrasher	Land bird	X		
Brown-headed cowbird	Land bird			X
Canada goose	Waterbird	X	X	X
Carolina wren	Land bird		X	X
Cedar waxwing	Land bird		X	
Chestnut-sided warbler	Land bird		X	
Chimney swift	Swallow	X		
Common grackle	Land bird	X	X	X
Common raven	Land bird			X
Common yellowthroat	Land bird	X	X	X
Double-crested cormorant	Waterbird	X	X	

Species	Bird type	Landin, Webb, and Knutson 1989	Buttermilk Sound 1 May 2019	Hardhead Island 2 May 2019
Downy woodpecker	Land bird	X		
Eastern kingbird	Land bird	X		X
Eastern wood pewee	Land bird	X		
European starling	Land bird	X		
Field sparrow	Land bird	X		
Gray catbird	Land bird	X	X	X
Great black-backed gull	Waterbird	X	X	
Great blue heron	Waterbird		X	
Great egret	Waterbird		X	X
Great horned owl	Raptor	X		
Green heron	Waterbird	X		
Hairy woodpecker	Land bird	X		
Herring gull	Waterbird	X	X	
Hooded warbler	Land bird		X	
House finch	Land bird		X	X
Indigo bunting	Land bird		X	
Killdeer	Waterbird	X		
Mallard	Waterbird	X	X	X
Marsh wren	Land bird	X	X	
Mourning dove	Land bird	X	X	
Mute swan	Waterbird	X	X	X
Northern cardinal	Land bird	X	X	X
Northern harrier	Raptor	X		
Northern mockingbird	Land bird	X		
Northern rough-winged swallow	Swallow	X		
Orchard oriole	Land bird		X	
Osprey	Raptor	X	X	X
Purple finch	Land bird	X		
Red-eyed vireo	Land bird		X	
Red-winged blackbird	Land bird	X	X	X
Ring-necked pheasant	Land bird	X		
Ruby-throated hummingbird	Land bird	X	X	
Savannah sparrow	Land bird	X		
Snowy egret	Waterbird		X	
Song sparrow	Land bird	X	X	X

Species	Bird type	Landin, Webb, and Knutson 1989	Buttermilk Sound 1 May 2019	Hardhead Island 2 May 2019
Spotted sandpiper	Waterbird	X		
Swamp sparrow	Land bird		X	
Tree swallow	Swallow	X		X
Tufted titmouse	Land bird		X	X
Vesper sparrow	Land bird	X		
Warbling vireo	Land bird			X
White-eyed vireo	Land bird	X		
Willow flycatcher	Land bird	X	X	
Wood thrush	Land bird	X		
Yellow warbler	Land bird	X	X	X

Appendix D.5

Comparison of birds detected during previous surveys conducted during the late 1970s to mid-1980s as reported by Landin, Webb, and Knutson (1989) to those conducted during a one-time visit of the current study on 25 May 2019 at Pointe Mouillee State Game Area, Michigan. Only species that are likely to occur during the breeding season according to current range maps are reported within this table, and no reference site occurred in this location.

Species	Bird type	Landin, Webb, and Knutson 1989	Pointee Mouillee 25 May 2019
Alder flycatcher	Land bird	X	X
American black duck	Waterbird	X	
American coot	Waterbird	X	X
American goldfinch	Land bird	X	
American kestrel	Raptor	X	
American redstart	Land bird	X	
American robin	Land bird	X	X
American woodcock	Waterbird	X	
Bank swallow	Swallow	X	
Barn swallow	Swallow	X	X
Belted kingfisher	Waterbird	X	
Black-crowned night heron	Waterbird	X	X
Blue jay	Land bird	X	
Blue-winged teal	Waterbird	X	X
Bobolink	Land bird	X	
Broad-winged hawk	Raptor	X	
Brown thrasher	Land bird	X	
Brown-headed cowbird	Land bird	X	
Canada goose	Waterbird	X	X
Carolina wren	Land bird		X
Caspian tern	Waterbird	X	X
Chestnut-sided warbler	Land bird	X	
Common gallinule	Waterbird	X	X
Common nighthawk	Nightjar	X	
Common tern	Waterbird	X	X
Common yellowthroat	Land bird	X	X

