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Case Study: Improving Marsh Resilience through the Hurricane Sandy Coastal Resilience Program

Contract # 5359

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Case Study: Improving Marsh Resilience through the Hurricane Sandy Coastal Resilience Program

Prepared by Abt Associates, September 2019

Summary

Purpose

This case study forms part of a larger 2019 evaluation of the Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) of the U.S. Department of the Interior (DOI) and the National Fish and Wildlife Foundation (NFWF). It provides an analysis of the *ecological resilience* benefits of marsh restoration projects.

Scope

We examined 24 projects in the Hurricane Sandy Program portfolio focused on enhancing ecological resilience at marsh sites through activities such as adding sediment to marshes to increase elevation, planting native marsh plants, removing invasive species, and dredging tidal channels to enhance hydrological connections and re-establish appropriate flood durations.

Findings

Key findings identified from archival materials, a survey and interviews of project leads, and peer-reviewed literature include:

- The portfolio of Hurricane Sandy Program marsh restoration projects restored or created over 190,000 acres of habitat.
- Projects that are complete have generally met design goals, though some mid-project adjustments were required for some projects to achieve success.
- Most projects had only recently been completed, or were not complete, at the time of the evaluation.
- A combination of factors delayed nearly all projects on average by more than 18 months, including permitting challenges, additional data collection or design work, and weather.
- Generally projects are recovering as quickly as expected after restoration, but results within projects are mixed, with some areas not maintaining expected elevation or plant cover.
- Resilient marshes have key, observable characteristics in common; some of these characteristics are being measured by restoration projects, allowing for an assessment of resilience improvements.
- Early observations suggest that many restored sites are likely to have improved resilience, but more time and data are needed to provide a robust assessment.

Conclusion

, these findings suggest that **investments the Hurricane Sandy Program has made in restoring marshes are generally on track to providing enhanced ecological resilience to marsh and nearby ecosystems.** Early project results typically show enhancements in marsh vegetation cover and growth, reduced invasive cover, and increased elevation of marshes, although these enhancements are not necessarily uniform in all project areas. Early project results also show improved hydrological dynamics – reconnecting marshes to nearby tidal systems or managing water level in freshwater systems. All of these near-term achievements are improving the ability of marshes to provide habitat for birds, fish, and other wildlife; and will improve their ability to withstand or recover from future storms or other forms of disturbance. However, these observations are preliminary, and several more years of recovery and monitoring data are needed to more fully understand the likely long-term impact of restoration actions on marsh ecosystem resilience.

1. Introduction

This case study forms part of a larger 2019 evaluation of the DOI and NFWF Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program). Between 2013 and 2016, the Hurricane Sandy Program, administered through DOI and NFWF, invested over $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise.[1] The program supported a wide array of activities, including aquatic connectivity restoration, marsh restoration, beach and dune restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform decision-making. Each of these activities has a distinct impact on ecosystem and community resilience.

DOI and NFWF drafted the following questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

The evaluation includes six case studies, each providing a deeper level of analysis on a subset of the projects.

1.1 Purpose

This case study provides an in-depth analysis of resilience activities that focused on marsh restoration, and is focused on evaluation questions #1, #2, and #5 (above). More specifically, we focused this case study on understanding the *ecological* resilience benefits of a subset of marsh restoration projects that were designed primarily to provide ecological, as opposed to socioeconomic, benefits. For the purposes of this case study, we **define *ecological resilience* as the capacity of an ecosystem to respond to a perturbation or disturbance either by resisting damage or recovering quickly from that damage**. Marsh restoration not only provides storm protection for nearby ecosystems, but also protects human communities and infrastructure from storm surge and chronic flooding associated with sea level rise. The resulting socioeconomic benefits of marsh restoration, when combined with building a living shoreline to reduce coastal erosion, are discussed in the Living Shorelines Case Study of the Hurricane Sandy Evaluation.

1.2 Scope

We examined 24 projects in the Hurricane Sandy Program portfolio that implemented marsh restoration primarily to improve the ecological resilience of those ecosystems. Twelve of these projects were selected for a more in-depth assessment of implementation issues and ecological outcomes achieved to date through marsh restoration. The selected projects all were completed or close to completion by 2017, had incorporated robust monitoring, and included at least one of the four most common marsh restoration actions implemented in the Hurricane Sandy Program

[1] The evaluation covers these 160 projects. In some cases DOI and NFWF reinvested unspent funds in new, additional projects after the December 2016 cutoff date. These new projects are not included in the evaluation.

portfolio (i.e., hydrologic reconnection, thin-layer deposition, invasive species control, and planting marsh vegetation). See Section 3 for a more detailed description of marsh restoration projects and Appendix A for a full list of relevant projects, including those selected for in-depth review. Many projects that focused on marsh restoration also included other types of resilience interventions (e.g., beach/dune restoration). We focus solely on the marsh habitat-related aspects of these projects in this case study, but provide an analysis of the potential synergies of different resilience activities in the main report.

1.3 Organization

The remainder of this document is organized as follows:

- Section 2 provides an overview of the methods and information sources used for this case study
- Section 3 provides a detailed overview of the marsh restoration projects included in the Hurricane Sandy Program
- Section 4 discusses key case study findings, organized by evaluation question and topic
- Section 5 provides a brief conclusion.

2. Methods Overview

This case study integrates information from the following sources:

- Archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument
- Interviews with eight project leads (i.e., grant recipients) who led the marsh restoration projects
- Quantitative information provided by project leads in their reports (e.g., acres of habitat restored)
- Literature searches addressing specific contextual issues (e.g., key marsh ecosystem properties associated with ecological integrity, the typical lag time between marsh restoration actions and full vegetative maturity).

