Coastal Habitats
1. Assisted Marsh Migration

DEFINITION

Assisted marsh migration is a strategy of marsh conservation that works with the inland movement of coastal marshes as a response to rising sea levels. Within a marsh, the plants closer to the coastline are more frequently inundated with water and are thus more salt tolerant (Vanderveer 2023). However, sea level rise has resulted in both high and low tides moving further up the shoreline, flooding a greater percentage of the marsh. In response to this, marsh plants begin to naturally move into upland zones, seeking conditions that best match their desired salinity and water exposure (LCCN n.d.). Barriers such as seawalls, roads, canals, and homes can prevent marsh from migrating inland, resulting in loss of marsh habitat with sea level rise. Assisted marsh migration often consists of creating marsh migration corridors, moving infrastructure, removing invasive species, transplanting plants, and digging runnels (Bergeson 2023, Vanderveer 2023).

TECHNICAL APPROACH

Assisted marsh migration consists primarily of three components: (1) removing or preventing upland obstacles, (2) enhancing upland topography and hydrology, and (3) facilitating the movement of marsh plants. Many assisted marsh migration projects do not contain all three components because of the land uses around the site (Bergeson 2023). Assisted marsh migration projects are often part of a larger resist-adapt-direct ecosystem management framework. Once land managers can no longer resist the inevitable decline of a marsh ecosystem resulting from sea level rise, they must adapt management strategies accordingly. Directing naturally occurring movement of coastal marsh ecosystems in a coherent manner is the final step of this process (Schuurman et al. 2020). This can take the following forms:

1. **Removing or preventing upland obstacles:** Once an area has been developed, it is very difficult to convince people to move out (Lipuma 2021). Thus, marsh migration corridors must be planned preemptively before significant development occurs in the region. Conservation easements and buyout programs are two of the most common ways of acquiring land (Field et al. 2017).
    - **Moving infrastructure:** It is very difficult to displace urban development for a marsh migration corridor. However, individual roads and outlying flood control infrastructure can sometimes be moved. As sea level rises, rural communities may move and flood control infrastructure may no longer be necessary (Enwright et al. 2016). Additionally, saltwater intrusion into nearby agricultural areas reduces yields and may make farming in many areas economically infeasible. Clearing old farm equipment is necessary before converting agricultural areas into marshes (Tully et al. 2019).

- **Removing invasive species:** Invasive species are common in the underbrush of forests in the path of marsh migration. While most native trees may die naturally, hardier invasive shrubs generally persist longer. These species will need to be removed as well as the common reed (*Phragmites australis*). While *Phragmites australis* can aid marsh migration due to its greater tolerance for brackish water, it can disrupt the growth of native marsh plants in the long term (Smith 2013).

2. **Enhancing upland topography and hydrology:** Many coastal areas have been diked and drained to accommodate farming in low-lying areas. This hydrology must be reversed to let water into the migration corridor (Anisfeld et al. 2016).

    - **Digging runnels:** As high tides penetrate further inland, large amounts of water often get trapped in upland areas as the tide recedes. These high levels of inundation cause marsh vegetation to drown. To solve this problem, shallow channels called *runnels* are dug to help drain the water (Figure 1). This restores the natural marsh hydrology and allows for the vegetation to grow back (Vanderveer 2023).

Figure 1.1 Digging ditches to improve drainage and remove invasive plants in Sachuest Point National Wildlife Refuge

Photo courtesy US Fish and Wildlife Service

- **Dike removal:** Dikes were built to convert former marshes into farmland or other human development. As sea levels rise, many of these areas are no longer as productive. Dikes must be removed to restore natural tidal exchanges, allowing frequent inundation to support marsh plants. Tides also bring in enough salt water to support halophyte marsh plants (Smith et al. 2009).
- **Microtopographic alterations:** Topography is one of the main factors limiting marsh migration. Marshes can only move to areas with a slightly higher elevation and cannot climb up steep slopes (Molino et al. 2022). To make upland areas more accessible for marsh migration, any high gradients must be lowered. This allows for tidal water to enter the area unimpeded.
- **Grass bundle staking:** Many tidal exchanges come into upland areas too fast, limiting the deposition of sediment that drives the natural accretion process. This is critical to help marshes keep adding elevation at the same pace as sea level rise. Grass bundle staking involves rolling cut grass into bundles and staking them in upland areas. The bundles help slow the tides and capture sediment (DU 2012).
- **Filling ditches with dredged material:** Many ditches have been created in marsh migration corridors to control mosquito populations or enhance agricultural productivity. These ditches lower the water table, making areas inhospitable to marsh species (Nolan 2018). To fill these ditches, or any other upland area that is frequently inundated with water, layers of dredged material are often used. Large amounts of dredged material are already being produced to deepen coastal waterways, making assisted marsh migration projects a great beneficial use of dredged material (Weinstein and Weishar 2002).

