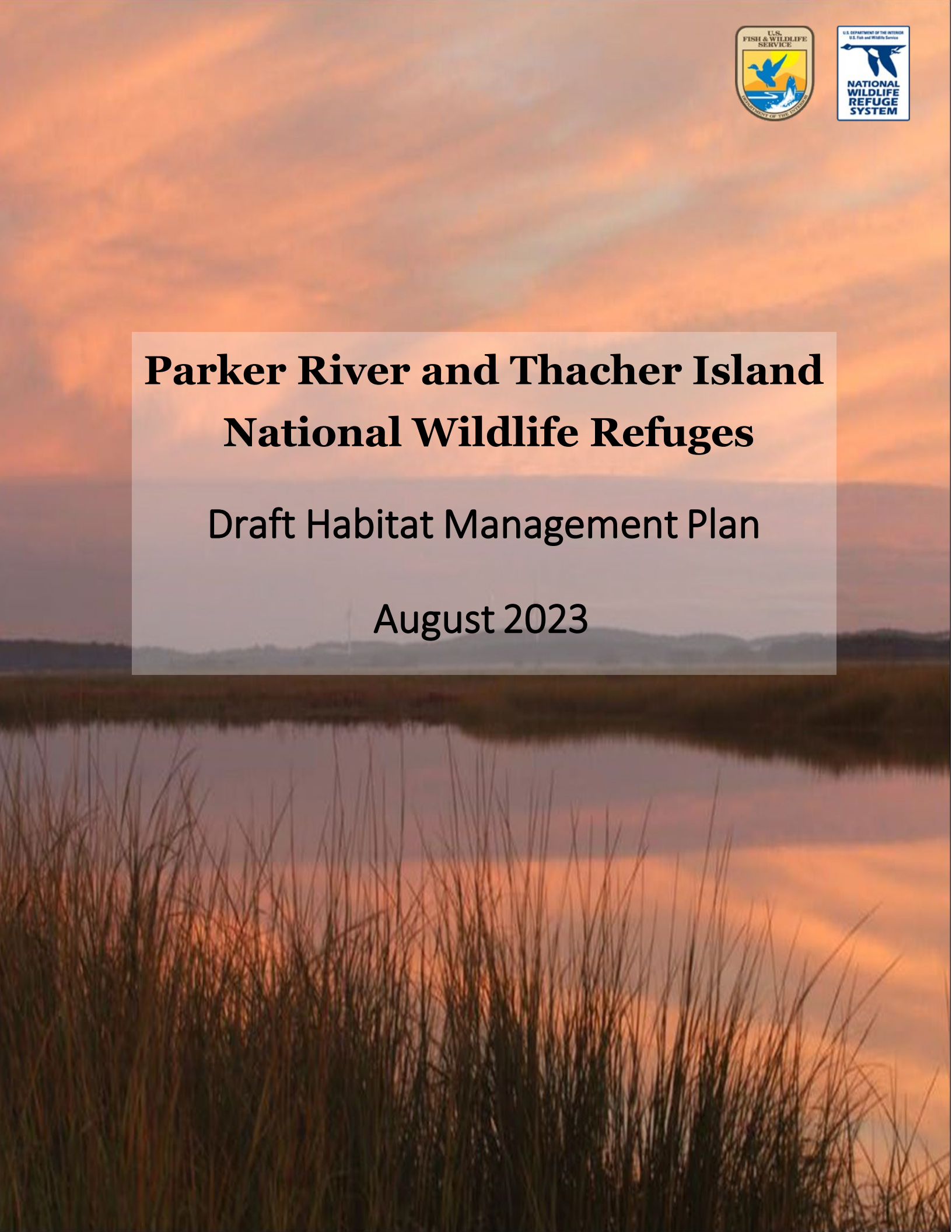

Parker River and Thacher Island National Wildlife Refuges

Draft Habitat Management Plan

August 2023

The mission of the U.S. Fish and Wildlife Service is working with others to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people.

The mission of the National Wildlife Refuge System is to administer a national network of lands and waters for the conservation, management, and, where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations.

Parker River and Thacher Island National Wildlife Refuges Habitat Management Plan

SIGNATURE PAGE

Action	**Signature/Date**
Prepared By:	Wildlife Biologist, Parker River NWR
Submitted By:	Project Leader, Parker River NWR
Reviewed By:	Chief, Division of Natural Resources and Conservation Planning
Reviewed By:	Refuge Supervisor, North Zone
Approved By:	Regional Chief, National Wildlife Refuge System

ACKNOWLEDGEMENTS

Nancy Pau, refuge biologist, was the lead author, with assistance by Kaytee Hojnacki, Kiah Walker, Lauren Healey, Amy Kirkey, Liana DiNunzio, Heather McIntosh, Luke Stuntz, and Austin Rizzo. Ellen Snyder, Jennifer Casey and Melinda Knutson provided technical editing. Noah Kahn, Matt Hillman, Graham Taylor, Scott Schwenk, Meta Miner reviewed the content.

Suggested citation: USFWS. 2023. Habitat Management Plan for Parker River and Thacher Island National Wildlife Refuges. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Department of Interior Region 1. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/142719*

ACCESSIBILITY

We have made this document accessible to all individuals. Some of the information displayed is complex due to the nature of biological systems, and thus may not always be fully accessible to all readers. If you need assistance reading or understanding any of the figures, tables, or maps, please contact the Parker River National Wildlife Refuge at parkerriver@fws.gov.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1. INTRODUCTION

SCOPE AND RATIONALE

This Habitat Management Plan (HMP) provides a long-term vision and specific guidance on managing priority species, habitats, and ecosystems at Parker River and Thacher Island National Wildlife Refuges (NWRs). This is accomplished by determining the refuges' priorities, setting goals and objectives for sustaining habitats and natural processes, and determining appropriate management strategies needed to achieve the refuges' desired conditions. The contributions of these refuges to ecosystem and landscape scale wildlife and biodiversity conservation are incorporated into this HMP.

This HMP adheres to the *Habitat Management Plan (HMP) policy* (620 FW 1) for the National Wildlife Refuge System (NWRS, System), which states that all refuge habitats shall be managed in accordance with approved Comprehensive Conservation Plans (CCPs) and HMPs that, when implemented, will help achieve refuge purposes, fulfill the System mission, and meet other mandates (USFWS 2002). This policy requires that an HMP and, where appropriate, a Habitat Work Plan (HWP) be developed for each refuge in the System. An HMP is a step-down management plan of the refuge CCP, and the HWP is a plan that steps down the HMP on an annual or biannual basis.

An Environmental Assessment (EA) that evaluates the potential environmental effects associated with implementing this HMP (the proposed action) is included as Appendix A. The EA complies with the National Environmental Policy Act of 1969 (NEPA; Public Law 91-190, 42 U.S.C. 4321 *et seq*.) in accordance with Council on Environmental Quality regulations (40 Code of Federal Regulations [CFR] 1500–1508) and U.S. Department of the Interior regulations and policies (Secretarial Order 3355; 43 CFR 46; 516 Departmental Manual 8; 550 FW 3).

The staff at Parker River NWR also administer Wapack NWR, Great Bay NWR, and the Karner Blue Easement in Concord, all of which are in New Hampshire. The New Hampshire refuges are not included in this HMP.

LEGAL MANDATES

Statutory Authority

National Wildlife Refuges are managed under the guidance of several statutory and acquisition authorities which may be specific to the refuge. In addition, habitat management on refuges is guided by federal policies, legal mandates, and regulations, as well as resource plans and conservation initiatives. The National Wildlife Refuge System Improvement Act of 1997 and the Biological Integrity, Diversity, and Environmental Health Policy are two of the most important mandates (Table 1-1).

Table 1-1 Statutory authority for refuge habitat management.

Statutory Authority	Description/Components
*National Wildlife Refuge System Improvement Act of 1997 (*PL 105-57*)*	The most important legislative mandate for refuges is the National Wildlife Refuge System Administration Act of 1966, as amended by the NWRS Improvement Act of 1997. The Improvement Act provides direction for how national wildlife refuges should be managed and used. (National Wildlife Refuge System Improvement Act of 1997, PL 105-57)
*Biological Integrity, Diversity, and Environmental Health Policy (*BIDEH*) (601 FW 3)*	A requirement that the Secretary of the Interior maintains the biological integrity, diversity, and environmental health of the Refuge System. (USFWS 2002b)

Enabling Legislation and Refuge Purposes

The enabling legislation is the legal authority by which the refuge was initially established and how lands were acquired. Each refuge has specific purposes derived from the legal documents establishing, authorizing, or expanding the refuge. Refuge policy (601 FW 1, and 601 FW Exhibit 1) describes the process for determining a refuge's purpose(s) (Table 1-2) (USFWS 2006).

Both Parker River and Thacher Island NWRs are administered by one refuge management team, based at refuge headquarters in Newburyport, Massachusetts.

Table 1-2 Summary of the establishment legislation for Parker River and Thacher Island National Wildlife Refuges.

National Wildlife Refuge	Date	Enabling Legislation, Encumbrances, Considerations	Purpose
Parker River NWR	1941	Migratory Bird Conservation Act (16 U.S.C. § 715d)	For use as an inviolate sanctuary, or for any other management purpose, for migratory birds.
Parker River NWR	1948	Proclamation 2817 (60 Stat. 238)	Closed 1,753 acres of tidal waters surrounding the refuge to pursuing, hunting, taking, capture, or killing of migratory birds, or attempting to take, capture, or kill migratory birds.
Parker River NWR	1962	Refuge Recreation Act (16 U.S.C. § 460k-460k-4)	For the: 1) incidental fish and wildlife oriented recreational development; 2) protection of natural resources; and 3) conservation of endangered or threatened species.

Thacher Island NWR	1972	An Act Authorizing the Transfer of Certain Real Property for Wildlife, or other purposes (16 U.S.C. § 667b)	For… particular value in carrying out the National Migratory Bird Management Program.
Parker River NWR	1974	Proposed: Wilderness Act of 1964 (16 U.S.C. 1131-1136, 78 Stat. 890)	Proposed Wilderness Area (3,110 acres) - These lands are managed in the same manner as designated wilderness, so that, if they become wilderness, their wilderness character is preserved.

Photo 1-1 Shorebirds flying above the surf.

REFUGE PLANS

These refuge-specific plans inform and guide management on the refuge. All refuge plans tier from the CCP.

Master Plan for Parker River National Wildlife Refuge (*1986*)

In 1980, a 9-step comprehensive planning process and extensive public involvement effort to document long-range management and development goals for Parker River was initiated. The planning process was accomplished through the cooperation of a Fish and Wildlife Service team of refuge planners, wildlife managers, landscape architects, biologists, resource specialists, computer mapping specialists, and cartographers. The resulting technical report describes management measures necessary to retain the natural, wildlife, and human values associated with the refuge.

Habitat Management Plan (*2007*)

In 2007, an HMP was developed for Parker River and Thacher Island NWRs (USFWS 2007). The 2007 HMP prioritized resources, including species and habitats, and served as a guide for management priorities and actions. Management goals, objectives, and strategies were developed for each habitat type in this earlier management plan (Taylor & Paveglio 2017; Adamcik et al. 2004; Powell & Casey 2019). The 2023 HMP will supersede the 2007 HMP.

Inventory and Monitoring Plan (*2021*)

The Parker River, Great Bay, and Thacher Island National Wildlife Refuges Inventory and Monitoring Plan (IMP) describes specific surveys and programs to monitor population trends, frequencies, and abundance for our highest priorities: barrier beaches and salt marshes (Pau 2021b). The IMP was used to help determine which surveys are needed to help inform management actions. Surveys selected are closely tied to priority habitats and species, and habitat objectives. The IMP was developed in collaboration with the Service's Inventory and Monitoring Program, and in accordance with Service Manual 701 FW 2 (USFWS 2013).

Fire Management Plan (*2005*)

A Fire Management Plan (FMP) was completed in 2005 for Parker River NWR as mandated by Service policy, which prescribed control of all wildfire events. However, the 2005 FMP did not address prescribed fire strategies. This HMP and EA incorporate prescribed fire as a management tool for achieving certain management objectives. Parker River NWR has not had an active prescribed fire program in over two decades. A map-based spatial Fire Management Plan will be completed within two years of finalizing the HMP, and a more detailed Prescribed Fire Plan will be completed as necessary following current agency policy and National Wildfire Coordinating Group guidelines as found in *NWCG Standards for Prescribed Fire Planning and Implementation*.

Habitat Work Plan

Each NWR prepares a Habitat Work Plan (HWP) that includes a review of the habitat management activities from the previous year, an evaluation of monitoring programs, and specific recommendations for habitat and wildlife management strategies and prescriptions for the coming year. It is a tool to implement and fulfill goals and objectives established in this Habitat Management Plan. The work plan incorporates adaptive management practices by evaluating the success or outcomes of specific management strategies and prescriptions that were implemented. While work is planned annually, due to staff capacity and the multiple-year nature of most biological programs, the habitat work plan is published bi-annually.