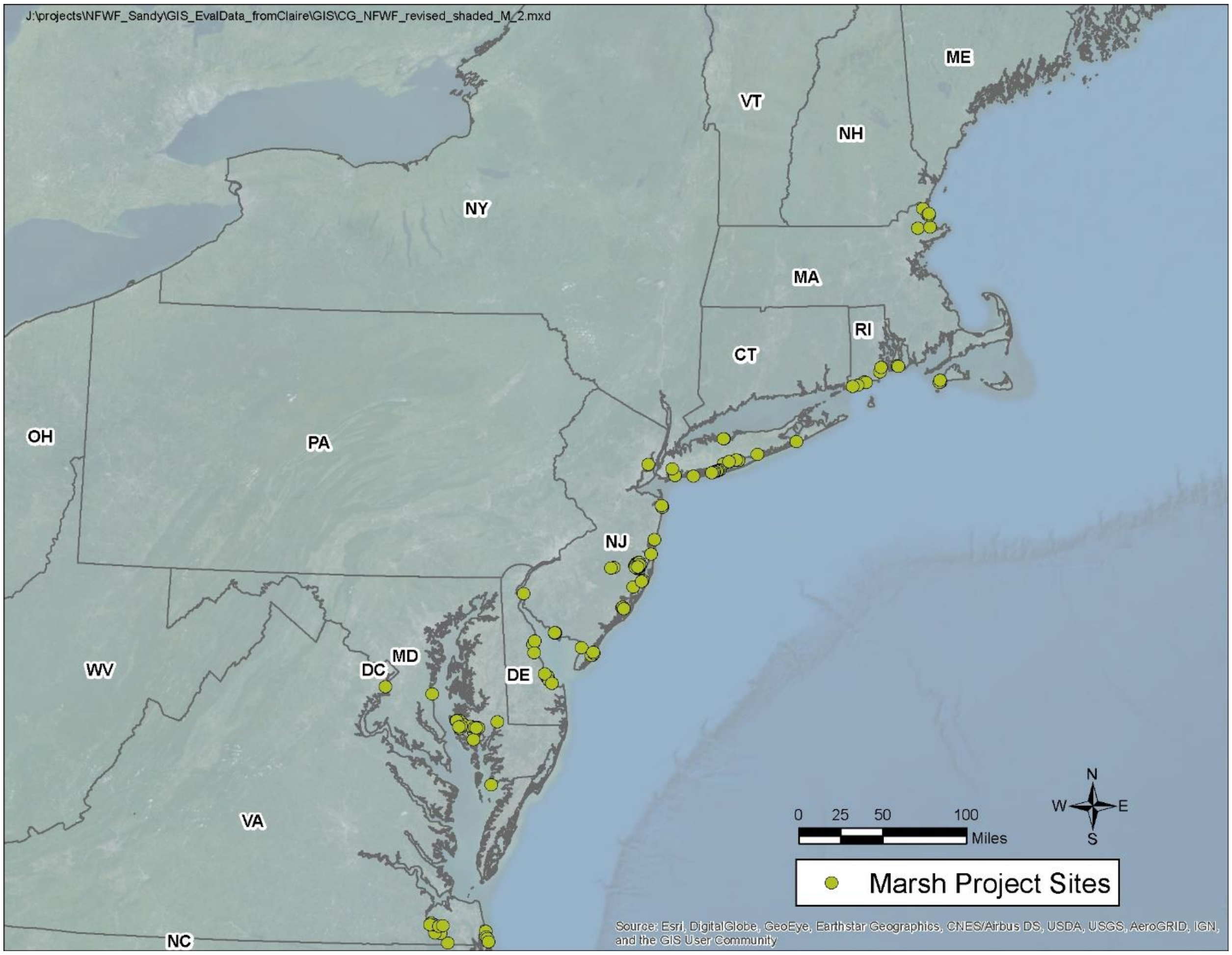
A more detailed description of evaluation methods can be found in Abt Associates (2019).

3. Overview of Projects

One of the objectives of the Hurricane Sandy Program is to strengthen natural ecosystems affected by Hurricane Sandy and reduce their vulnerability to future storms and sea level rise. Resilient ecosystems are more likely to continue providing critical ecosystem services, including habitat for threatened and endangered species, storm protection for nearby habitat and communities, as well as recreation and scenic beauty. DOI and NFWF have supported a range of habitat restoration activities designed to strengthen natural ecosystems, but a key focus of their efforts has been the restoration of freshwater and coastal marshes because of the important role they play in supporting key wildlife, protecting coastal resources, and supporting commercial and recreational fisheries.

Overall, there were 24 projects that included ecologically focused marsh restoration, and they spanned 7 states (Delaware, Maryland, Massachusetts, New Jersey, New York, Rhode Island, and Virginia; Figure 1); 15 of these projects also supported other resilience activities. Overall, the Hurricane Sandy Program invested more than $92.6 million in marsh restoration in 24 projects (Table A.1), 15 of which also included other resilience activities; the total funding provided by the program for all of the activities in the 24 projects was $119.7 million.[2]

Figure 1. Location of marsh restoration activities.[a]



a. Since some projects conducted restoration activities in multiple sites (see Appendix A), the number of marsh restoration project sites (dots) in the figure exceeds 23.

Hurricane Sandy projects undertook four primary marsh restoration activities: hydrologic reconnection, thin-layer deposition, invasive species control, and planting marsh vegetation (see Box 1). In addition to the actions described in Box 1, many marsh restoration projects also installed water control structures of various types, removed debris or contaminated sediment, and planted riparian vegetation. For the 12 projects that were included in our in-depth analysis, we characterized the specific combination of restoration actions they undertook (Table 1). See Box 2 for examples of marsh restoration projects being carried out in different states.

[2] Table A.1 presents the amount of project funding specifically allocated to marsh restoration activities. For nine projects, this was the full project funding amount. For 15 projects, this is a subset of the total project funding. The allocation was based on available project documentation.

Box 1. Key marsh restoration activities.

Hydrologic reconnection removes artificial drainage or water conveyance structures and restores natural marsh channels. It aims to restore tidal hydrology and support healthy, native marsh vegetation, which is expected to help maintain marsh elevation and improve their persistence in the face of sea level rise.

Thin-layer deposition aims to increase marsh elevation to support native marsh vegetation and preserve marsh habitat. It is commonly used in areas with active ponding, a sign that the marsh is losing elevation, and will eventually be flooded and convert to open-water habitat.

Removing or controlling invasive species is performed to improve habitat quality and resilience.

Planting native marsh vegetation can enhance vegetative recovery. This is nearly always performed in conjunction with at least one other restoration action (e.g., thin-layer deposition, hydrologic reconnection, invasive species removal).

Table 1. Information about the 12 projects included in the in-depth analysis for this case-study, including project identification (ID), title, location, major activities performed, and status as of June 2019.