3. **Facilitating the movement of marsh plants:** As coastal conditions change, marsh plants will naturally begin to migrate inland. However, this movement is contingent upon there being the appropriate space, salinity, topography, and hydrology to support marsh plants (Linhoss et al. 2015). While it is rare to see marsh migration projects moving plants inland, there are several ways to facilitate movement into marsh migration corridors.

   - **Cutting marsh grass:** Mowing marsh grass and placing the cuttings further inland helps direct marsh migration. Seeds from stems in the cuttings will colonize the upland habitat (DU 2012).
   - **Transplanting endangered species:** While most species can migrate on their own to upland habitats, endangered species already on the decline may not have the ability to do so. The Endangered Species Act lists many species that reside in marshes threatened by sea level rise, including the Cape Sable thoroughwort (*Chromolaena frustrata*) and aboriginal prickly-apple (*Harrisia aboriginum*). Endangered species should be transplanted to ensure their survival (Lopez 2015).
   - **Seeding:** Distributing seeds across upland fields in marsh migration corridors infuses genetic diversity into marsh communities when sexual reproduction occurs. Seeding jump-starts the succession process of old agricultural fields, preventing a *Phragmites australis* invasion before the native marsh plants arrive (Gedan and Fernández-Pascual 2019).

OPERATIONS AND MAINTENANCE

Similar to restored coastal marshes, maintenance needs are likely to include periodic invasive species removal and may require occasional replanting with native species.

FACTORS INFLUENCING SITE SUITABILITY

- ✓ **Old agricultural fields:** While marsh communities in old agricultural fields tend to have a greater composition of shrubs than traditional marshes, they are better able to repel invasive species. Furthermore, agricultural fields are in early stages of succession and devoid of canopy cover that limits light necessary for marsh plants to grow. Agricultural fields also provide fewer ecosystem services than terrestrial forests, limiting the trade-offs that occur when they are replaced by coastal marshes (Gedan and Fernández-Pascual 2019).
- ✓ **Lawns:** Similar to old agricultural fields, lawns lack canopy that stymies growth and provide virtually no ecosystem services. Unlike upland forests, lawns do not have leaf litter that discourages marsh plant growth (Anisfeld et al. 2016).
- ✓ **Tidal inundation frequency of 0.5% to 20% of high tides:** Inundation is the driver of plant movement. As the tides creep up the shore, both upland and marsh plants track this movement to be aligned with their ideal salinity and inundation conditions. Areas with current tidal flooding frequencies between 0.5% and 20% are good candidates for marsh migration. This range captures areas that receive enough tidal exposure to support halophytes but still accounts for future sea level rise (Anisfeld et al. 2016).
- ✓ **Areas with slopes less than 1%:** Marshes need extremely flat topography to migrate inland because of their need for hydric soil and inundation from tidal exchanges (Smith 2020).
- ✓ **Salinity levels of 5 to 30 ppt:** Halophytes need a baseline level of salt to survive and compete against established upland plants (VDCR 2021).
- × **Hazardous and contaminated sites:** In many urbanized areas, brownfield sites often abut coastal marshes. If a marsh migrates into one of these sites, then the inundation of the soil has the potential to release toxic chemicals in the water (Burman et al. 2023).
- × **Urbanized areas:** *Coastal squeeze* refers to the convergence of urban development and sea level rise compressing intertidal habitats from both sides. Urban areas are not ideal marsh migration corridors because of the prevalence of impervious surfaces and contaminated runoff (Enwright et al. 2016).
- × **Diked areas that won't be removed as a part of the project:** Dikes alter tidal flow, limiting the amount of salt water that reaches the area. Diked areas generally do not have enough water to support marsh plants (Wasson et al. 2013).
- × **Far away from current marshes:** Marshes do not tend to migrate long distances and usually are displaced to the habitat directly upland of their original location.