Regional and National Plans

Regional and national conservation plans issued by partner agencies and organizations also inform habitat management on refuges, especially the selection of priority species and habitats. Conservation concerns documented by these groups alert refuge staff about current and potential future threats and influence management priorities via the process of selecting Priority Resources of Concern (Chapter 3). The following list of plans and initiatives were used in the selection process:

- Federal Threatened and Endangered Species (USFWS 2022b)
- Massachusetts List of Threatened and Endangered Species (MassWildlife 2022a)
- Massachusetts State Wildlife Action Plan (MassWildlife 2022b)
- USFWS Priority At-Risk Species, Northeast Region (USFWS 2021c)
- North Atlantic Landscape Conservation Cooperative Representative Species (USFWS 2014)
- North Atlantic Landscape Conservation Cooperative Rare Plants
- The State of the Birds 2016 Report (NABCI 2016)
- New England/Mid-Atlantic Coast Bird Conservation Region (BCR 30) Implementation Plan (Steinkamp 2008)

- USFWS Birds of Conservation Concern (USFWS 2021a)
- Marine Bird Species Priority List (AMBCC 2014)
- North American Waterfowl Management Plan (NAWMP 2012, 2018)
- Endangered and Threatened Marine Species under NMFS Jurisdiction (Whale Sense 2022)
- Marine Mammals Protection Act Species List (NOAA 2022b)
- Species of Greatest Conservation Need (USGS 2022)

RESEARCH AND MONITORING

Refuge staff are engaged in several research and monitoring projects designed to inform habitat management and decision making. These shift over time to address changing priorities and emerging scientific uncertainties. The highest priority projects are outlined in the refuges' 2021 *Inventory and Monitoring Plan*.

Salt Marsh

Refuge staff have been involved in several long-term salt marsh habitat studies. From 2001 to 2010, the Open Marsh Water Management (OMWM) study investigated the response of this commonly used mosquito control technique on hydrology, vegetation, mosquito breeding, fish, and bird use (James-Pirri et al. 2012; James-Pirri et al. 2008). The OMWM study generated questions that led to the Salt Marsh Integrity (SMI) study (2008 to 2016), which attempted to identify indicators of salt marsh integrity that are effective across large geographic regions, responsive to a wide range of threats, useful from a management perspective, and feasible to implement within funding and staffing constraints of the NWRS (Neckles et al. 2013). The SMI study identified diversity across the Refuge marsh and rapid changes that led to additional investigations.

In 2014, refuge staff collaborated with partners within the Great Marsh and larger northeast region to better understand rapid changes in the salt marsh ecosystem. Several innovative restoration techniques (runnel, ditch remediation, ditch plug removal, OMWM plug modification, microtopography, alternative *Phragmites* control) were piloted at Parker River NWR (Burdick et al. 2020; Pau 2021b). These studies culminated in a suite of restoration techniques to restore marsh hydrology and improve habitat for Saltmarsh Sparrow; the techniques are being implemented by multiple organizations in the Great Marsh. Refuge staff are collaborating with partners to investigate other innovative marsh restoration techniques, such as thick layer deposition, mud engines (where sediment is placed in intertidal zones to be deposited on marsh surface with flooding tides), and methods that will promote marsh accretion.

Natural salt marsh adaptation monitoring

We are also documenting and monitoring several natural salt marsh adaptation strategies. These include natural breaching of pools, which is used to inform runnel creation, and natural sediment deposition and sediment flux. In 2019, a winter Nor'easter deposited significant sediment on top of salt marshes from Boston, MA to Portland, ME (Fitzgerald et al. 2020). The largest deposit that occurred at the refuge included a 40-acre marsh area just west of the North Pool impoundment. The event deposited 15-years' worth of sediment in 1 week, and the entire marsh area revegetated within 3 months (Moore et al. 2019; Moore et al. 2021). Refuge staff collaborate with The Plum Island Estuary Long Term Ecological Research station (PIE LTER), the University of New Hampshire, Boston University, and U.S. Geological Survey (USGS) scientists to monitor and understand these marsh processes that are evolving with a changing climate. Understanding these changing processes ensures that management intervention complements natural resilience and helps to inform future innovative and nature-based restoration techniques.

Impoundment restoration study

From 1999 to 2004, the refuge collaborated with Massachusetts Division of Ecological Restoration to investigate the feasibility of restoring the North Pool impoundment (Konisky 2004; Louis Berger Group 2004). The study determined that restoration of the impoundment to tidal estuary is feasible and should move forward. Restoration was deferred, however, due to opposition from the Massachusetts Division of Fisheries and Wildlife (MassWildlife) and local bird watchers. From 2015 to 2019, the refuge contracted for more detailed field data and hydrodynamic modeling for all three impoundments (Woods Hole Group 2019b). Follow-up conversations with MassWildlife used a structured decision-making framework to identify agency values and decision points. The objectives for impoundments and salt marshes were developed based on these studies and discussions.

Photo 1-2 View of North Pool Impoundment from the Hellcat dike. Open water was created when marsh peat was excavated to create the berm. USFWS photo.

Geomorphological Studies

In response to increased beach erosion and storm activity, Parker River NWR participated in two geomorphological studies of the beach and dunes from 2011 to 2021. The surveys were designed to monitor changes in beach profile and mean high water line through time, providing a baseline of the beach and dunes. At Parker River, the refuge has not found evidence of dune rollover and westward erosion; however, increased flux in beach and dune dynamics has been recorded (Psuty et al. 2017). With no directional retreat, we have decided to pause this monitoring protocol. Future surveys can be re-initiated if erosion concerns arise.

Saltmarsh Sparrow Study

From 2006 to 2012, the refuge conducted a long-term monitoring and research of Saltmarsh Sparrows, and the role mercury may play in their life cycle and reproduction. We monitored productivity, food chain pathways, and environmental sources of mercury. Results of this study are summarized in (Pau et al. 2021; Lane et al. 2020; Lane et al. 2011).

From 2011 to 2014, a collaboration of academic researchers from Maine to Delaware formed the Saltmarsh Habitat & Avian Research Program (SHARP) to study the demographics and conservation needs of tidal marsh nesting birds (SHARP 2023). Parker River contributed to this regional study by hosting a demographic research site and contributing additional point count and demographic data.

As the refuge and partners focus marsh restoration to benefit Saltmarsh Sparrows, we are using historical survey data and existing protocols to detect local population trends and monitor restoration success for this species. We are using SHARP rapid demo protocol to evaluate whether we can detect changes in productivity from long term marsh changes and from restoration efforts.

Photo 1-3 Saltmarsh Sparrow. Credit: Brian Harris/USFWS.

Shrub Restoration

Maritime shrublands support many berry-producing native shrubs that provide important food sources for migrating songbirds in the fall. Unfortunately, invasive, non-native shrubs are highly competitive in these habitats, creating a need to better understand the effectiveness of our restoration practices. Parker River NWR collaborated with other New England refuges to test methods which will improve shrub habitat for birds (Koch et al. 2008). The goal is to create very dense shrubs that provide cover and high-quality berries to fuel the birds during migration. More details can be found in the draft Shrub Adaptative Management Project (Pau et al. 2012).

Migratory Movement Study Using Nanotags

Parker River NWR was an early adopter of the Motus Wildlife Tracking Network (Taylor et al. 2017). This coordinated array of automated radiotelemetry towers allows detection of any tagged individual migrating from Canada to South America. Six nanotag receiver stations were installed at Parker River and Great Bay NWRs starting in 2013 for various research projects; two of these are still operational as of 2023. Staff collaborated with other researchers to study shorebird migration, Saltmarsh Sparrow spring and fall migration, and movement of Red and Northern Long-eared Bats during fall migration. The towers currently operating on the refuge support partner research projects and provide valuable information on species migrating or stopping over at the refuges.

Chapter 2. LOCATION, LANDSCAPE & CLIMATE

LOCATION

Parker River and Thacher Island NWRs are located along the coast of northeast Massachusetts, approximately 30 miles apart. Both refuges are approximately 40 miles north of Boston, MA, which has a metro area population of 694,000 people (2020 U.S. Census). Refuge headquarters and the visitor center are located on the mainland, in Newburyport, a city with a population of approximately 18,300 people (2020 U.S. Census). The 4,727-acre Parker River NWR is located within the towns of Newbury, Newburyport, Rowley, and Ipswich in Essex County. It occupies the southern three-fourths of Plum Island, a 9-mile-long barrier island, and hosts salt marshes, maritime dunes, maritime shrubland and forest, interdunal swales, sandplain grasslands, pitch pine woodlands, tidal estuary, beaches, rocky shores, and mudflats (Figure 2-1).

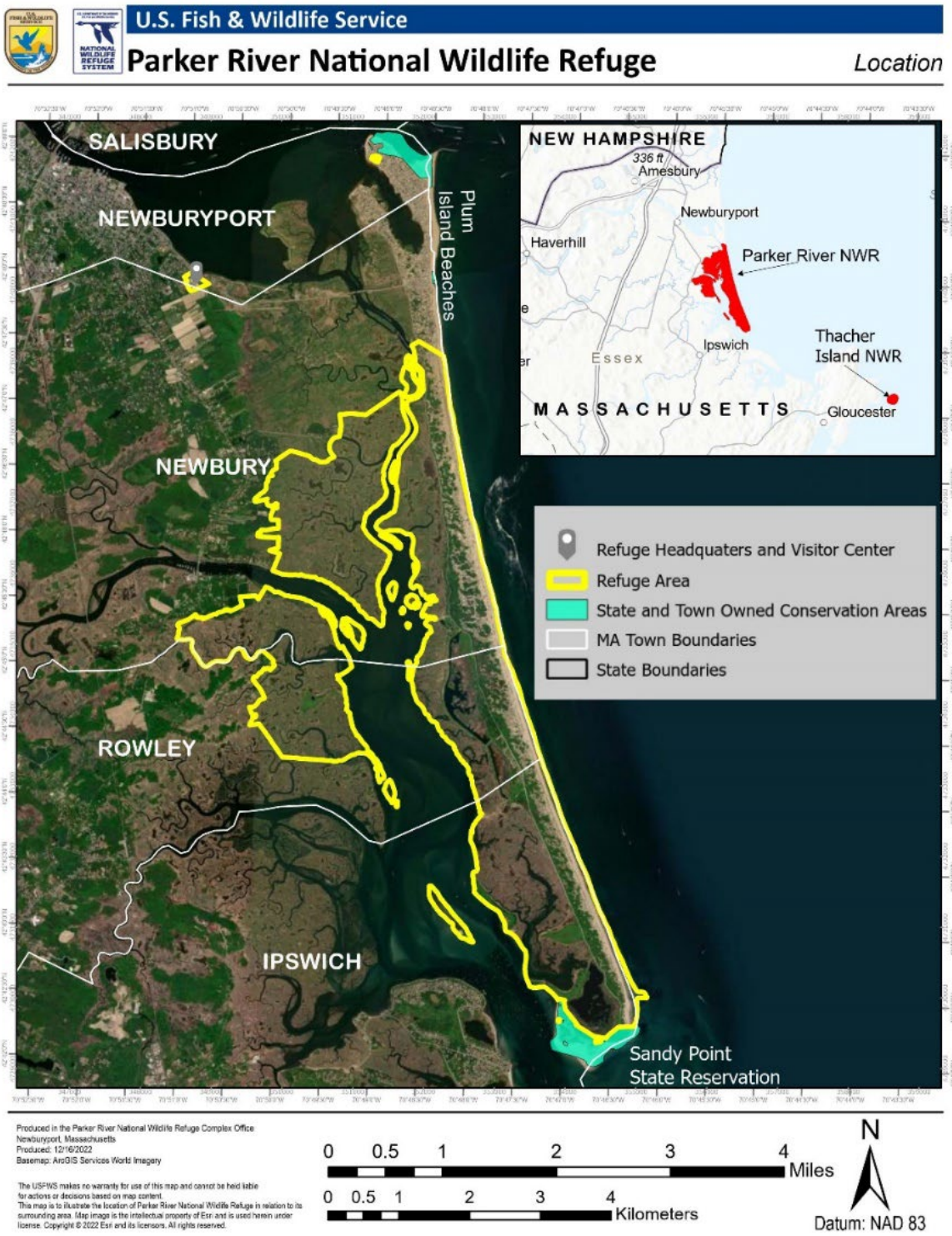

Figure 2-1 Map of Parker River NWR showing refuge boundary.

Thacher Island NWR is located at the northern end of Thacher Island, a 50-acre island one mile off the coast of the mainland portion of Rockport, Massachusetts. The refuge encompasses 22 acres of rocky intertidal shore and maritime shrubland ecosystems (Figure 2-2). The town of Rockport owns the remaining 28 acres of the island, which is managed by the Thacher Island Town Committee and the Thacher Island Association as a historic site and tourist destination; they provide transportation to the island for the public.