Project ID	Title	State	Thin-layer deposition	Hydrologic reconnections	Invasive species control	Planting vegetation	Status[a] (Anticipated completion date)
NFWF-41739	Reusing dredged materials to enhance salt marsh in Ninigret Pond, Rhode Island	RI	●	●		●	Active (2019)
NFWF-41766	Coastal resiliency planning and ecosystem enhancement for northeastern Massachusetts	MA			●		Complete
NFWF-42942	Increasing salt marsh acreage and resiliency for Blackwater National Wildlife Refuge (NWR), Maryland	MD	●		●	●	Complete[b]
NFWF-42958	Restoring Spring Creek Park's salt marsh and upland habitat, New York	NY			●	●	Active (2019)
NFWF-43095	Reusing dredged material to restore salt marshes and protect communities, New Jersey	NJ	●			●	Complete
NFWF-43849	Developing coastal resiliency regional models, Virginia	VA				●	Complete
USFWS-1	Salt marsh restoration and enhancement at Seatuck, Wertheim, and Lido Beach NWRs, Long Island, New York	NY	●	●	●		Active (2018)
USFWS-15	Prime Hook NWR coastal tidal marsh/barrier beach restoration	DE	●	●	●	●	Complete
USFWS-37	Restoring coastal marshes in New Jersey NWRs	NJ	●	●			Active (2018)
USFWS-43	Restoring resiliency to the Great Marsh, Parker River NWR, Massachusetts	MA		●	●		Complete
USFWS-65	Protecting property and helping coastal wildlife: Enhancing salt marsh and estuarine function and resiliency for key habitats on impacted wildlife refuges from Rhode Island to southern Maine	Multi-state	●	●	●	●	Complete
USFWS-85	Pocomoke Sound marsh enhancement, Ferry Point, Nanticoke River	MD			●		Complete

a. Expected year of completion is included in parentheses for active projects. In a few cases, projects are listed as active even if they were expected to be completed in 2018 or if their major restoration activities were completed because final reports have not yet been submitted.

b. Major project activities are complete, but adaptive management is underway and lessons learned are being documented.

Box 2. Marsh restoration activities by state.

Delaware: Two projects. Projects focused on restoring marsh hydrology primarily by removing or restoring water control structures and restoring drainage channels.

Before and after restoration of a water control structure in Little Creek Wildlife area, DE.

Maryland: Three projects. One project included thin-layer deposition (pictured), and the other two projects involved channel creation and invasive species removal.

Thin-layer dredge is applied to Blackwater NWR.

New Jersey: Five projects. Most projects have performed thin-layer deposition, along with other activities such as coir log installation and planting native vegetation.

Project ecologist shows coir logs installed to contain applied dredge at New Jersey-Cape May Wetlands Wildlife area (Cape May County Herald).

Massachusetts: Three projects. Projects removed invasive plants and restrictions to tidal flow.

Biologist explains ditch remediation technique used to restore natural marsh habitat and tidal flow in the Great Marsh (Margie Brenner, USFWS).

Rhode Island and Maine: Two projects (one in RI only and one in both states). Projects focused on thin-layer deposition, including a large application of dredged material to provide a template and lessons learned for future projects.

Hydraulic placement of dredged sediment on Ninigret Salt Marsh (Chaffee and Frisel; 2017).

New York: Six projects. Projects created channels in existing marsh habitat, as well as regrading and planting upland marsh habitat.

Volunteer plants Spartina *marsh grass in Sunken Meadow State Park (Save the Sound).*

Virginia: Three projects. Projects improved water levels on freshwater wetlands by installing water control structures.

Right: Hydrologic technician demonstrates newly installed aluminum culvert (Jonathon Gruenke, Daily Press).

4. Findings

Topic: Project implementation (PI)

Finding PI.1: Most projects had only recently been completed, or were not complete, at the time of the evaluation.

Archival and web-based materials show that 8 out of the 12 projects in the in-depth analysis were completed[3] at the time of the evaluation, with 4 projects still active. Of the eight projects completed, two were completed in 2016, one in 2017, and five in 2018.

Finding PI.2: A combination of factors delayed nearly all projects, including permitting challenges, additional data collection or design work, and weather.

A combination of issues resulted in nearly every examined project experiencing significant delays compared to original completion estimates. The data available through official contract amendments submitted to NFWF and DOI show that 11 of the 12 projects in the in-depth analysis requested extensions for completing their work, with many projects submitting multiple contract extensions. Of the 12 projects with confirmed timelines, requested extensions delayed projects on average by more than a year-and-a-half (627 days). Most projects cited a combination of factors that contributed to project delays (Box 3).

Finding PI.3: Projects that are complete have generally met design goals, though adjustments were required for some projects to achieve success.

Project reports and project lead interviews suggest that the completed marsh restoration projects have generally met their construction goals. For example, all eight projects included in the in-depth analysis that were completed at the time of the evaluation reported reaching target elevations, restoring tidal regimes, or removing invasives as designed. In addition, final project reports showed that across all projects, 1,600 more acres were restored than proposed and individual projects nearly always met or exceeded the proposed marsh acreage restored. However, project reports and interviews suggested that adaptive management should be expected and built into project timelines. For example, in thin-layer deposition projects, the deposition of sediment was sometimes uneven and project leads moved dredge sediment or added more sediment to some locations. For hydrologic reconnection projects, typically some adjustments to the site needed to be conducted to increase flow and reduce ponding (e.g., cleaning out channels).

[3] While our evaluation generally provides findings elicited through the review of archival materials received through December 2018, project status information reflects information gathered through April 2019 (updated project status information was obtained through a supplementary web search in March 2019 and an updated spreadsheet provided by NFWF).

Box 3. Factors contributing to the delay of marsh restoration projects.

Permitting of novel, complex approaches

In reports, interviews, and contract amendments, five project leads noted that existing permitting systems were often not well-equipped to handle the projects, often due to the novel and multifaceted nature of the marsh restoration work. One project lead noted in a report, “Federal and state permitting systems are not well suited to address climate resiliency action or restoration work in an aquatic environment. Because we did not fit into a navigation or harbor improvement category, the regulators needed to be creative in their application of existing guidelines, standard protocols, and permitting forms.” NFWF and DOI staff noted that a specific challenge encountered by multiple project leads was securing permits for a project that caused short-term damage to a marsh but improved its functioning over the long-term (e.g., sediment deposition on top of an existing marsh kills vegetation for a short period of time, but ultimately makes the marsh more productive and resilient). This type of “regulatory rigidity” is a common barrier to securing permits for ecologically focused restoration projects (Ulibarri et al., 2017).

Additional data collection or design work

Four project leads noted that they needed to do extensive research or testing to ensure proper project design or implementation, which caused project delays. For example, one project was utilizing thin-layer deposition in a novel context (i.e., wetlands in a micro-tidal environment, where marsh collapse is not due to coastal erosion but to gradual sea level rise, and where sediment accretion is minimal). Project leads needed to ensure that the proper approach was used to increase marsh height while also maintaining natural vegetation.