Species	Bird type	Landin, Webb, and Knutson 1989	Pointee Mouillee 25 May 2019
Dickcissel	Land bird		X
Double-crested cormorant	Waterbird	X	X
Downy woodpecker	Land bird	X	
Eastern bluebird	Land bird	X	
Eastern kingbird	Land bird	X	X
Eastern meadowlark	Land bird	X	
Eastern screech owl	Raptor	X	
Eastern towhee	Land bird	X	
Eastern wood pewee	Land bird	X	X
European starling	Land bird	X	X
Field sparrow	Land bird	X	
Forster's tern	Waterbird	X	X
Gadwall	Waterbird	X	X
Gray catbird	Land bird	X	X
Great blue heron	Waterbird	X	X
Great egret	Waterbird	X	X
Great horned owl	Raptor	X	
Great-crested flycatcher	Land bird	X	
Green heron	Waterbird	X	X
Herring gull	Waterbird	X	X
House sparrow	Land bird	X	
House wren	Land bird	X	
Indigo bunting	Land bird	X	X
Killdeer	Waterbird	X	X
Mallard	Waterbird	X	X
Marsh wren	Land bird	X	
Mourning dove	Land bird	X	
Mute swan	Waterbird		X
Northern cardinal	Land bird	X	X
Northern flicker	Land bird	X	
Northern rough-winged swallow	Swallow	X	
Northern shoveler	Waterbird		X
Osprey	Raptor		X
Pied-billed grebe	Waterbird	X	X

Species	Bird type	Landin, Webb, and Knutson 1989	Pointee Mouillee 25 May 2019
Prothonotary warbler	Land bird	X	
Purple martin	Swallow	X	X
Red-eyed vireo	Land bird	X	X
Redhead	Waterbird		X
Red-tailed hawk	Raptor	X	
Red-winged blackbird	Land bird	X	X
Ring-billed gull	Waterbird	X	X
Ruddy duck	Waterbird	X	X
Savannah sparrow	Land bird	X	
Sharp-shinned hawk	Raptor	X	
Song sparrow	Land bird	X	X
Spotted sandpiper	Waterbird	X	
Swamp sparrow	Land bird	X	
Traill's flycatcher	Land bird	X	
Tree swallow	Swallow	X	X
Warbling vireo	Land bird	X	
Willow flycatcher	Land bird		X
Wilson's snipe	Waterbird	X	
Wood duck	Waterbird	X	X
Yellow warbler	Land bird	X	X
Yellow-billed cuckoo	Land bird	X	

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Nia R. Hurst and Jake F. Jung

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14. ABSTRACT

The beneficial use of dredged materials improves environmental outcomes while maximizing navigation benefits and minimizing costs, in accordance with the principles of the Engineering With Nature® (EWN) initiative. Yet, few studies document the long-term benefits of innovative dredged material management strategies or conduct comprehensive life-cycle analysis because of a combination of (1) short monitoring time frames and (2) the paucity of constructed projects that have reached ecological maturity. In response, we conducted an ecological functional and engineering benefit assessment of six historic (>40 years old) dredged material–supported habitat improvement projects where initial postconstruction beneficial use monitoring data was available. Conditions at natural reference locations were also documented to facilitate a comparison between natural and engineered landscape features. Results indicate the projects examined provide valuable habitat for a variety of species in addition to yielding a number of engineering (for example, shoreline protection) and other (for example, carbon storage) benefits. Our findings also suggest establishment of ecological success criteria should not overemphasize replicating reference conditions but remain focused on achieving specific ecological functions (that is, habitat and biogeochemical cycling) and engineering benefits (that is, storm surge reduction, navigation channel maintenance) achievable through project design and operational management.

15. SUBJECT TERMS

Dredging spoil—Management
Dredging
Dredging spoil--Environmental aspects
Habitat (Ecology)

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