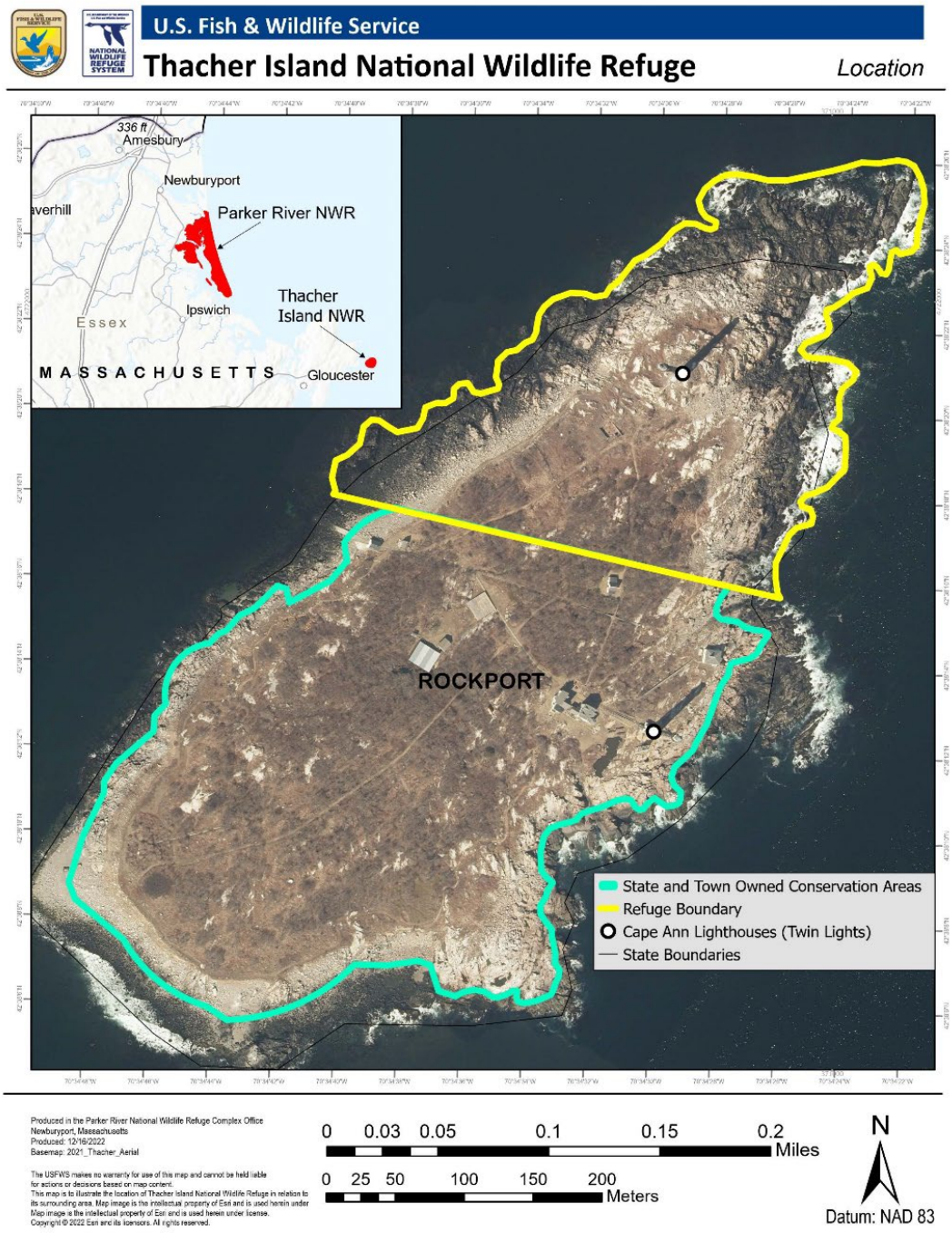

Figure 2-2 Map of Thacher Island NWR showing refuge boundary.

LANDSCAPE

The Parker River and Thacher Island 2007 HMP (USFWS 2007) provides a comprehensive description of the landscape and geographic setting of the two refuges. We provide a short summary here.

Ecological Region

Ecological regions (or ecoregions) are broad landscape classifications with distinct ecology, geography, and climate that help focus efforts to preserve the ecological integrity of these large landscapes. The Nature Conservancy (TNC) classified Massachusetts into three ecoregions. Parker River and Thacher Island are in the North Atlantic Coast TNC Ecoregion (Figure 2-3). It has a straight-line distance of 475 miles but encompasses almost 5,000 miles of irregular shoreline habitat.

Anderson and Ferree (2010) suggested that within a given climatic region (e.g., Northeastern North America), geologic diversity, latitude, and elevation range, rather than climate, explain species diversity patterns. Thus, in the face of climate change, conserving geophysical settings rather than predicted distributions of species based on climatic conditions, may be more effective in conserving biodiversity over long time scales. Conserving functioning ecosystems in specific geophysical settings, in addition to near term strategies for conserving rare species, places more emphasis on allowing dynamic processes, maintaining ecological function, and building adaptive capacity. Using these concepts, TNC developed a *resilient lands mapping tool* to assist land managers in assessing resiliency at their site.

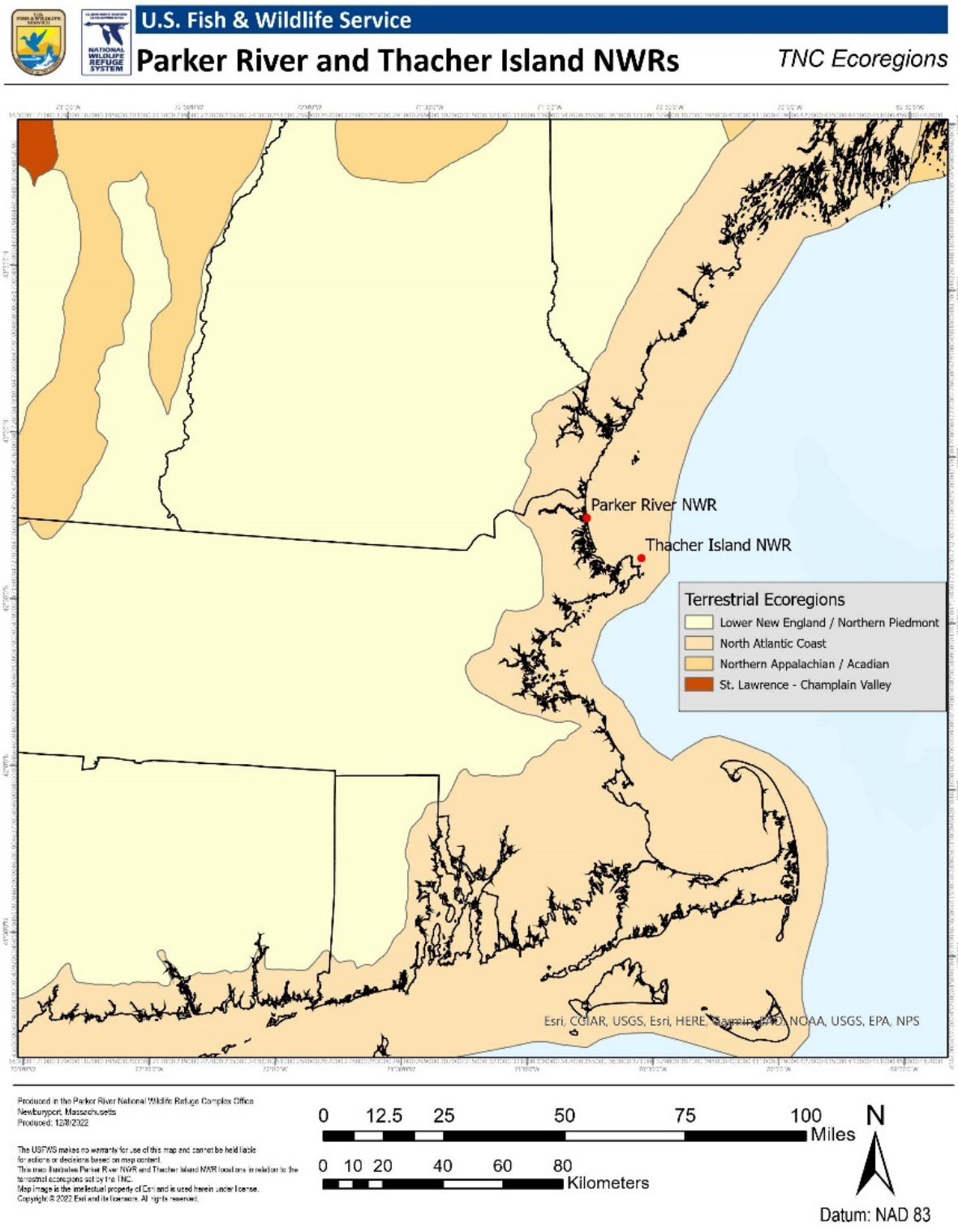

Figure 2-3 Map showing Parker River and Thacher Island NWRs within The Nature Conservancy's North Atlantic Coast Ecoregion.

Gulf of Maine Watershed

Both Parker River and Thacher Island NWRs lie within the Gulf of Maine watershed, which extends from Nova Scotia and New Brunswick, Canada to Cape Cod, Massachusetts (Figure 2-4). One of the world's most productive environments, the Gulf of Maine's marine waters and shoreline habitats host some 2,000 species of plants and animals. Ocean currents control temperatures and bring nutrients and food to the plants and animals that occupy the rich undersea terrain.

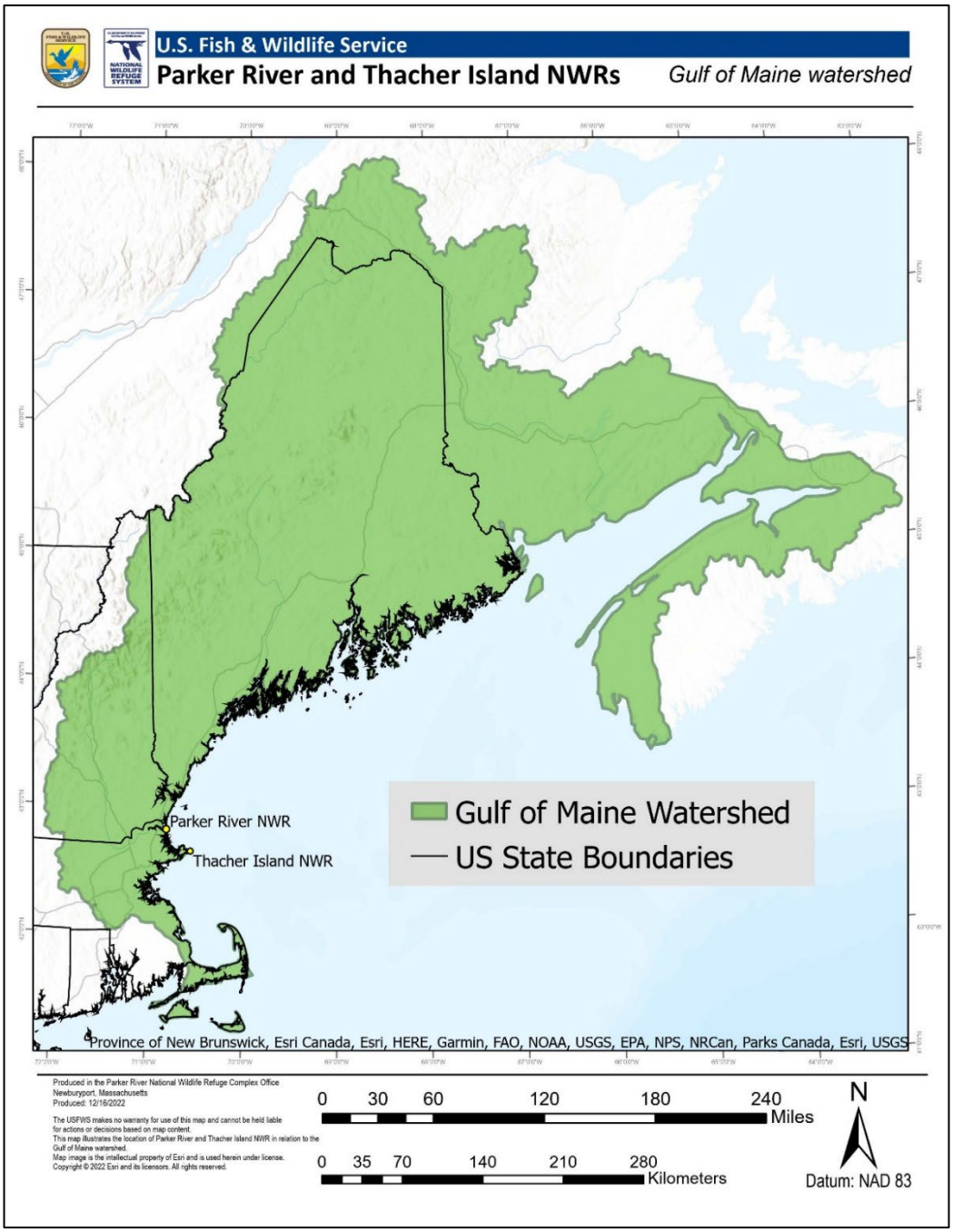

Figure 2-4 Map showing the location of Parker River and Thacher Island refuges within the Gulf of Maine Watershed.