Seasonal limitations

Five project leads noted that the weather- and seasonal-dependent nature of marsh restoration activities, particularly dredging and vegetation planting, contributed to delays. Weather events and growing seasons can limit the time available to perform restoration, and work was sometimes delayed for months while waiting for appropriate working conditions to return. In addition, permit conditions can restrict some construction activities, including dredging, to specific times of the year to avoid harming wildlife (e.g., during migration or breeding seasons).

Contracting or procurement

Six project leads reported difficulties in contracting or procurement. Some delays were due to the contractor bidding process. One project noted that it was difficult to secure contractors because of the complex nature of the work and the narrow timeframes involved.

Topic: Project outcomes (PO)

4.1 Habitat, Fish, and Wildlife Outcomes

Finding PO.1: The portfolio of Hurricane Sandy Program marsh restoration projects restored or created more than 190,000 acres of coastal marsh, freshwater wetland, and associated habitats, providing critical support to fish and wildlife in the region.

Project lead-reported data show that the portfolio of marsh restoration projects included in this case study have restored or created a total of 190,491 acres, including 71,223 acres of coastal marsh habitat, 119,236 acres of freshwater wetland habitat, 19 acres of riparian habitat, and 13 acres of associated upland habitat as part of their overall activities.[4]

Coastal marsh habitats are important nursery, foraging, and refuge habitats for many commercially and recreationally important species of fish and crustaceans found along the Atlantic Coast, including blue crab (*Callinectes sapidus*), striped mullet (*Mugil cephalus*), Atlantic croaker (*Micropogonias undulatus*), and black drum (*Pogonias cromis*).

Coastal marsh habitats also provide breeding and foraging habitats for many migratory and resident bird species, including those species of conservation concern either at the federal or state level[5] (Box 4).

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[4] These data include projects that have not yet been completed, and thus the final number of miles and acres restored may change; for active projects, we assumed that projects will achieve the proposed miles and acres restored.

[5] Salt marsh is comprised of low and high marsh habitats, which provide distinct benefits to different wildlife species, including birds (e.g., the endangered black rail requires high marsh habitat for nesting). However, we discuss the collective benefits of both types of salt marsh habitats in this evaluation because most projects did not distinguish between them in their reporting.

Box 4. Representative bird species noted by project leads as likely to benefit, or that are already benefiting, from marsh restoration projects*.

Seaside sparrow (*Ammodramus maritimus*) depend on salt marsh habitat for breeding and foraging. (photo: Wikipedia). Multiple subspecies are along the Atlantic Coast, most of which are of conservation concern (photo: Wikipedia).

Red knot (*Calidris canutus)* are migratory shorebirds that depend on mid-Atlantic marsh and beach habitats for foraging during migration. Red knot are protected as a threatened species under the Endangered Species Act (photo: Gregory Breese, USFWS).

Black skimmer (*Rynchops niger*) use marsh-adjacent areas to forage, including tidal areas, estuaries, ditches, and rivers. The North American Waterbird Conservation Plan lists the black skimmer as a species of high concern (photo: Andreas Trepte/ Wikimedia).

Saltmarsh sparrow (*Ammodramus caudacutus*) live solely in salt marshes, where their nests are threatened by sea level rise. Approximately 80% of the population has disappeared over the last 15 years and it is currently being considered for listing under the Endangered Species Act (photo: Evan Lipton, Macaulay Library).

Sources: Atlantic Coast Joint Venture (2014), Audubon (2014, Undated), USFWS (2018, 2019), Cornell Lab of Ornithology (2019), NYSDEC (Undated).

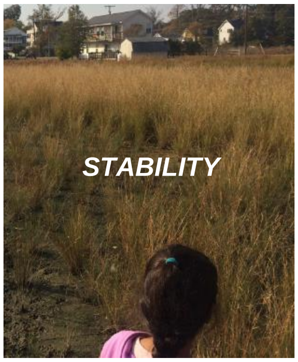
Finding PO.2: Resilient marshes have key, observable characteristics in common, some of which are being measured by restoration projects, allowing for an assessment of resilience improvements.

Our team analyzed whether key, measureable marsh characteristics exist that are typically associated with high marsh integrity and resilience. We then used this information to assess whether the restoration actions were improving marsh ecosystem resilience.

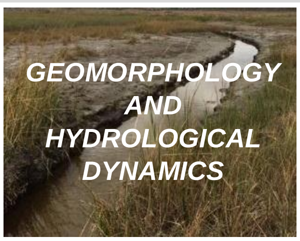
We conducted a literature review that identified four primary ecosystem traits indicative of marsh integrity and resilience, each of which can be affected through restoration actions: **marsh vegetation, marsh stability, and geomorphology and hydrological dynamics**. Our literature review also identified that the health of the **surrounding landscape** also influences marsh integrity and resilience (Box 5, Table 2).

Box 5. Resilience indicators for marsh restoration.

- **Increased plant productivity and stability** can reduce waves and erosion, stabilize sediment, and help marshes persist over time.
- **Decreased invasive species** can allow for increased native vegetation cover, which provides requisite foraging and nesting habitats for native wildlife.



- **The presence of stabilizing species**, such as ribbed mussels (*Geukensia demissa)*, can stimulate the root growth of cordgrass and other marsh plants. They can also bind sediment, which increases marsh height and reduces erosion.
- **Increased accretion rates** (the rate of sediment and vegetative additions to a marsh) can help maintain marsh elevation and buffer the effects of erosion and sea level rise, helping maintain a marsh's position in the landscape.
- **Decreased erosion rates** improve marsh stability; high coastal erosion rates can lead to marsh habitat degradation and loss.
- **Decreased wave energy and power** reduce the likelihood of marsh erosion and collapse.



- **Wider marshes with gentle slopes** generally enhance resilience through reducing erosion, dampening waves, and supporting robust plant communities.
- **Appropriate flooding duration** enhances marsh vegetation establishment, productivity, and persistence. Target metrics for the tidal regime at a restored marsh (e.g., the duration and frequency of inundation) will vary based on local conditions.

- **Increased cover of natural areas** near the marsh (e.g., forests, brushlands, shrubs, inland wetlands) is linked to improved wetland condition and persistence. Intensive development and agriculture can also be a source of nutrient pollution, which may alter vegetation dynamics and possibly contribute to marsh collapse.