- **Lack of connectivity:** If anthropogenic barriers lie in between the marsh migration corridor and the current location of the marsh, the area is not suitable for marsh migration. Levees, urban development, and dikes are all barriers that threaten to disconnect marsh migration corridors (Clough 2013).

TOOLS, TRAINING, AND RESOURCES FOR PLANNING AND IMPLEMENTATION

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Sea Level Affecting Marshes Model (SLAMM)	Online model	Created in the 1980s, updated every year	National Oceanic and Atmospheric Administration (NOAA), Warren Pinnacle Consulting	National	Part of NOAA's Digital Coast toolbox, SLAMM helps predict where marshes will migrate to under threat from rising seas. The model contains helpful inputs including dike locations, accretion rates, and erosion rates. An explainer document is available.	✓	✓	—	—
Sea Level Rise Viewer	Online model	Updated in 2023	NOAA	National	To plan for future sea level rise, this tool allows viewers to visualize coastal flooding for up to 10 ft of sea level rise. The model also contains photo simulations of landmarks under certain sea level rise scenarios, projected marsh migration and socioeconomic vulnerability.	✓	✓	—	—
Marshes on the Move	Document	2011	NOAA, The Nature Conservancy (TNC)	National	This guide helps project managers make sense of the variety of marsh migration modelling software available. The authors discuss the pros and cons of using models as well as the factors the determine marsh migration.	✓	✓	—	—

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Managed Retreat Toolkit	Website	N/A	Georgetown Climate Center	National	Focusing on the policy tools needed to implement an assisted marsh migration project, this website helps weigh the social and ecological concerns related to marsh migration. Additional topics covered include regulatory considerations, infrastructure removal, and planning tools.	✓	—	—	—
A Guide to the Control and Management of Invasive *Phragmites*	Guidebook	2014	Michigan Department of Environment, Great Lakes and Energy	Designed for the Great Lakes region but most of the information is more broadly applicable	Covering all aspects of *Phragmites* control, this guide recommends a plethora of control and management strategies. Eliminating *Phragmites* and other invasive species is a major challenge for assisted marsh migration projects.	✓	—	✓	—
Conservation Reserve Enhancement Program	Fact sheet	2021	US Department of Agriculture	National	The Conservation Reserve Enhancement Program is one of the main mechanisms by which project managers can acquire farmland suffering from saltwater intrusion for assisted marsh migration projects. This document highlights the benefits of using this program for both farmers and the environment.	✓	—	—	—
Coastal Wetlands and Sea Level Rise: A Path to Climate Change Adaptation	Document	2015	Massachusetts Office of Coastal Zone Management	Designed for New England but most of the information is more broadly applicable	The report focuses on translating marsh migration model results into implementing a successful project. Additional topics covered include monitoring, case studies, and overcoming barriers to marsh migration.	✓	—	✓	✓

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Resource Includes: Site Selection?	Resource Includes: Monitoring Guidance?	Resource Includes: Example Projects?
Wetland Monitoring Guidelines	Guidebook	1999	US Fish and Wildlife Service (USFWS)	National	This guide covers all aspects of monitoring protocols for wetlands, including baseline data requirements and qualities to monitor for. The authors also discuss how to align monitoring operations with the goals of the project.	—	✓	✓	—
Use of Thin Layer Placement of Dredged Material for Salt Marsh Restoration	Guidebook	2017	Georgia Coastal Research Council, University of Georgia	National	Thin layer placement is a tool used in many restoration projects to replace natural accretion processes or make microtopographic alterations. Additional topics covered include case studies, monitoring, site suitability and site surveys.	✓	✓	✓	✓

LIKELY BENEFITS AND OUTCOMES

Primary objectives for each strategy are highlighted.

Climate Threat Reduction

- **Sea level rise adaptation and resilience:** While sea level rise is the driver of marsh migration, an intact marsh further upland is more resilient to future increases in sea level rise than a drowning marsh in its original location. Marshes that have undergone migration are better equipped to trap sediment, increasing accretion rates to generate elevation gains (Raposa et al. 2016).