Great Marsh

Parker River NWR is also situated within the 25,500-acre Great Marsh, a state-designated Area of Critical Environmental Concern (ACEC) (CZM 2000). The Great Marsh is the largest contiguous salt marsh in New England, extending from Gloucester, Massachusetts to the New Hampshire border (Figure 2-5). Ecosystems within the Great Marsh include the barrier beach, dune, salt marsh, tidal river, and other water bodies. In recognition of its important wildlife value, a large portion of the area was designated by the State of Massachusetts as the Parker River/Essex Bay Area of Critical Environmental Concern in 1979. An ACEC receives special consideration and protection by the State. The Great Marsh was also designated a Western Hemisphere Shorebird Reserve Network Regional site in 2004 for its importance as a migration stopover for shorebirds.

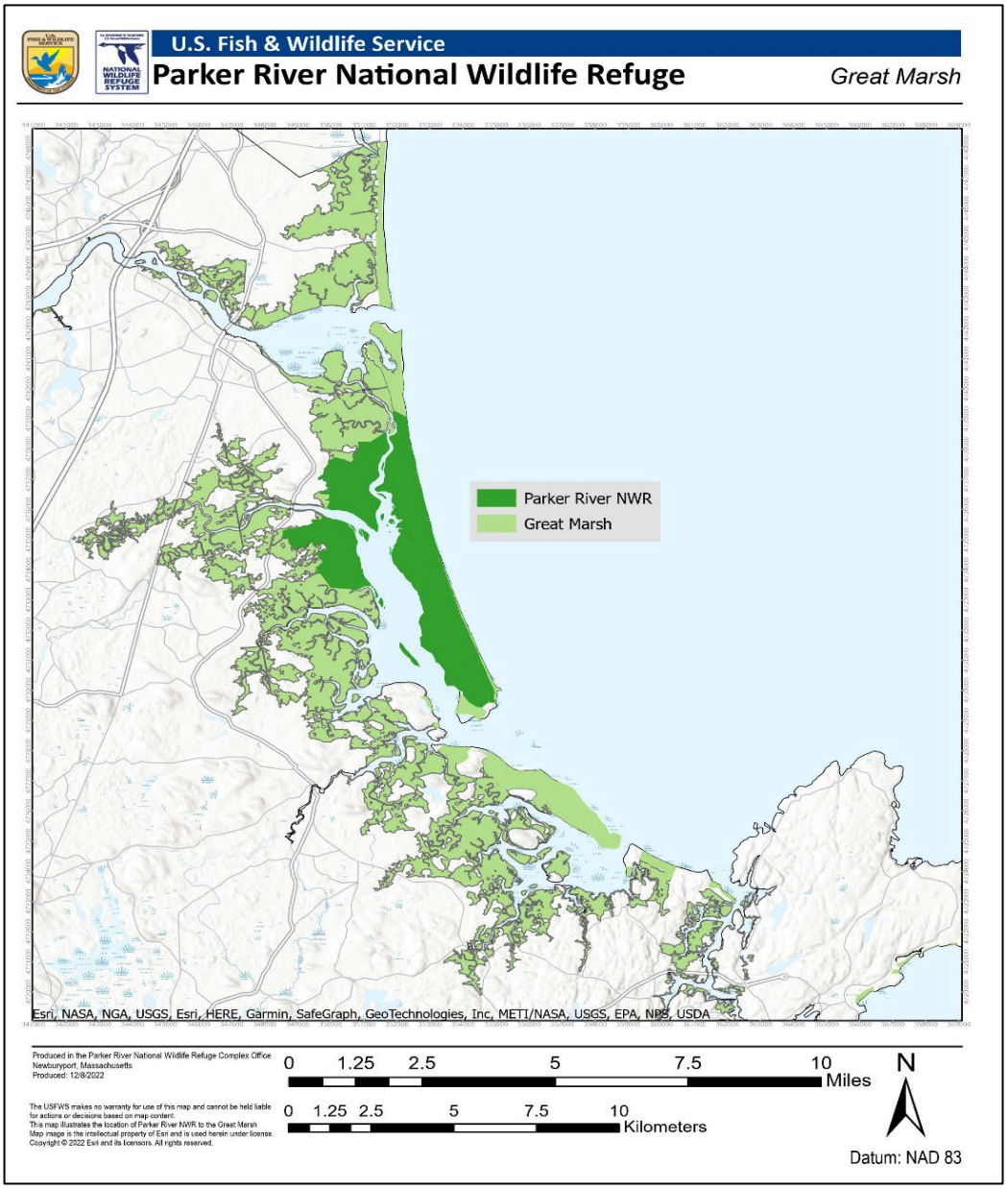

Figure 2-5 Map showing the extent of Great Marsh.

Parker River Watershed

The Parker River watershed is in the northeast corner of Massachusetts, between the Merrimack River watershed to the north and the Ipswich River watershed to the south (Figure 2-6). It drains an area of 82 square miles, meandering 21 miles from its headwaters through a rolling landscape before emptying into Plum Island Sound at Parker River NWR (Figure 2-8). Of the estimated 52,000 acres in the Parker River watershed, approximately 15,000 acres, or 29% of the watershed, are in some form of permanent protection either through public ownership or with conservation easements or agriculture preservation restrictions (Tomczyk 2002).

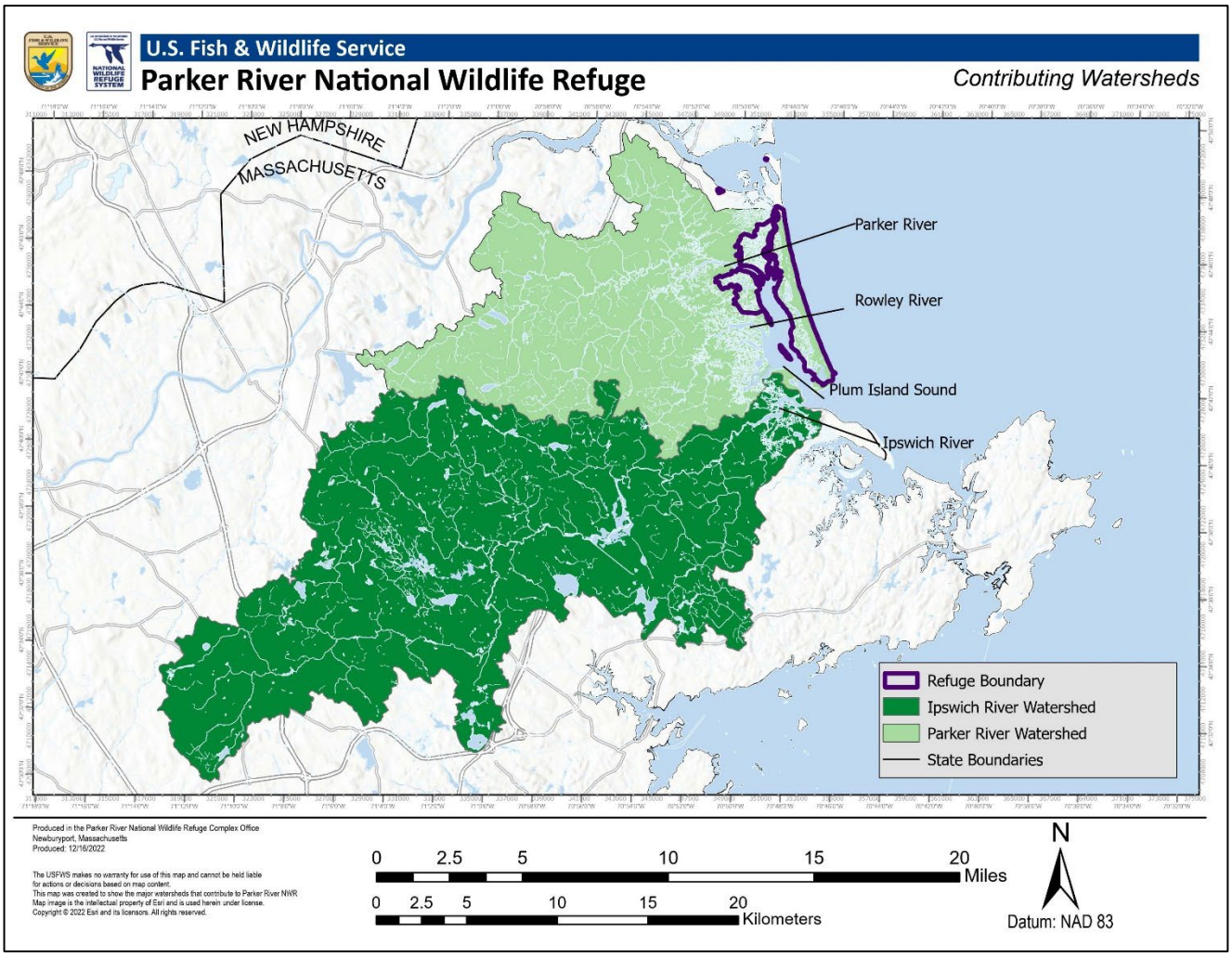

Figure 2-6 Map showing the Parker River and Ipswich Watersheds.

SITE CAPABILITIES

Topography

Elevations in the Parker River watershed range from 300 ft in the western headwaters to sea level at the river's mouth where it enters Plum Island Sound. The eastern portion of the watershed is composed of extensive salt marshes interlaced with tidal creeks and streams. Topography on the refuge ranges from 0 to 64 feet above sea level (Wurster & Hunt 2015).

Geology and Soils

The geology of the Parker River watershed has been shaped by past glaciations. The present-day barrier island overlies tills of Wisconsin and Illinois glaciations as well as late Pleistocene glaciomarine clay deposited during the post-glacial sea-level high stand approximately 17,000 years ago. The present-day barrier island and its tidal marshes are believed to have originated approximately 6,000 years ago from reworking of nearshore sediment and glacial-fluvial deposits from the Merrimack River (Hein et al. 2012). These same currents dominate present-day sediment supply to some portions of Plum Island (Hein et al. 2019). More recent (Holocene-age) sediment began to accumulate around 7,000 to 8,000 years ago from erosion of the Parker River channel. Plum Island stabilized in its modern position about 3,500-4,000 years ago and has undergone relative stability in the last 3,000 years, with relative low rates of sea level rise (Hein et al. 2012).

Soil types in the lower section of Parker River include Ipswich and Westbrook mucky peats (poorly drained, inundated daily), Agawam fine sandy loam (well drained, moderate to rapid permeability), Maybid silt loam (deep, poorly drained, and slow permeability) and Canton extremely fine silty loam (moderately rapid permeability) (USDA NRCS). The peaty salt marsh and glacial till soils that make up most of the refuge boundary (44%) are characterized by slow infiltration and high runoff potential. Soils with the highest capacity for infiltration occur in the beaches and dunes of Plum Island. For more information on geology and soils, see Wurster and Hunt (2015).

The soil horizon layer on Nelson Island, Stage Island and Cross Farm have been altered due to a long history of farming prior to refuge establishment and extensive grassland management after refuge establishment (Weare 1996). The large dike separating North Pool and Bill Forward pool from the adjacent salt marsh consists of Udorthents soils. These soils are common in areas where sediment has been artificially deposited; they range from sand and gravel to fine sandy loam.

Thacher Island consists of exposed granite rock, covered in places by a thin layer of Rock Outcrop-Hollis Complex soil (USDA NRCS 2022).

Current Hydrology

Over 75% of Parker River NWR is considered estuarine marsh and saline habitat, while 5% is classified as freshwater marsh (mostly human-made). There are four major rivers (Merrimack, Parker, Rowley, and Ipswich) that influence the hydrology and ecosystem function within the refuge. With Parker River's location on the ocean, the refuge's habitats are also heavily influenced by tidal forces.

Hurricanes and Nor'easter storms can abruptly alter refuge habitats and physical features. Nor'easters generally occur during the fall, winter, and spring, and are characterized as slow moving, low-pressure systems that move up the Atlantic coast, generating strong northeast winds that cause flooding and erosion. Seasonal extreme high tides affect the refuge periodically.