Sources: **Vegetation**: 1. Gleason et al., 1979; Christiansen et al., 2000; Turner et al., 2001, 2004; Gedan et al., 2011; Shepard et al., 2011; Fagherazzi et al., 2012; Staszak and Armitage, 2012. 2. Benoit and Askins, 1999; Meyerson et al., 2000; Currin et al., 2003; Jivoff and Able, 2003; Gratton and Denno, 2005. **Stability**: 2. Shafer et al., 2003; Roland and Douglass, 2005; Fagherazzi et al., 2013. 3. Mendelssohn and Morris, 2000. 4. Kuenzler, 1961; Bertness, 1984; Nielsen and Franz, 1995; Angelini et al., 2015; Leonardi et al., 2018. **Geomorphology and Hydrology**: 1. Moeller et al., 1996; Möller et al., 1999; Zedler et al., 1999; Schwimmer, 2001; Tonelli et al., 2010; Palmer and Wainger, 2011. 2. Palmer and Wainger, 2011. **Landscape:** Findlay and Houlahan, 1997; Findlay and Bourdages, 2000; Bertness et al., 2002; Deegan et al., 2012.

Because most projects reviewed were either recently completed or still being implemented at the time of the evaluation, we also identified a subset of the above metrics that could serve as leading indicators of ecological resilience (Table 2). These metrics are (1) commonly measured on marsh restoration projects, (2) respond relatively quickly following restoration, and (3) linked to improved ecological resilience in the peer-reviewed literature.

Table 2. Marsh indicators of ecological resilience that were used for assessing restoration-related marsh improvements. We articulate how restoration-driven changes in key marsh characteristics may improve marsh resilience over the short- and long-term.

Resilience indicators	Metrics	# of projects monitoring[b]	Relation to resilience
Vegetation	% cover and/or stem density[a]	9	• **Short-term**: Contributes to ability to minimize or recover quickly from storm damage • **Long-term**: Contributes to ability to adapt to changing environmental conditions (e.g., temperature, precipitation)
	Belowground biomass	2	
	Persistence	0	
	Presence of invasive species[a]	9	
Stability	Erosion rates	0	• **Short-term:** Contributes to ability to minimize or recover quickly from storm damage • **Long-term:** Contributes to ability to maintain ecological/food web dynamics under changing conditions
	Wave energy/power	0	
	Accretion rates	6	
	Presence of stabilizing species	1	
Geomorphology and hydrologic dynamics	Elevation[a]	7	• **Short-term:** Contributes to ability to minimize storm damage
	Width	0	
	Area	1	
	Flooding duration[a]	8	• **Short-term:** Promotes native salt marsh vegetation
Landscape	Natural vegetation within buffer	0	• **Short-term:** Protects/conserves natural habitat • **Long-term:** Provides opportunity to migrate landward in response to sea level rise

a. Metrics that could serve as leading indicators of improved resilience.

b. Represents the number of projects conducting monitoring with support of the Hurricane Sandy Program. Third party monitoring, which may be occurring at some sites, is not included in this table.

4.2 Metric Measurements in Marsh Restoration Projects

Multiple restoration projects measured changes in key resilience metrics to help assess project performance (Table 2). More specifically, all 12 projects proposed to monitor some aspects of marsh vegetation, and most projects (9 of 12) included geomorphologic and/or hydrologic monitoring. Other marsh resilience variables (e.g., belowground biomass, marsh accretion) were less commonly measured (Table 2).

Finding PO.3: Early observations suggest that many restored sites are likely to have improved resilience, but more time and data are needed to provide a robust assessment.

Observations made through project reports, archival materials, and project lead interviews indicate that marsh restoration efforts have resulted in improvements in some indicators of marsh resilience (i.e., those described in Table 2). The most reported data are related to (1) marsh vegetation and (2) geomorphology and hydrologic dynamics, as they are the best early indicators of project success. However, no information was yet available about marsh stability (e.g., accretion rates), and no Hurricane Sandy Program projects are measuring the impact of the broader landscape on marsh resilience. Taken together, this means that our ability to assess the impact of restoration on marsh resilience is limited at this time. However, after more time has passed and more complete data are available, a fuller assessment of the impact of marsh restoration on ecological resilience will be possible. Below, we discuss early project resilience-related observations for projects that implemented hydrologic reconnection and thin-layer deposition; note that some projects implemented both of these major activities (Table 1) and thus are included in both discussions.

Hydrologic reconnection projects. Five of six projects in our in-depth assessment that included hydrologic connection activities (see Table 1) provided post-restoration information. Early observations are summarized in Box 6. The five projects all reported success in reconnecting the marsh hydrologically (i.e., projects observed improvements in tidal flow and the re-establishment of appropriate flood durations), with some adaptive management necessary to achieve desired outcomes. While many projects were recently completed, early observations suggest that the vegetation community is responding relatively quickly to changing environmental conditions and transitioning to native salt marsh species.

Thin-layer deposition projects. Five of seven projects in our in-depth assessment that included thin-layer deposition (see Table 1) provided post-restoration information. Early observations are summarized in Box 7. The projects were generally able to reach the target elevation of the marsh, sometimes after taking needed corrective action (e.g., redistributing sediment). As with the hydrologic reconnection projects, vegetation cover and productivity are generally increasing in all projects, though some specific areas within projects are underperforming with respect to elevation, percent cover of vegetation, or vegetation growth. Projects are aiming to improve vegetation-related outcomes through the redistribution of sediment or through replanting.

Box 6. Hydrologic reconnection projects: Early observations of resilience related metrics.[a]

A multi-state project noted that hydrologic modifications appeared to be effective at two sites, resulting in **reduced impounded water** on the marsh surface at both sites. Since the impounded water has been removed, some areas that previously had standing water are now **becoming vegetated**.

Following initial restoration activities, another channel was added to the Sachuest NWR (USFWS)

A Delaware project observed **reduced water levels** post-restoration in much of the marsh interior. Tidal wetland grasses and other **vegetation had begun to recolonize** many of the exposed mud flat areas. Based on remote sensing, there has been an observed reduction of 700 acres of open water and an increase of over 500 acres of vegetated marsh in the 2 years post-project.

A small channel dug on Prime Hook NWR to reconnect the flow of water (Cape Gazette).

One component of a New Jersey project included restoring tidal flow to a marsh that was formerly impounded for mosquito control. The cuts were successfully made in the impoundments, and **increased tidal flow** has been observed.

Community surrounding Forsythe NWR, NJ (Lia McLaughlin, USFWS).