- **Reduced flooding:** Marshes are a vital buffer zone protecting urban and agricultural areas from storm surges. However, with sea level rise, the area occupied by the marsh is decreasing, reducing its ability to protect against catastrophic flooding. Assisted marsh migration preserves the storm protection capabilities of marshes by allowing them to grow. This protects the areas behind the marsh from property damage and saltwater intrusion (Guimond and Michael 2020).

- **Storm protection:** While marsh migration results in greater amounts of coastal inundation than an intact marsh, a marsh that has moved upland still retains many of the same protective qualities. Protecting marsh migration corridors keeps vital infrastructure out of harm's way during severe storms (Bigalbal et al. 2018). Preserving the marsh area helps protect its storm attenuation abilities (Narayan et al. 2017).

Social and Economic

- **Property and infrastructure protection:** Marshes that moved upland still provide the same protection against high wave energy and storm surges. This protects properties behind the marsh from the impacts of severe storms (Kirwan et al. 2016).
- **Resilient fisheries:** Marshes serve as nurseries and habitats for a plethora of fish species. This results in an increase in both finfish and shellfish harvests in the surrounding waterbodies (Olander et. al. 2021).
- **Food security:** Some rural residents rely on locally caught seafood as their primary source of nutrition. Therefore, increases in fish harvests enhance food security (Olander et. al. 2021).
- **Jobs:** Contractors will need to be hired to perform restoration activities, investing in the local economy.
- **Mental health and well-being:** Preserving marsh habitat enhances residents' access to greenspace, boosting mental health and psychological well-being.
- **Cultural values:** Assisted marsh migration protects the marsh ecosystem for future generations, increasing awareness and appreciation of this special ecosystem.

Ecological

- **Improved water quality:** Marshes trap and absorb sediment, nutrients, and chemical pollutants such as heavy metals and hydrocarbons, preventing them from entering nearby waterways (Craft 2001, Padial and Thomaz 2008, Mason et al. 2018).
- **Increase in primary productivity:** In marshes, light availability is generally the limiting factor of phytoplankton abundance. As more light can reach the phytoplankton, their biomass increases, supporting the entire food web (Cole and Cloern 1987).
- **Enhanced biodiversity:** Birds, fish and invertebrates all rely on marshes for parts of their life cycles. Marshes are vital nursery grounds for many fish and multiple bird species use marshes as their primary habitat. A growth in marsh area increases biodiversity through all trophic levels (French McCay and Rowe 2003).

BARRIERS AND SOLUTIONS FOR PRACTITIONERS

Common Barriers

Several barriers are common across many of the nature-based solutions strategies; these are described in more detail in Section 1 of the Roadmap. Additional notes about the barriers specific to assisted marsh migration are included here.

- **Expense:** For projects that use dredged material to alter topography, transporting this heavy material over long distances can be quite costly. However, if there is already planned dredging activity nearby, then this material can be used in assisted marsh migration, reducing these costs (TNC 2023).
- **Capacity**
- **Public opinion**
- **Conflict with other land uses:** Marsh migration is frequently seen as a threat to agriculture because of the amount of agricultural land it replaces. Agricultural land is generally flat and lacks thick canopy cover, making it ideal for marsh migration. Marsh migration has already overtaken significant amounts of farmland in many coastal counties (Gedan et al. 2020). Despite this, farmers can still use their land to create additional revenue streams in the wake of decreasing yields. Farmers have shown willingness to profit from hunting, birding, and conservation programs on their properties (Sudol et al. 2023). Coastal squeeze, where marshes are trapped between encroaching development and rising seas, is also a major threat to marsh migration. Developers often resist marsh migration and attempt to protect land by armoring the shoreline or adding additional substrate to raise their property. Properties in marsh migration corridors are often expensive because of their proximity to the coast (Mills et al. 2015).
- **Regulation**
- **Lack of effectiveness data**

Community

- **Declining property values:** Marsh migration has been shown to depress surrounding property values. It is difficult to control where marsh plants migrate because of local topographic and hydrological regimes. Marsh plants will often independently migrate to lawns of residences further inland, creating a soggy and potentially structurally unsound structure (Van Dolah et al. 2020). However, this impact is inevitable with rising seas, regardless of whether an assisted marsh migration program is undertaken.
- **Displacement of local communities:** The spillover effects of marsh migration, including more frequent tidal inundation, may cause some residents living near marsh migration areas to leave (Van Dolah et al. 2020). Some amount of community displacement in response to sea level rise is likely inevitable whether or not assisted marsh migration occurs.