The salt marshes and tidal flats of Plum Island Sound are the most extensive wetland types within the refuge. These habitats are currently experiencing increased inundation associated with sea level rise, storm-driven tides, and legacy alterations (see Historic Influences). From 2009 to 2019, refuge staff and partners observed unprecedented acceleration of marsh conversion and marsh loss. Therefore, we have been investigating several innovative restoration techniques to help counteract these threats, including the use of runnels and ditch remediation (Burdick et al. 2020; Pau et al. 2022). Success from these pilot projects has led to planning large-scale hydrological restoration throughout the Great Marsh. The refuge implemented the 100-acre marsh project in 2021 and 2022, using all the piloted restoration techniques to restore flood/ebb hydrology to the entire project area (Pau 2021a).

Photo 2-1 Coastal salt marsh at Parker River National Wildlife Refuge in Massachusetts. Credit: Matt Poole/USFWS.

Refuge impoundments and the numerous small freshwater wetlands in Plum Island's dunes make up a much smaller portion of the wetlands in the refuge's boundary. The natural freshwater habitats are interdunal swales, which are low, shallow depressions that form between sand dunes as part of the barrier beach ecosystem. Most of these swales are cranberry bogs, and a small number act as vernal pools, providing important amphibian breeding habitat and a source of freshwater for other wildlife within the otherwise very dry dune system.

The three brackish impoundments on the refuge receive their water source from precipitation and tidal water from the Sound. Since the 1970s, the refuge has been addressing various issues related to impoundment management, including the lack of a fresh water source, invasive plants, anaerobic conditions, threats from sea-level rise, poor water quality, silting of channels and ditches, and increasing maintenance cost. These issues are detailed in the *2007 HMP* and in the North Pool Restoration Feasibility Study report {Louis Berger Group, 2004 #38534} . A detailed field survey and hydrodynamic modeling study was conducted from 2015-2020 to better understand the vulnerability of these impoundments to climate impacts and feasibility of restoring tidal flooding to these systems (Fitzgerald et al. 2017; Woods Hole Group 2018, 2019a).

For a more thorough assessment of hydrology and hydrological issues on the refuge, refer to the 2015 Water Resources Inventory and Assessment of Parker River NWR (Wurster & Hunt 2015).

Historic Influences

From the 1600s to the 1800s, salt hay farmers systematically installed berms (embankments) and water control structures (boots) that worked in conjunction with the ditches to divide salt marshes into individual haying units, controlling hydrology to increase yield (Photo 2-2) (Adamowicz et al. 2020).

Photo 2-2 Painting (1985) by Azor Vienneau “Repairing a dyke", depicting life in Belle Isle, Nova Scotia circa 1720s; Nova Scotia Museum. Access number 87.120.2.

In the 1930s, the Works Progress Administration further altered the salt marsh by adding additional ditches to help drain the marsh platform--with the objective to reduce mosquito breeding habitat.

In 1948, after the refuge was established, refuge staff created two brackish impoundments (North and Bill Forward Pools) by building a 1.5-mile dike in the salt marsh. A second shorter dike was built perpendicular to the first, splitting the area into two pools. Several years later, a third brackish impoundment (Stage Island Pool) was created at the southern end of the refuge by similarly damming the salt marsh.

From 1984 to 2009, the refuge partnered with the Mosquito Control District to implement open marsh water management (OMWM), a tool widely used to biologically control mosquito larvae and reduce pesticide use. OMWM involved installing plugs in ditches, creating additional pools as fish habitat, and constructing shallow access channels to connect the pools. The objective of OMWM is to keep water from ebbing from the marsh so that fish have access to all potential mosquito breeding areas during the entire tidal cycle. Following a regional study (James-Pirri et al. 2012; Rochlin et al. 2012), concerns were raised regarding the effects of impounding water on the marsh and the impact to marsh peat, particularly with sea-level rise (SLR) concerns. These discussions prompted the refuge in 2012 to discontinue further OMWM restoration.

Photo 2-3 Side by side comparison of a site impacted by ditch plugs installed as part of OMWM before (2015) and after (2020) runnels were installed. USFWS photo.

These layers of human alternations resulted in a heavily impacted salt marsh system. The impacts are compounded by increased flooding from sea level rise and storm surge, resulting in widespread and rapid loss of high marsh habitat in recent years.

Photo 2-4 Aerial images showing remnants of previous human practices. Credit: Geoff Wilson.

Note: Photo on left shows a marsh area with open water and wet areas, converting S. patens to S. alterniflora and open water. In photo on right, the same image but with overlay of old ditches (white) and hay farming berms (orange) that caused the ponding and inundation of the marsh platform.

Contaminants

There are four areas of potential concern regarding environmental contaminants on the refuge; these are described in the 2007 HMP (USFWS 2007). Additionally, recent studies have shown that Saltmarsh Sparrows at Parker River NWR have significantly higher levels of methyl mercury than sparrows in other New England marshes, with marsh processes (anaerobic conditions, high organic content) methylating historical mercury input. Research by refuge staff and partners from 2004 to 2016 demonstrated that mercury levels in sparrows and their invertebrate prey were higher in sites that were less frequently flooded, with dilution as a major mitigation for methyl mercury concentration (Pau et al. 2021). Marsh sites that supported Saltmarsh Sparrows had the highest concentration of methyl mercury. Saltmarsh Sparrows typically nest in high elevation areas that are the least frequently flooded, and thus, where the methyl mercury is less diluted. Also, the areas preferred by nesting sparrows—near pools and salt pannes — methylate mercury at a higher rate.

ANIMAL COMMUNITIES

Birds

Parker River NWR is noted as one of the best bird watching spots in the country with over 350 species recorded. Raptors migrate through in April and May, with high single-day counts of several hundred. Waves of migrating songbirds, especially warblers, vireos, thrushes, and flycatchers pass through in May and June and again in September and October. Up to hundreds of thousands of shorebirds migrate through the refuge from July to October. The refuge has the highest productivity of nesting purple martins in the State and attracts more than 200,000 tree swallows during fall migration. The refuge provides quality stopover habitat for fall migrating songbirds due to its density of berry-producing shrubs and trees that provide a carbohydrate-packed food source. Winter brings a different suite of songbirds to the refuge, including the Ipswich Savannah Sparrow, Horned Lark, and Snow Bunting.

Songbirds

More than 150 species of songbirds use the shrub and forested habitats on the refuge. These include BCR 30 high priority birds such as Brown Thrasher, Eastern Towhee, and Baltimore Oriole (Steinkamp 2008). The Whip-poor-will, a species of high concern in BCR 30 and the State of Massachusetts, nests in refuge forests. Willow Flycatcher and Eastern Kingbird, two other species of high priority, use the refuge's shrublands for nesting and the salt marsh and other open areas for feeding. Several salt marsh-obligate songbirds use the refuge, including Saltmarsh Sparrow, Nelson's Sparrow, and Seaside Sparrow. Other songbird species that nest regularly in the marsh include Red-winged Blackbird, Bobolink, and Marsh Wren.

Saltmarsh Sparrow

The Saltmarsh Sparrow is unique among passerines in being an obligate tidal-marsh specialist. The Seaside Sparrow is also a tidal marsh obligate but is uncommon on the refuge. Flooding, particularly during new and full moon tides, is the primary cause of nest failure for the Saltmarsh Sparrow, which is synchronized to nest immediately after a flooding tide (Greenlaw et al. 2020). Females wedge or suspend a nest in medium-high salt marsh grass just above the substrate or water.

Parker River NWR has a large area of potential nesting sites and a relatively large population of Saltmarsh Sparrows; it provides essential habitat for a species that has declined more than 80% over 15 years, down to less than 30,000 individuals (Hartley & Weldon 2020). Trend analysis of the refuge population does not show the population decline seen throughout the rest of the range (Hartley & Weldon 2020; Walker & Pau 2021). The Atlantic Coast Joint Venture has worked with partners to set a population goal of 25,000 individuals, which would stabilize the population (Figure 2-7).

As noted under the "Contaminants" section, Saltmarsh Sparrows on the refuge have extremely elevated levels of blood mercury (Lane et al. 2011; Lane et al. 2020), compounding concerns about impacts that sea level rise will have on this species (ACJV 2020b). Their very narrow habitat requirements and nesting window make the species highly vulnerable to extinction if salt marshes are consistently flooded. Due to these concerns, the USFWS has developed several *regional goals and strategies* for this species (Figure 2-7).

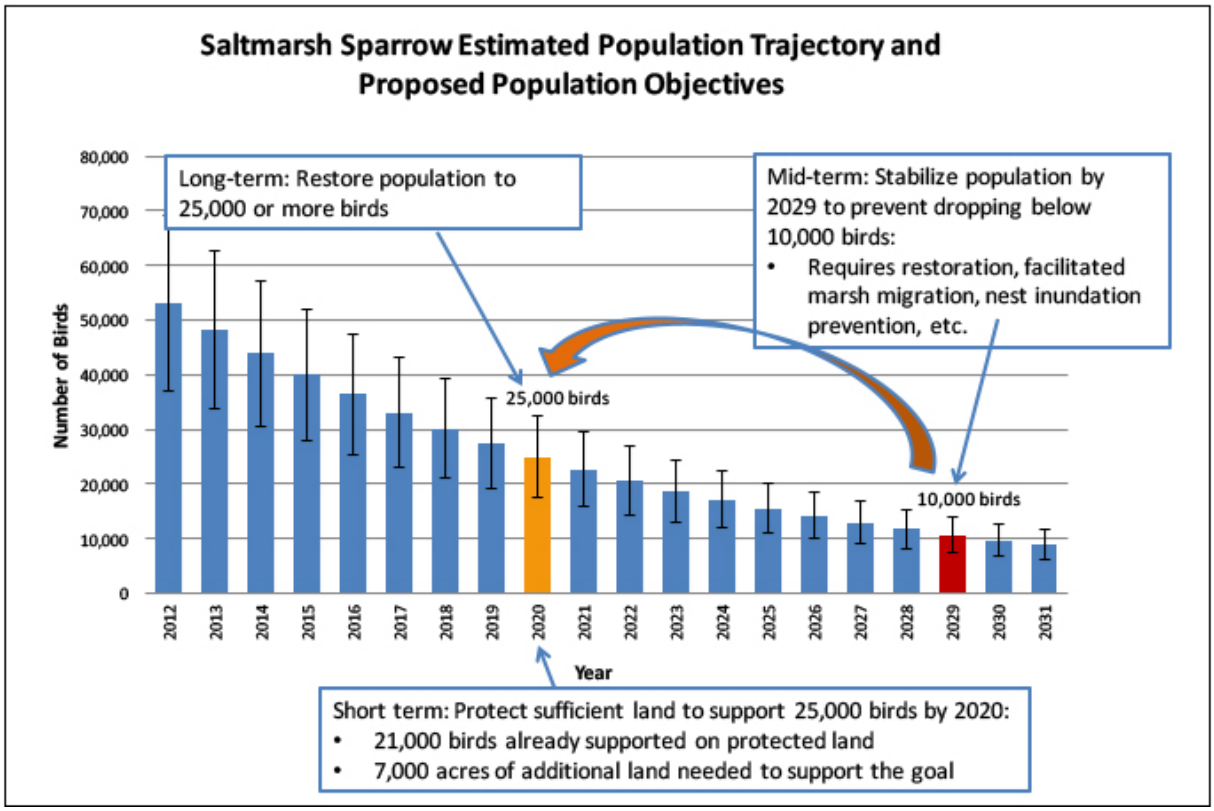

Figure 2-7 Saltmarsh Sparrow population trajectory and proposed population objectives. Credit: Atlantic Coast Joint Venture.

Shorebirds

Sandy beaches, rocky shores, ponds, salt marshes, and tidal flats are used by migrating shorebirds as refueling stops before continuing their long travels to wintering areas (Helmers 1992). For this reason, Parker River NWR and the surrounding Great Marsh were designated a Western Hemisphere Shorebird Reserve Network Site of Regional Importance in 2004. Shorebirds headed north arrive on the refuge in April through May and again from July through September on their southward migration. Sanderling and Ruddy Turnstone (highest priority species in BCR 30); Semipalmated Sandpiper, Greater Yellowlegs, Dunlin, Short-billed Dowitcher, White-rumped Sandpiper, and Black-bellied Plover (high priority species in BCR 30); and Semipalmated Plover and Lesser Yellowlegs (moderate priority species in BCR 30) use the refuge during migration (Steinkamp 2008). Four shorebird species breed on the refuge: the federally threatened Piping Plover occupies the beach and foredunes, Willets (BCR 30 high priority) nest in the salt marsh, American Woodcocks (BCR 30 highest priority) use the refuge's early successional and shrubland habitats, while Killdeer nest in a variety of open habitats including the beach, roadsides, dikes, and gravel areas.