While not fully complete, a New York project anecdotally observed **reduced water ponding** on the marsh surface and **increased flushing**. At both of its sites, **vegetation growth** was observed during the post-construction growing season.

Wertheim Salt Marsh, NY (Greg Thompson, USFWS)

a. See Table 2 for a list of relevant metrics related to marsh resilience, and the specific subset that marsh projects have been tracking to date

Box 7. Thin-layer deposition projects: Early observations of resilience related metrics.[a]

A New Jersey project **reached elevation targets** post-construction, but some areas have been losing elevation from compaction or erosion. **Vegetation became established relatively quickly**, but in **some areas underperformed**; these areas were planted with vegetation two years after restoration.

Vegetation growth before and after one growing season at Forsythe NWR, NJ (Jessie Buckner, TNC; Jaci Wollard, NJDEP).

A Maryland project **reached target elevations** and **vegetation came back strongly** within the first year. Additional plantings were done in the second year, increasing vegetative cover. Project leads also **observed seaside sparrows** onsite following restoration.

Seaside sparrow nesting in the salt marsh at Blackwater NWR, MD (USFWS).

Two Maryland project sites also conducted thin-layer deposition in combination with hydrologic reconnection on the marsh platform. The project successfully **raised marsh elevation**, but vegetation survival has been mixed. At one site, plantings appeared to be stressed in the first year, but the **vegetation survived and grew well** during the second season. At another site, however, plantings had high mortality likely due to compaction of sediment and hypersaline conditions.

A Delaware project placed approximately 640,000 cubic yards of dredged material to restore the marsh tidal channels. Marsh vegetation has **recolonized approximately 25%** of the damaged wetlands.

Spartina grasses repopulating in the Prime Hook NWR marsh area (Ron MacArthur, Cape Gazette).

Vegetation growth was observed in a New York project site after marsh elevation increased. However, ponding was observed in some locations and is being addressed; project leads expect vegetation will continue to re-establish.

Workers at the Lido Beach WMA (Robin Donohue, USFWS).

The examples listed from Lido Beach and Seatuck NWRs were two sites funded through the same Hurricane Sandy Program project.

a. See Table 2 for a list of relevant metrics related to marsh resilience, and the specific subset that marsh projects have been tracking to date

4.3 Trajectories of Outcome Achievement

Finding PO.4: Generally projects are recovering as quickly as expected after restoration, but results within projects are mixed.

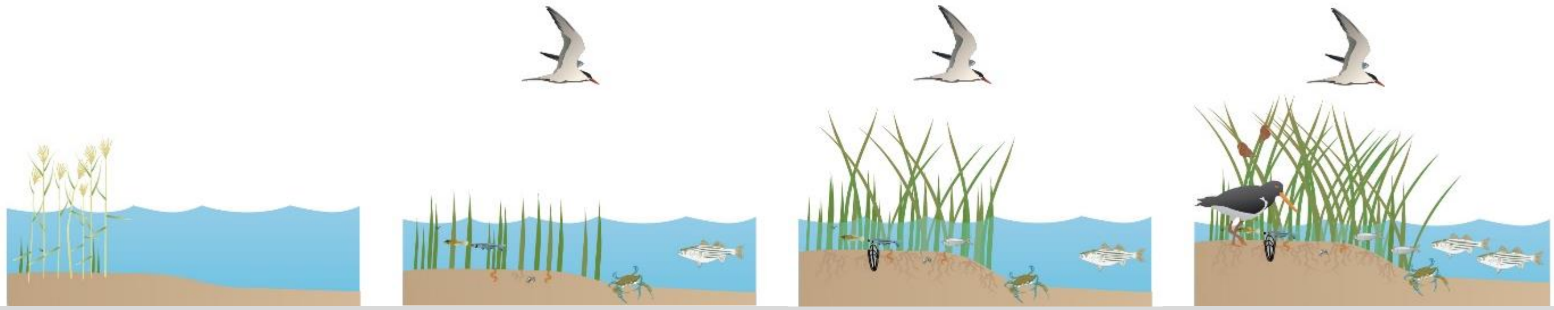
Ecological benefits of most marsh restoration projects funded through the Hurricane Sandy Program will take time to materialize after restoration activities are completed. To better understand and convey the potential timing of the achievement of key outcomes, the Abt Associates (Abt) evaluation team developed conceptual timelines of recovery after restoration using information from key peer-reviewed articles in combination with professional judgment from our team's subject matter experts (Figure 2).

More specifically, while ecological components of the marsh (e.g., vegetation, wildlife use of habitat, hydrologic functions) typically begin recovering immediately following restoration actions, they may require 10–100 years to reach maximum function (Warren et al., 2002; Craft et al., 2003; Moreno-Mateos et al., 2012; Verdonschot et al., 2013; Ebbets et al., 2019; Hollweg et al., In review). The rate of vegetation recovery can depend on many factors, including the specific type of restoration (e.g., hydrologic reconnection vs. created marsh) and whether the vegetation was planted or allowed to recolonize naturally.

Improvements in water quality and storm protection are also expected to be realized soon after restoration. In the context of hydrologic connectivity projects, water quality is tied to the return of tidal influence, which flushes formerly stagnant water and brings in oxygenated water. Storm protection for nearby ecosystems and communities will likely improve over time as restored marsh elevation increases with sediment accretion and strength (Sasser et al., 2013), though these benefits are likely to be constrained by future sea level rise.

The early observations noted in finding PO.3 above are generally consistent with what the literature and Abt team experts identified as likely short-term outcomes of marsh restoration (i.e., outcomes that will be observed one to two years after restoration; Figure 2). For example, vegetation is recovering in nearly all project sites, hydrological dynamics have been restored in reconnection projects, and birds and other wildlife are beginning to utilize newly restored marshes (Boxes 6 and 7). However, as noted in finding PO.3, some areas of specific projects have been underperforming (Boxes 6 and 7). The reasons for underperformance in these areas varied, and included storm-related disturbance, overly thick applications of dredging material, and plantings being located in hypersaline areas with potential sediment compaction. In addition, as noted in Figure 2, mid-term outcomes for marsh restoration projects may take several years to materialize, and long-term outcomes may not be apparent for more than a decade. This suggests that for projects implemented from 2017 to 2020, long-term outcomes for even the most successful projects are not likely to be realized until 2027–2030.

Figure 2. Site recovery following marsh restoration activities over time.