- **Infrastructure loss:** Rising water tables associated with marsh migration may compromise the structural integrity of nearby roads. Many roads are often maintained by a different entity than the one leading the migration project, a source of potential conflict (GCC n.d.).

Ecological

- **Loss of carbon sequestration:** Although coastal wetlands are large carbon sinks, the conversion of upland forests to marshes can result in net carbon emissions. The loss of the original marsh closer to the coast as well as the millions of tons of carbon emissions from dying forests further upland can make marsh migration a carbon source (Warnell et al. 2022).
- **Loss of upland forest habitat:** As saltwater intrudes into upland forest ecosystems and freshwater wetlands, these ecosystems experience a rapid die-off. Termed *ghost forests*, degraded upland forests emit large amounts of carbon and become scarcer with sea level rise. Complex trade-offs are involved when weighing the benefits of these forests versus marshes (Kirwan and Gedan 2019).
- **Invasive species:** *Phragmites australis,* a widespread invasive species, is primarily located at the upper boundary of marshes, meaning that it is the first colonizer in marsh migration. While thought to only grow in high light areas, *Phragmites australis* has been shown to grow in areas with dense canopy cover. The result is that when the native marsh plants migrate, the new site has already been invaded by *Phragmites australis* (Shaw et al. 2022).

EXAMPLE PROJECTS

Name and Link	Location	Leading Organizations	Techniques Used	Size, acres	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Blackwater National Wildlife Refuge Marsh Migration	Blackwater National Wildlife Refuge, MD	**USFWS,** TNC, US Army Corps of Engineers (USACE)	Sediment dredging, invasive species removal, cutting down dead or dying trees, planting transitional crops	870	Not provided	7 years	TNC has helped USFWS acquire more land to create marsh migration projects within the corridor. Many strategies are being used, including dredging sediment, removing *Phragmites* and nutrias, cutting down trees, and planting transitional crops in agricultural areas.	Sea level rise, coastal flooding	Local farmers were involved in the restoration activities to help gain their support for the project.
Ocean View Farms Marsh Migration Project	Dartmouth, MA	Dartmouth National Resources Trust, US Environmental Protection Agency, Southeast New England Program	Invasive species removal, digging runnels, seeding	125	Not provided	4 months	Workers removed invasive species, seeded salt marsh plants, and dug runnels to help water escape from impounded areas inland.	Sea level rise, coastal flooding, increased storm severity	Additional cobenefits of the project are reduced rates of erosion and natural mosquito control.
Narrow River Restoration Project	John H. Chafee National Wildlife Refuge, RI	**USFWS,** TNC, USACE	Dredged material placement, planting native marsh plants	14	Not provided	3 months	After this marsh was devastated by Hurricane Sandy, a thin layer of dredged material was placed to revive the marsh. This will give the marsh the opportunity to migrate landward in the future.	Sea level rise, coastal flooding, increased storm severity	Dredged material was placed on the site using a bulldozer that used computer-aided design to place the sediment in ideal locations.

Name and Link	Location	Leading Organizations	Techniques Used	Size, acres	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Community Science Salt Marsh Restoration and Monitoring Project	Charleston County, SC	South Carolina Sea Grant Consortium, NOAA, SC Department of Natural Resources, Clemson Cooperative Extension	Collecting and planting *Spartina alterniflora* seedlings	Not provided	Not provided	4 years	Volunteers collected seeds of *Spartina alterniflora,* which were then grown in a greenhouse. The seedlings were then planted in locations further inland.	Sea level rise	Volunteers also helped with monitoring efforts using the Anecdata app.
Island Road Marsh Creation and Nourishment	Isle de Jeane Charles, LA	NOAA, **US Geological Survey,** Louisiana Coastal Protection and Restoration Authority	Placement of a layer of sediment, creating gaps in a dike	295	34.3 million	Ongoing	In an area experiencing severe land loss, workers will create gaps in a dike and placement of a layer of sediment to promote marsh growth. The project will consolidate the remaining marsh in the area to protect the only hurricane evacuation route for the Isle de Jeane Charles community.	Sea level rise, coastal flooding, increased storm severity	Not provided

Bolding indicates DOI affiliates.

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