Red Knot

The Red Knot, federally listed as threatened, is a medium-sized shorebird known for long flights during migration and large concentrations at major stopover sites. Plum Island is one of five stopover areas in Massachusetts with significant flocks of Red Knots. Harrington and Leddy (1982) documented peak numbers of 200 Red Knots on Plum Island in August of 1972 and 50 to 150 birds each year for the remainder of the 1970s. Recreational bird watchers reported more than 100 birds in the years 1990, 1994, 1995, 2019, and 2021. In 2011 and 2020, a total of over 1000 Red Knots were reported on Plum Island by refuge staff and recreational birders from mid-July to mid-November. Most were concentrated at the south end of the island at Emerson Rocks and Lot 7, with a peak count of 260, and at Sandy Point with a peak count of 93 (in 2011). Over many years, Bill Forward Pool also saw moderate-sized flocks of Red Knots (peak count of 30), with less usage of Stage Island Pool (eBird 2022).

Knots that migrate through Plum Island may be of two distinct wintering populations: one winters in Patagonia and Tierra del Fuego (Argentina and Chile), the other in the Southeast U.S. (Harrington et al. 2010). The two populations are distinguished by body molt and timing of migration. Argentina-bound birds tend to move through in July and August and retain their breeding plumage. Those bound for southeastern U.S. continue to be seen in Massachusetts through October and even early November, and molt during migration (Harrington et al. 2007). Although Red Knots do not consistently use Plum Island from year to year, protecting these migratory flocks from human disturbance when present is critical to the recovery of this species.

Piping Plover

The Piping Plover is a federal and State-listed threatened species (USFWS 1996). Massachusetts supports the largest population of breeding Piping Plovers along the Atlantic Coast, and within the State, Plum Island supports the second largest population north of Boston (Vitz et al. 2021). Up to 50 pairs of Piping Plovers nest on approximately six miles of refuge beach. Plovers return to Plum Island in late March or early April when they begin to establish nesting territories; their nesting season can extend to mid-August. High quality nesting habitat generally consists of wide, flat, sparsely-vegetated barrier beaches; and may be located near or within areas containing abundant moist sediments associated with blowouts, washover areas, spits, unstabilized and recently closed inlets, ephemeral pools, and sparsely vegetated dunes (USFWS 2009; Zeigler et al. 2019b). Plovers forage along the waterline, on the mudflats, and among the wrack line.

Habitat loss from development and recreation has drastically reduced the Piping Plover population along the Atlantic Coast, which highlights the value of Parker River NWR for this species. However, even on undeveloped beaches, there are still threats to successful nesting; predators (e.g., coyote, fox, skunk, raccoon, weasel, crow, and gull) and flooding are two major causes of nest loss. In addition, beach recreation can displace plovers from prime nesting habitats, reduce foraging opportunities, and increase predator pressure.

Piping Plover management on the refuge began in 1986 following federal listing of the species. The first record is of two pairs attempting to nest in 1980. In subsequent years, between two and five nests were recorded annually on the refuge beach. Then, in 1990, the refuge closed the beach to public use during the breeding season to increase nesting pairs, and the birds responded with a dramatic increase in the number of breeding pairs. There was a plateau around 2000 followed by steady growth and a recent peak of 50 pairs in 2019 and 2021 (Figure 2-8).

The Piping Plover recovery plan has a productivity objective of having 1.5 chicks per pair survive to fledging (able to fly), on average, over 5 years (USFWS 1996). The average fledgling rate on the refuge beach for 2018 to 2022 is 1.1 chicks per pair, which is below the recovery goal. In the past ten years, only 2014 and 2016 had productivity above the recovery goal (Figure 2-8). The refuge historically managed plovers at Sandy Point State Reservation and the towns of Newburyport and Newbury. However, since 2013, either the Massachusetts Audubon Society or the Massachusetts Department of Conservation and Recreation have monitored plovers at those sites.

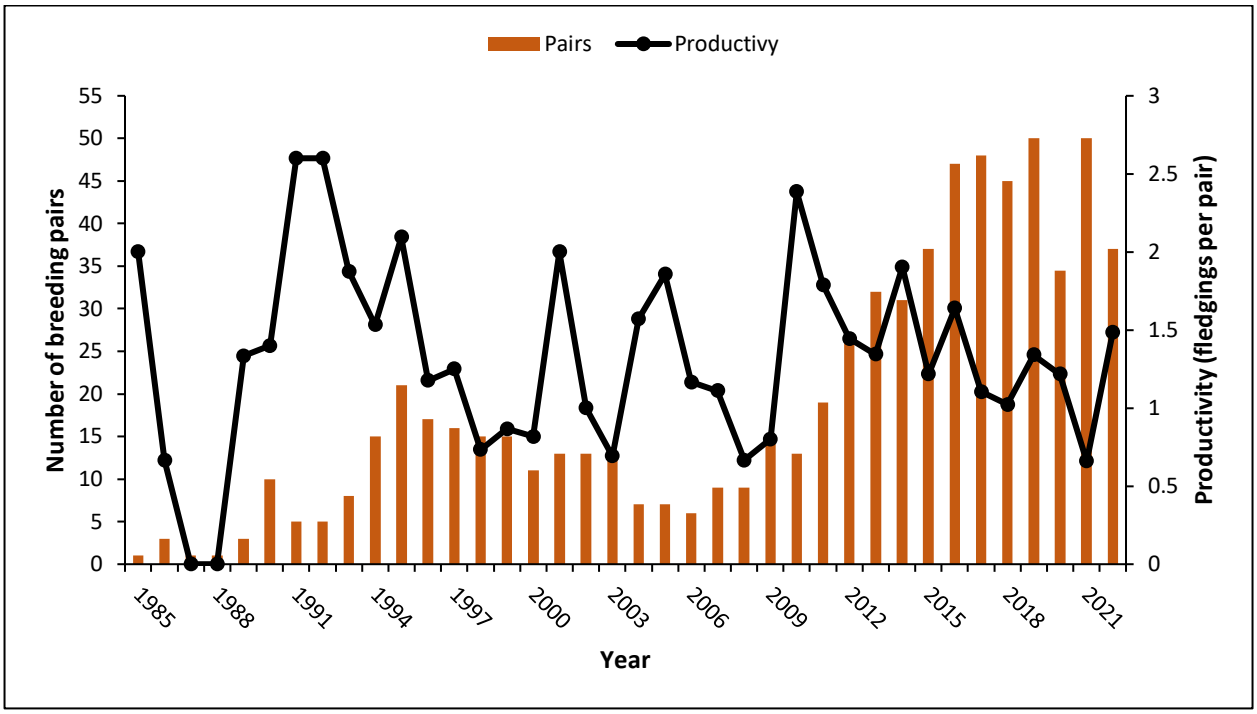

Figure 2-8 Piping Plover nesting data on Parker River NWR beach, 1985-2022.

Least Terns

The Least Tern, a State-listed species of special concern, has declined in Massachusetts in recent years (MassWildlife 2022b). The Least Tern is also a high priority for conservation in BCR 30 (Steinkamp 2008). Between 7 and 106 breeding pairs of Least Terns have nested each summer at Parker River NWR since recent records began in 1991. Least Terns nest in colonies on the beach and require similar habitat to Piping Plovers, but they require a larger patch size and only nest within the upper beach that has a mix of sand, pebbles, shells, and minimal vegetation (Thompson et al. 2020). The birds arrive at the refuge in early May; nesting continues through late August. Least Tern numbers on the beaches vary annually, depending upon beach geomorphology. Nest failure is moderate to high due to overwash and predation.

In the late 1800s, the Least Tern was a common bird in Massachusetts but was decimated at the turn of the century by the millinery trade (Nisbet 1973). Like many other seabirds, populations rebounded after the passage of the Migratory Bird Treaty Act of 1918. After initial recovery, populations declined in many areas between 1950 and the early 1970s due to displacement by humans, predation, and organochlorine pesticides (Hall & Kress 2004). Today, Least Terns face threats from development, predation, expanding gull populations, and recreational beach use.

In Massachusetts, the Least Tern population has fluctuated during the past 40 years. Since 1985, numbers have ranged from 2,109 to 4,309 pairs with a mean of 3,013 pairs (Mostello et al. 2019). In 2019, the three largest colony sites supported 32.3% of pairs, while the top ten colonies supported 63.5% of pairs, which suggests an increasing vulnerability in the State population overall.

Roseate Terns

Roseate Terns benefit from Parker River NWR shorebird management strategies. Although the refuge supports no breeding pairs, Roseate Terns use the refuge during migration and for foraging during the breeding season. Refuge beach closures help minimize human disturbance at roosting sites during spring migration (May) and during the breeding season. Protection of the refuge beach, intertidal zones, and salt marsh provides foraging habitat for Roseate Terns breeding at Seavey Island at the Isle of Shoals, thus helping to increase productivity for that colony.

Marsh and wading birds

Marsh and wading birds are present on the refuge throughout the summer months, with Great Egrets, Snowy Egrets, and Great Blue Herons being the most abundant species. Glossy Ibis and Black-crowned Night Heron are also regularly present. These birds take advantage of the plentiful fish found within the salt marsh pools and the shallower areas of the impoundments. Nesting on the refuge is not confirmed, although rookeries can be found in the surrounding area, including in Salisbury, just north of Plum Island and on Kettle Island in Cape Ann.

The refuge salt marshes support rails and bitterns during migration, and the refuge impoundments, particularly North Pool, support breeding secretive marsh birds (i.e., rails and bitterns). Over the past decade, we have recorded American Bittern, Least Bittern (State-listed endangered), King Rail (State-listed threatened), Common Gallinule (State-listed species of concern), Virginia Rail, and Sora (MassWildlife 2022a). However, both the number and diversity of marsh and wading birds have decreased since a peak in 2006 (6 species totaling 26 individuals). Surveys conducted by MassWildlife staff in 2019 and 2020 found only least bitterns (3) and Virginia rails (5) breeding in North Pool. These are birds that require dense stands of robust vegetation, such as cattail or *Phragmites* to nest and are more regularly heard than seen. A nest of the federally listed Black Rail was documented on high marsh habitat just north of the refuge in 2005 (Reilly, pers. comm. 2005).

Raptors

The abundant population of Meadow Voles in the refuge grasslands and salt marshes attract numerous raptor species during the winter including Rough-legged Hawk, Short-eared Owl (State endangered), and Northern Harrier (State threatened). Bald Eagles and Snowy Owls readily feed upon ducks within the refuge's salt marshes and coastal waters during the winter months while Peregrine Falcons hunt over the dunes and salt marshes, chasing flocks of shorebirds. The refuge is one of the top locations for hawk watching during spring migration. The most abundant species seen are American Kestrel, Sharp-shinned Hawk, Northern Harrier, and Merlin. Red-tailed Hawks use the refuge year-round.

Waterfowl

In October and November, dabbling ducks feed in the impoundments and salt marsh, and diving ducks congregate in deeper waters. Gadwall (BCR 30 moderate priority), Canada Goose, Mallard (BCR 30 high priority), and American Black Duck nest in the salt marsh and three impoundments. Refuge impoundments, large salt marsh pools, and tidal creeks host a suite of waterfowl species during fall migration including Atlantic Brant (BCR 30 highest priority), Bufflehead (BCR 30 high priority), American Wigeon, Northern Pintail, Green-winged Teal, and Hooded Merganser (BCR 30 moderate priority) (Steinkamp 2008). In winter months, Common and Red-throated Loons, Horned and Red-necked Grebes, Red-breasted Merganser, and sea ducks (Common Eider, White-winged, Surf, and Black Scoters, and Long-tailed Duck) are present along the ocean side of the refuge. Northern Gannets are observed offshore from mid-October through November.

American Black Duck

Parker River NWR was established, in part, to benefit American Black Ducks, which use the refuge during fall migration and in winter. The refuge is one of the most important wintering sites for this species in New England, with more than 2,500 ducks at peak times. It is not particularly selective in its habitat, using both freshwater and salt marshes during breeding; coastal salt marshes, estuaries, and sheltered coves are especially important to migrating and wintering individuals (Longcore et al. 2020). Black ducks use salt marsh, tidal creeks, sound, and impoundment habitats at Parker River. Land use changes as well as hunter exploitation led to widespread population declines, followed by harvest restrictions, beginning in 1983. Changes in hunting regulations are believed to be the primary reason that populations have now stabilized or increased (Longcore et al. 2020).

Gulls and terns

Least and Common Terns nest on or around the refuge. Annual counts for Common Terns in the surrounding salt marshes typically detect between 70 and 130 pairs in four to six colonies, although counts have been much reduced in the past six years with counts ranging between 0 and 50 pairs. Roseate, Forster's, and occasionally Caspian Terns are present on the refuge during migration. More than seven species of gulls have been documented on the refuge annually; Great Black-backed, Herring, Ring-billed, and Bonaparte's Gulls are the most common. There is no confirmed nesting of gulls at Parker River NWR, but they use the refuge for foraging and resting.