Realization timeframe[a]	Year 0 (pre-project) –	Short-term (1–2 years) outcomes 2018–2022	Mid-term (3–7 years) outcomes 2020–2027	Long-term (10+ years) outcomes 2027+
Vegetation[b]	Native vegetation may be sparse or missing; invasive species frequently dominate.	Vegetation planted during restoration begins to establish.	Vegetative productivity approaches reference conditions; predominantly native vegetation.	Vegetation comparable to reference marshes achieved between 15 and 30 years after restoration.
Habitat/ wildlife use[b]	Habitat does not support key biota.	Native biota begin returning (e.g., macroinvertebrates, fish); birds return as vegetation establishes.	Biota continue returning to restored locations, increasing in abundance but not approaching reference conditions.	Fish and bird assemblages increase, and may match reference marsh conditions.
Hydrology	Hydrologic functions (e.g., tidal influence, freshwater inputs) are compromised.	Many hydrologic features (e.g., tidal influence, sediment deposition) return to natural conditions immediately following restoration.	Features that respond more slowly (e.g., water table) continue to recover.	Hydrologic dynamics are similar to those of reference sites (20 years post-restoration).
Water quality[c]	Water is stagnant and often contaminated.	Water quality begins to improve as tidal flushing and oxygenated water return.	Water quality continues to improve as hydrologic conditions recover (e.g., tidal dynamics, sediment trapping).	Water quality continues to improve as hydrologic conditions recover (e.g., tidal dynamics, sediment trapping).
Storm protection	Degraded marshes provide little or no storm protection.	Storm protection begins to improve as marsh elevation increases and vegetation becomes established.	Marsh elevation, vegetation, and storm protection continue to increase.	Marsh elevation, vegetation, and storm protection continue to increase, but may be constrained by sea level rise.

a. Assuming projects completed between 2017 and 2020.

b. Most relevant to projects that include thin-layer deposition.

c. Most relevant to projects that include hydrologic reconnection.

Sources: **Vegetation**: Warren et al., 2002; Craft et al., 2003; Moreno-Mateos et al., 2012; Ebbets et al., 2019. **Habitat/wildlife use**: Warren et al., 2002; Craft et al., 2003; Borja et al., 2010; Moreno-Mateos et al., 2012; Verdonschot et al., 2013; Hollweg et al., In review. **Hydrology**: Warren et al., 2002; Moreno-Mateos et al., 2012. **Water quality**: Professional judgment. **Storm protection**: Sasser et al., 2013; Leonardi et al., 2018; professional judgment.

Topic: Information gaps regarding resilience impacts (IG)

Finding IG.1: Most projects were not initially funded by the program to gather long-term, post-restoration measures of ecological resilience; however, some projects secured monitoring support from other partners.

Monitoring for most projects was short-term and focused on ensuring that they met design goals; it was not intended for assessing long-term resilience impacts of the project after project completion. The findings discussed under Project Outcomes, above, reflect these short-term monitoring results.

Project leads noted in archival materials that long-term monitoring requires dedicated funding because it is time-consuming, costly, and requires technical expertise. Typically, standard performance metrics are not included in permit-required monitoring plans, and thus are not included in most project budgets. While most projects did not initially secure funding for long-term, post-project monitoring through the Hurricane Sandy Program, 6 of the 12 projects partnered with other funders, organizations, or volunteers to conduct at least some post-project monitoring at their sites. In one case, project leads received a two-year grant from the U.S. Environmental Protection Agency to continue ecological monitoring. It is also likely that projects completed at NWRs will be monitored as part of routine refuge maintenance. In addition, additional funding for long-term monitoring has been secured from NFWF and DOI for 17 of the 23 projects (see Finding IG.3 below).

Finding IG.2: Project monitoring often includes only a small subset of indicators of marsh resilience.

As shown in Table 2, only a subset of the potential indicators of marsh resilience are being measured by Hurricane Sandy Program project implementers. Most of the monitoring being done is focused on metrics that are likely to change soon after restoration (e.g., vegetation and marsh geomorphology/hydrology). While some projects did plan to measure accretion, a key indicator of marsh stability, no projects planned to assess wave energy or erosion rates, key factors that affect the long-term resilience of marshes. In addition, no projects planned to examine the composition of the nearby landscape, another key factor that can influence marsh resilience. While this latter measure of marsh resilience may not be expected to be directly affected by restoration actions, landscape composition could be used to help explain differences in restoration success across different projects. See Finding PO.2 above for additional information about how these metrics were identified and are related to marsh resilience.

Finding IG.3: Subsequent funding from NFWF and DOI will support the long-term monitoring needed to assess the impact of restoration on marsh ecosystem resilience, though some data gaps will likely remain.

Recognizing the need for long-term, systematic data collection to assess restoration success, NFWF and DOI are supporting additional, future long-term monitoring for 17 of the 23 marsh restoration projects through 2024 (see Table A.1). To identify the most appropriate metrics for these projects to measure over the long-term, NFWF and DOI leveraged work done by an internal DOI metrics expert group, which developed a suite of standardized performance metrics for different types of Hurricane Sandy resilience projects (DOI, 2015). Projects selected for long-term monitoring had to propose a specific subset of these metrics for monitoring. Most of the projects including in long-term monitoring are assessing the ecological effectiveness of restoration actions by measuring changes in habitat use by marsh birds (i.e., abundance, distribution, breeding productivity), salt marsh vegetation (i.e., cover and community composition), and elevation (e.g., real-time kinematic measurements) over time. A smaller subset of projects are evaluating other metrics, including nekton abundance and diversity, water quality, and accretion. All of the ecological metrics included are consistent with those identified in the DOI (2015) report, but have been adapted in some cases to meet project specific needs. While these data will provide important information about marsh resilience over time, fewer than four projects plan to monitor wave energy and erosion rates; these key data gaps will likely remain for most projects.

In addition to these ecologically focused metrics, NFWF and DOI are also supporting long-term monitoring to understand the impacts of marsh restoration on human well-being, primarily through the benefits gained by reducing flooding related impacts on human health, infrastructure, including transportation and critical facilities, and economic resilience. As with the ecological monitoring described above, the socioeconomic metrics being monitored were previously identified as potential standardized performance metrics for Hurricane Sandy resilience projects (Abt Associates, 2015).

5. Conclusion

Investments that the Hurricane Sandy Program has made in restoring marshes are generally on track to providing enhanced ecological resilience to marshes and nearby ecosystems. Early project results typically show enhancements in marsh vegetation cover and growth, reduced invasive cover, and increased elevation of marshes, although these enhancements are not necessarily uniform in all project areas. Early project results also show improved hydrological dynamics – reconnecting marshes to nearby tidal systems or managing water levels in freshwater systems. All of these near-term achievements are improving the ability of marshes to provide habitat for birds, fish, and other wildlife, and will improve their ability to withstand or recover from future storms or other forms of disturbance. However, these observations are preliminary, and several more years of recovery and monitoring data are needed to more fully understand the likely long-term benefits of restoration actions on marsh ecosystem resilience. More specifically, more information is needed about whether (1) vegetation continues to grow and flourish, (2) marsh elevation is maintained at appropriate levels, and (3) marsh stability improves over time. Further monitoring and sharing of lessons learned is particularly important given the novel and innovative nature of some of the projects, and the setbacks in some areas that a few projects have noted to date.

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Appendix A. Project Summaries

Table A.1. Marsh restoration projects supported through the Hurricane Sandy Program. This table presents the amount of project funding specifically allocated to marsh restoration activities. For nine projects, this is the full project funding amount; and for 15 projects, this is a subset of the total project funding. The allocation was based on available project documentation. Projects organized by those selected for the in-depth assessment of implementation issues and ecological outcomes achieved to date through marsh restoration. All dollars rounded to the nearest hundred.

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds	Acres of marsh restored[d]
				Values represent marsh restoration activities only[c]		
NFWF-41739[a, b]	Reusing dredged materials to enhance salt marsh in Ninigret Pond, Rhode Island	RI	Rhode Island Coastal Resources Management Council	$2,925,000	$347,400	30
NFWF-41766[a, b]	Coastal resiliency planning and ecosystem enhancement for northeastern Massachusetts	MA	National Wildlife Federation	$1,764,000	$958,400	503
NFWF-41812	Preventing erosion and restoring hydrology in the Pine Barrens, New Jersey	NJ	New Jersey Conservation Foundation	$280,000	$106,300	1,111
NFWF-42442[b]	Strengthening Sunken Meadow State Park's resiliency, New York	NY	Connecticut Fund for the Environment	$750,000	$17,300	4
NFWF-42942[a]	Increasing salt marsh acreage and resiliency for Blackwater National Wildlife Refuge, Maryland	MD	The Conservation Fund	$3,500,000	$1,331,600	782
NFWF-42958[a, b]	Restoring Spring Creek Park's salt marsh and upland habitat, New York	NY	New York City Department of Parks and Recreation	$3,843,000	$6,270,800	6
NFWF-42959[b]	Rejuvenating Sunset Cove's salt marsh and upland habitat, New York	NY	New York City Department of Parks and Recreation	$4,850,000	$2,240,000	10
NFWF-43006[b]	Wetland restoration in Suffolk County, New York	NY	County of Suffolk	$1,310,000	$688,700	400
NFWF-43095[a, b]	Reusing dredged material to restore salt marshes and protect communities, New Jersey	NJ	New Jersey Department of Environmental Protection – Office of Natural Resource Restoration	$3,420,000	$4,681,600	53

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds	Acres of marsh restored[d]
				Values represent marsh restoration activities only[c]		
NFWF-43322[b]	Enhancing Wampanoag Tribe of Gay Head's land resiliency in Martha's Vineyard, Massachusetts	MA	Wampanoag Tribe of Gay Head	$335,000	$116,000	700
NFWF-43849[a]	Developing coastal resiliency regional models, Virginia	VA	Wildlife Foundation of Virginia	$3,139,600	$301,200	3,783
NFWF-43939	Restoring Newark Bay's wetlands, New Jersey	NJ	City of Newark	$780,000	$7,500	17
NFWF-43986[b]	Strengthening Monmouth Beach's marshes and dunes, New Jersey	NJ	Monmouth Beach, New Jersey	$356,000	$350,000	0
NFWF-44157[b]	Repairing infrastructure and designing wetland and beach restoration plans along the Central Delaware Bayshore	DE	Delaware Department of Natural Resources	$1,800,000	$1,053,100	1,353
NFWF-44167[b]	Protecting North Beach's salt marsh and emergency route, Maryland	MD	Town of North Beach	$261,100	$58,600	5
NFWF-44225[b]	Improving Shinnecock Reservation's shoreline habitats, New York	NY	Shinnecock Indian Nation	$375,000	$31,400	5
NPS-27	Dyke marsh restoration to promote resource protection from storm response and adaptation to sea level rise	VA	U.S. Army Corps of Engineers; National Park Service	$24,897,600	$0	5
USFWS-1[a, b]	Salt marsh restoration and enhancement at Seatuck, Wertheim and Lido Beach National Wildlife Refuges, Long Island, New York	NY	U.S. Fish and Wildlife Service	$10,498,700	$1,355,800	516
USFWS-15[a, b]	Prime Hook National Wildlife Refuge coastal tidal marsh/barrier beach restoration	DE	U.S. Fish and Wildlife Service	$11,883,000	$816,000	4,000
USFWS-37[a, b]	Restoring coastal marshes in New Jersey National Wildlife Refuges	NJ	U.S. Fish and Wildlife Service	$7,500,000	$1,500,000	34,909

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds	Acres of marsh restored[d]
				Values represent marsh restoration activities only[c]		
USFWS-43[a, b]	Restoring resiliency to the Great Marsh, Parker River Parker River National Wildlife Refuge, Massachusetts	MA	U.S. Fish and Wildlife Service	$340,000	$506,000	27,000
USFWS-50[b]	Increasing water management capability at Great Dismal Swamp National Wildlife Refuge to enhance its resiliency for wildlife and people	VA	U.S. Fish and Wildlife Service	$3,130,000	$2,929,000	113,000
USFWS-65[a, b]	Protecting property and helping coastal wildlife: Enhancing salt marsh and estuarine function and resiliency for key habitats on impacted wildlife refuges from Rhode Island to southern Maine	Multi: RI, MA, ME	U.S. Fish and Wildlife Service	$3,983,300	$240,000	300
USFWS-85[a]	Pocomoke Sound marsh enhancement, Ferry Point, Nanticoke River	MD	U.S. Fish and Wildlife Service; Maryland Department of Natural Resources	$638,000	$55,000	2,000

a. Denotes a project included in the in-depth analysis for the case study.

b. Denotes a project for which long-term monitoring funding has been secured through NFWF and DOI.

c. Costs in the table do not represent the full cost of the project and may not reflect the total match.

d. These data include projects that have not yet been completed, and thus the final number of acres restored may change; for active projects, we assumed that projects will achieve the proposed acres restored.