Thacher Island birds

The Gulf of Maine watershed includes a network of offshore islands that support colonial nesting birds. Thacher Island historically supported a large colony of nesting terns, with a record of 1,125 pairs of nesting Common and Roseate Terns in 1956 (RSPB 2021), but nesting Herring and Great Black-backed Gulls have since displaced the tern colony. Canada Geese, Mallards, Common Eiders, Double-crested Cormorants, and American Oystercatchers are documented as breeding in small numbers on the island.

Several species of songbirds have been documented breeding on Thacher Island NWR, including Mourning Dove, Willow Flycatcher, Tree and Barn Swallows, Gray Catbird, European Starling, Yellow Warbler, Chipping and Song Sparrows, Northern Cardinal, Red-winged Blackbird, Common Grackle, Orchard Oriole, and American Goldfinch.

Mammals

Terrestrial mammals

More than two dozen species of terrestrial mammals use Parker River NWR, including White-footed Mouse, Meadow Vole, Common Muskrat, Meadow Jumping Mouse, Eastern Chipmunk, Eastern Gray Squirrel, Red Squirrel, Woodchuck, and American Beaver. Carnivores found at Parker River NWR include Eastern Coyote, Red Fox, Gray Fox, Striped Skunk, Fisher, Ermine, American Mink, Northern River Otter, Long-tailed Weasel, and Raccoon. Other terrestrial mammals on the refuge include White-tailed Deer, Eastern Cottontail, Masked Shrew, and Virginia Opossum. No mammal surveys have been conducted at Thacher Island, although Thacher Island Association volunteers have seen rats on the island.

Eight species of bats are documented at Parker River NWR: Big Brown, Little Brown, Eastern Small-footed, Northern Long-eared, Tricolored, Eastern Red, Hoary, and Silver-haired. All but the Hoary Bat have been documented as infected with the white-nose syndrome (WNS) caused by the fungus *Pseudogymnoascus destructans*, which was introduced from Europe. Population declines of bats due to WNS has been one of the most critical wildlife-related crises in the twenty-first century (Warnecke et al. 2012).

Some bat species are more severely affected by WNS than others, including the Northern Long-eared Bat, which is the first species of bat to be federally listed due to impacts from WNS (USFWS 2016a). The Tricolored Bat is currently under review for listing as threatened. Little Brown and Eastern Small-footed Bats have also been heavily impacted, and are listed as endangered by the State of Massachusetts, along with the previous two species (MassWildlife 2022b).

Solitary tree bats, including Eastern Red, Silver-haired, and Hoary Bats, migrate to southern locations to spend their winters instead of clustering into large hibernaculum (Bat Cons. Int. 2020). This has mostly spared these species from the severe impact of WNS, but proposed wind turbines in their key migratory routes (mountain ridges and coastal habitat) are becoming a major concern.

Marine mammals

Marine mammals such as Harbor Porpoise and White-sided Dolphin can often be seen in the water off the Parker River NWR beach. Harbor Seals and Gray Seals commonly use the refuge beach and dunes as haul-out areas, especially during late winter when juveniles leave the breeding colony in the mouth of the Merrimack River. Other seals using the refuge include Hooded Seal, and on rare occasions Harp Seal and Ringed Seal.

Fish

The waters surrounding the refuge in the Parker River-Plum Island Sound Estuary have been identified as essential fish habitat by NOAA, and the Gulf of Maine is essential fish habitat for Cod, Haddock, Red Hake, Silver Hake, Winter Flounder, and Yellowtail Flounder (NOAA 2020). The fin-fisheries of Parker River-Plum Island Sound were historically very important to the local economy, although their commercial importance declined in the early 1900s and remains low today (Buchsbaum et al. 2005). Dams on area rivers reduced the amount of habitat available for spawning by Alewife and Blueback Herring (collectively called River Herring) and smelt, thus reducing their populations. Fishways, constructed in the 1930s at six dams along the Parker River, were repaired in the 1990s to increase access to available habitat for anadromous fish species.

Plum Island Estuary is an important foraging ground for Striped Bass. Overfishing and pollution of their spawning grounds caused population levels of this fish to hit all-time lows in the 1980s, but a rebound of the population in the 1990s has been touted as one of fishery management's success stories (Buchsbaum et al. 2005).

Plum Island Sound is an important foraging area for federally listed threatened Atlantic Sturgeon. In 2021, many breaching sturgeon were documented in the mouth of Plum Island Sound (Kieffer 2021) and Steele Associates (2021) found important hibernating grounds for thousands of sturgeon in the Merrimac River.

The Parker River salt marsh and associated tidal flats are nursery habitats for many fish species, including most prey fish for the commercially important species. The most abundant fish species found in the salt marsh ecosystem (mainly pools and ditches) is the Mummichog. Other common species include Atlantic Silverside, Three-spined Stickleback (State-listed threatened), Four-spined Stickleback, Nine-spined Stickleback, and American Eel.

Since 2001, the Mass Audubon Salt Marsh Science Project has collected fish data in North and Bill Forward Pools and in the adjacent salt marsh (Mass Audubon 2020). Species diversity is typical of a salt marsh environment. In addition, Yellow Perch were recorded in Bill Forward pool in 2001 and 2002 and a few Green Sunfish were recorded in this pool in 2002. In 2004, the refuge began managing the North Pool as a closed system, leaving the water control structure closed year-round. This led to a drop in salinity levels and a rise in Pumpkinseed, a fish more typical of freshwater ponds and lakes, and a decline in Mummichogs (Duff et al. 2013). White Perch were only caught in two years (2004 and 2014) but electroshocking in 2015 revealed numerous individuals within North Pool, along with American Eel.

Common Carp migrated to the Bill Forward and North Pools during an extreme rain event in 2006. While we were able to remove carp from the Bill Forward Pool in 2009, North Pool has been a bigger challenge. Carp have continued to proliferate in this pool despite attempts to eliminate them, including an electroshocking attempt in 2015. Short of restoring tidal flow, North Pool's large size, deep water, and low salinity levels makes elimination of carp there unlikely.

Reptiles and Amphibians

Frog-call surveys conducted by refuge staff from 1999 to 2006 documented Eastern Spadefoot Toad, Spring Peeper, American Toad, Fowler's Toad, Bullfrog, Wood Frog, and Green Frog all breeding on the refuge. Northern Leopard Frog, Gray Treefrog, and Eastern Red-backed Salamander are also documented on the refuge.

Reptile coverboard surveys conducted on the refuge in 2010 only detected Common Gartersnake. In addition, Snapping Turtle, Painted Turtle, Ringneck Snake, Smooth Green Snake, Milk Snake, and Brown Snake are documented on the refuge.

No reptiles or amphibians have been documented on Thacher Island, although no formal surveys have been conducted.

Invertebrates

Roughly 97% of all animal species are considered invertebrates (Center for Biological Diversity 2020), and include insects, spiders, earthworms, bivalves (e.g., mussels and clams), shellfish and snails, among others. Invertebrates are the main prey base for many wildlife species, and in estuaries are the primary consumers that transfer energy up the food chain, feeding on phytoplankton, plants, and detritus. On the beach, invertebrates break down organic matter and serve as a primary food source for foraging birds.

The Soft-shell Clam is the most important shellfish fishery in Plum Island Sound. However, pollution, overharvesting, and predation (primarily by Moon Snails, Horseshoe Crabs, and Green Crabs) affect their populations. Within the Sound, the most common macroinvertebrates are Sand Shrimp, Grass Shrimp, Green Crab, Rock Crab, White-fingered Mud Crab, and Ribbed Mussel (Buchsbaum et al. 1998). The most common macroinvertebrates in the refuge's salt marsh and tidal creeks include Grass Shrimp, Sand Shrimp, Green Crab, Horseshoe Crab, and Coffee Bean Snail (Mikula et al. 2019). Common mollusks using the beach intertidal zone include Bay Scallop, Razor Clam, Common Periwinkle, Dogwinkle, New England Dog Whelk, Lagillerts Whelk, Stimpsons Whelk, Horse Mussel, Black Clam, and Purplish Tagelus.

In 2004, the refuge started an inventory of terrestrial insects; more than 300 species in 60 families and 13 orders have been recorded. Additionally, staff and volunteers have conducted focused inventories of bees, dragonflies, butterflies, and moths. The species lists can be found *here* in Table 4.

Globally, Insect pollinators are in decline due to loss and fragmentation of habitat and extensive pesticide use (Xerces Society 2020). Viable populations of these important insects can be sustained in small habitat units, which means that refuges are important places for pollinator conservation. Additionally, Parker River NWR hosts many exemplary barrier island habitats that have been lost throughout much of New England, many of which support endemic species of insects and pollinators (Swain 2020). Three species of moths found on the refuge are listed as species of special concern for Massachusetts: Sandplain Euchlaena, Dune Noctuid, and Coastal Heathlands Cutworm (MassWildlife 2022a). Additionally, bee surveys in 2011 and 2012 found six uncommon and two rare species. Insects are also sensitive to climate change impacts, as they have closely evolved with their host plants and can be used as early indicators of climate change response.

CLIMATE AND CLIMATE CHANGE

Local Climate

Parker River and Thacher Island NWRs experience a coastal climate that is more moderate than that of nearby inland locations because of their proximity to the ocean.

The weather around the refuges is cool and wet for much of the year, with the average annual precipitation of 50 inches evenly distributed throughout the year. Prevailing winds are from the west, with an average velocity of 5.3 to 10.5 miles per hour, depending on the season. High winds are most prevalent from October to April, with average wind speeds of more than 7.9 miles per hour. February is the windiest month with an average hourly wind speed of 10.4 miles per hour.

Winters are generally cold, cloudy, and snowy from November into March, with average temperatures of 28 ˚F in January. Snowfall is moderate, with an annual average of 35 inches. Summers are generally warm and sunny from late-May through September, reaching the warmest temperatures in July.

Changes in Extreme Events – Heat Waves, Cold Events, Rainstorms

The total number of hot days in Essex County is expected to increase as this century progresses (Commonwealth of MA 2022). The frequency and duration of heat waves, defined as three or more consecutive days with maximum temperatures at or above 90˚F, are also expected to increase. In contrast, extreme cold events, defined as the number of days per year with a minimum temperature at or below 32˚F, are expected to decrease as average temperatures rise. In general, the climate of the northeast and Massachusetts is expected to become warmer, with shorter, warmer winters (Dupigny-Giroux et al. 2018; Karmalkar & Bradley 2017; Runkle et al. 2022).

Precipitation is projected to continue to increase, with more intense rain events occurring more frequently. Monthly precipitation in the northeast is projected to be about 1-inch greater for December through April by the end of the century (2070 to 2100) (Runkle et al. 2022). This is expected to result in more flood events. Although precipitation is expected to increase, short-term droughts are projected to occur more frequently. This is projected to result in low streamflow conditions lasting an additional month. These conditions are already occurring in the Ipswich River and Parker River.

Photo 2-5 Peggotty Beach and Kent Street marshes in Scituate, Massachusetts are overrun by coastal flooding during a midday high tide on March 4, 2018. Credit: Karl Swenson/SKYWARN Spotter.

Sea Level Rise, Metonic Cycle and Storm Surges

Boston's mean sea level has risen greater than 25 millimeters between 1950 and 2022 (NOAA 2022a) (Figure 2-9). In recent decades (1990 to 2018), sea level rise rates within Plum Island Estuary have increased to 4.8 mm per year compared to the historic rate of 2.83 mm per year (1921 to 2018) (Langston et al. 2020).

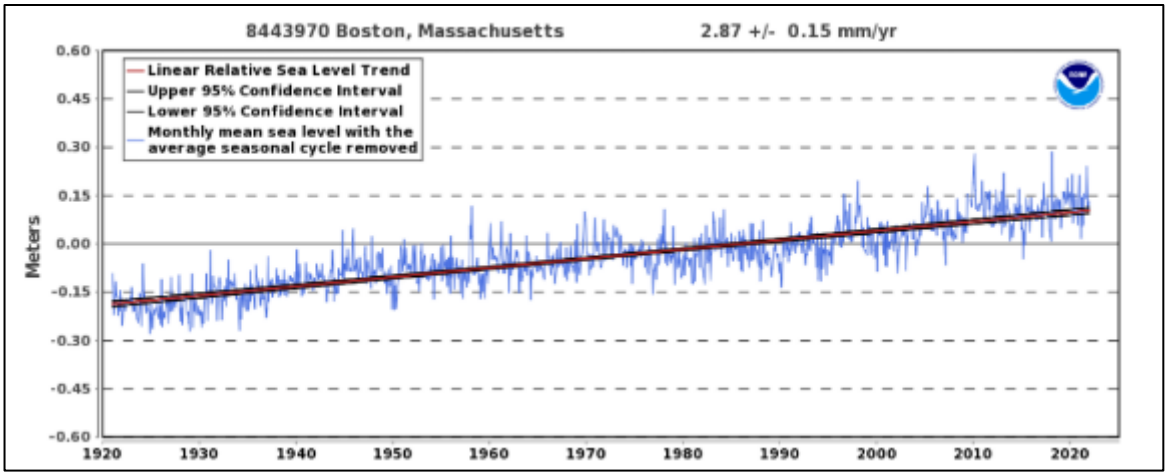

Figure 2-9 The relative sea level trend at Boston, MA.

Note: Sea level is increasing by approximately 2.87 millimeters/year, based on data from 1921 to 2020. This is equivalent to a change of 0.94 feet in 100 years. Figure taken from NOAA (2022b).

As illustrated in Figure 2-9, there is a high variation in sea level from year to year. Mean sea level is a way to track change over long periods. Sea level rise, coupled with an increase in storm frequency and intensity are leading to increased storm surge amplitude and occurrence (Murdukhayeva et al. 2013).

The orbit of the earth, moon, and sun repeats every 18.6 years—known as the Metonic Cycle—whereby the gravitational pull of the celestial bodies influences the tidal amplitude on earth. Because the moon influences ocean tides, this cycle causes tides to be higher or lower, depending on where the moon is in the cycle (Szabados 2008). Figure 2-10 represents the observed tide data from the NOAA Boston tide gauge from 1984 to 2020 showing the interaction of sea level rise and variations in tidal amplitude due to the Metonic cycle. The years 2005 to 2017 show a period of increasing tidal amplitude, and 2017 to approximately 2025 is a period of decreasing tidal amplitude. We are in the "down phase" of a 19-year *tidal pattern* which may cause sea level to appear to go down, but that is a temporary phenomenon.

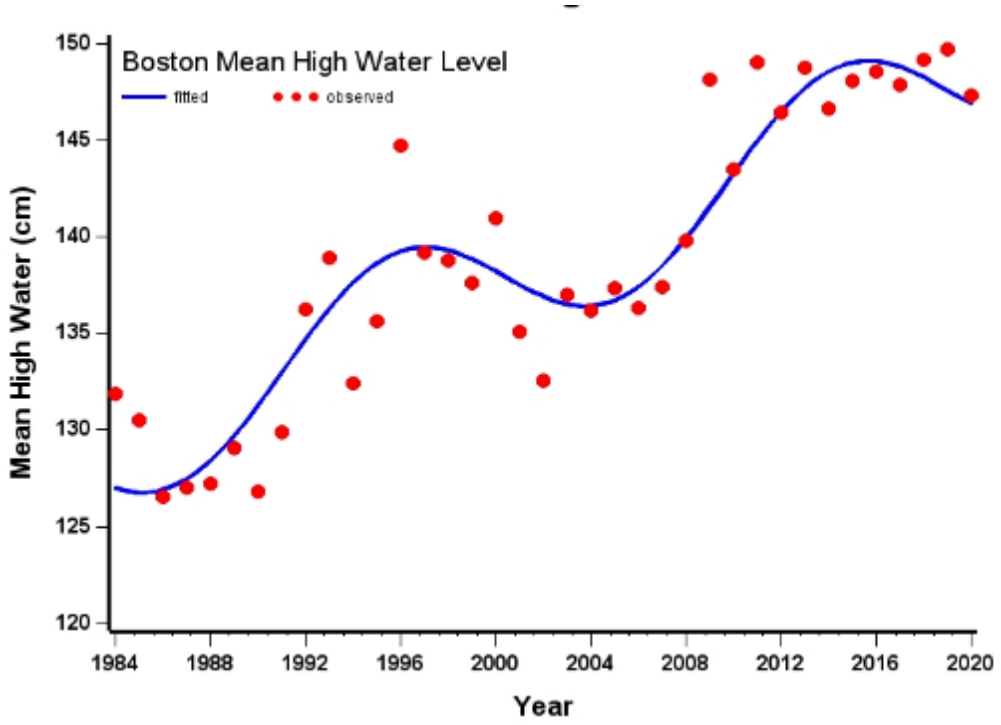

Figure 2-10 Observed tides from NOAA Boston tide gauge from 1984 to 2020.

Note: Observed tides from NOAA Boston tide gauge from 1984 to 2020, compiled by Jim Morris, University of South Carolina. The blue line indicates predicted tides based on the 19-year Metonic cycle; 2007-2016 was a period of increasing flooding due to higher lunar gravity. Red dots are actual observed tides. Noticed the increased tides from 2009 to 2019. The next period of increased tides starts in 2026.

Rising Sea Temperature

Since 2012, the *Gulf of Maine* has warmed seven times faster than the rest of the Atlantic Ocean and all the other oceans on the planet. In fact, this area is experiencing more rapid temperature increases than 99% of the world's oceans (GMRI).

While sea surface warming has been documented as occurring during all seasons, it has been strongest during the summer months, with the duration of summer-like sea surface temperatures (SST) expanding (Thomas et al. 2017). From 1982 to 2021, summertime SST in the Gulf of Maine has warmed at an average rate of 0.55°C per decade. For the last 10 years of this period (2011 to 2021), though, the average warming rate increased nearly 15% to 0.63°C per decade (Figure 2-11).

This accelerated warming has been linked to both atmospheric and ocean circulation changes (Chen & He 2015; Chen et al. 2014). Gulf Stream meanders and possible detached eddies, creating warm-core rings, can create significant anomalies in these seasonal temperature means (Andres 2016; Gawarkiewicz et al. 2012). Warming ocean temperatures also increase storm intensity and frequency (Saunders & Lea 2008).

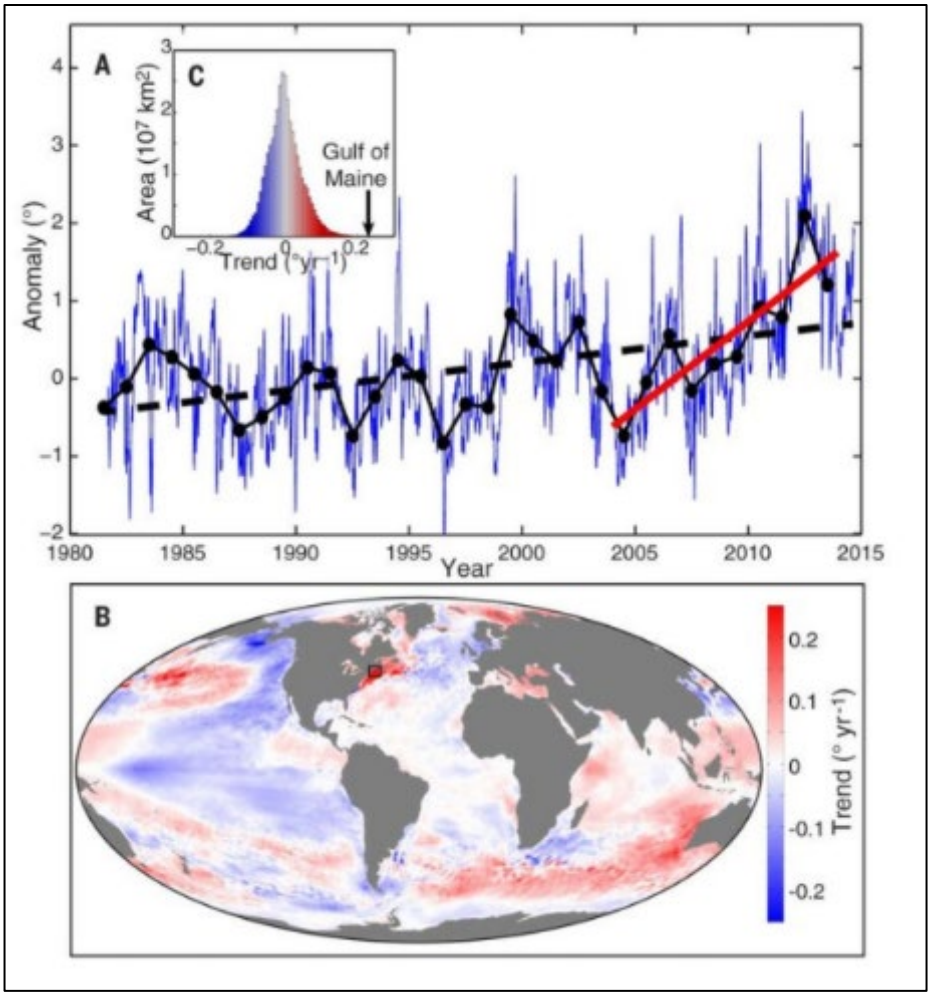

Figure 2-11 Graph of sea surface temperature trends from the Gulf of Maine and the global ocean.

Note: Daily (blue, 15d smoothed) and annual (black dots) sea surface temperature (SST) anomalies from 1982-2013 with the long-term trend (black dashed line) and trend over the last decade (2004-2013) (red solid line). (B) Global SST trends (° per yr.) over the period 2004-2013. The Gulf of Maine is outlined in black. (C) Histogram of global 2004-2013 SST trends with the trend from the Gulf of Maine indicated at the right extreme of distribution. Figure and caption taken from Pershing et al. (2015).

Effects of Climate Change on Ecosystems and Species

Warming weather

As the climate of the Northeastern U.S. continues to warm and winters become shorter and milder, ecosystems and their species are being impacted. Early emergence from winter dormancy, followed by late frosts, stresses trees and other vegetation, and negatively affects fruit production that supports a wide variety of wildlife (Rai et al. 2015). Warmer winters are also contributing to earlier insect emergence and expansion in the geographic range and population size of nuisance tree pests, such as the Hemlock Woolly Adelgid, Emerald Ash Borer, Spotted, Lanternfly and Southern Pine Beetle (Dukes et al. 2009).

Increased drought events

Increased drought events can increase stress on both natural and managed ecosystems and on water supplies in Massachusetts (Frumhoff et al. 2007). Altered freshwater flows into Plum Island Sound, including heavier runoff in early spring and reduced flows in summer could exacerbate water quality problems such as low dissolved oxygen events and harmful algal blooms (Minchinton 2002).

Increased precipitation and frequency and intensity of rain events

Increased precipitation and frequency and intensity of rain events is leading to more flood events. Increases in flood frequency or severity can increase the spread of contaminants into soils and waterways, resulting in increased risks to the health of nearby ecosystems, animals, and people—a set of phenomena well documented following Hurricane Sandy (Erickson et al. 2019). Increased freshwater flows into the Sound will also leave the estuary more susceptible to invasion by non-native plants such as *Phragmites australis* and perennial pepperweed (Minchinton 2002).

Sea level rise and storm surges

Thirty-two percent of open-coast North and Mid-Atlantic beaches are predicted to overwash during an intense future nor'easter type storm, a number that increases to more than 80 percent during a Category 4 hurricane (Dupigny-Giroux et al. 2018). When coupled with storm surges, sea level rise can pose severe risks of flooding.

Because of the diversity of the Northeast's coastal landscape, the impacts from storms and sea level rise will vary at different locations along the coast. Rocky and heavily developed coasts have limited infiltration capacity to absorb these impacts, and thus, these low-elevation areas will become gradually inundated. However, more dynamic environments, such as mainland and barrier beaches, bluffs, and coastal wetlands, have evolved over thousands of years in response to physical drivers. Such responses include erosion, overwashing, flooding and vertical accretion (increasing elevation due to sediment movement), and landward migration over the longer term as sea level rises. Uplands, forests, and agricultural lands can provide transitional areas for these more dynamic settings, wherein the land gradually converts to a tidal marsh. Marshes and beaches serve as the first line of defense for coastal property and infrastructure in the face of storms.

Photo 2-6 Coastal erosion occurring near Plum Island Center, Newbury, MA in April 2013. Credit: Bryan Eato, Newburyport Daily News.

Built infrastructure along the coast, such as seawalls, bulkheads, and revetments, as well as natural barriers, such as coastal bluffs, limit landward erosion; jetties and groins interrupt longshore sediment transport; and culverts and dams create tidal restrictions that can limit habitat suitability for fish communities. An estimated 26 percent of open ocean coast from Maine to Virginia contains engineering structures (Dupigny-Giroux et al. 2018).

Long-term coastal erosion, as driven by sea level rise and storms, is projected to continue, with shorelines eroding inland at rates of at least 3.3 feet (1 m) per year along 30 percent of sandy beaches along the U.S. Atlantic coast (Gutierrez et al. 2014). The eastern tip of Crane Beach in Ipswich has narrowed by 5 feet since the 1950s, a loss of 112 acres. The northern section of Plum Island has lost nearly 300 feet of beach due to storm surge and erosion (TTOR 2020).

Two Plum Island beach studies indicate that there is no westward migration of the barrier island beach (Figure 2-12). The swash line is the upper limit of the active beach that is reached during a normal monthly tide. Annual surveys of the swash line at Parker River found dynamic movement of the shoreline from season to season and year to year (Psuty et al. 2017). Hein et al. (2019) found a similar cyclic erosion and accretion cycle on the north end of Plum Island, recurring on a multi-decadal time period.

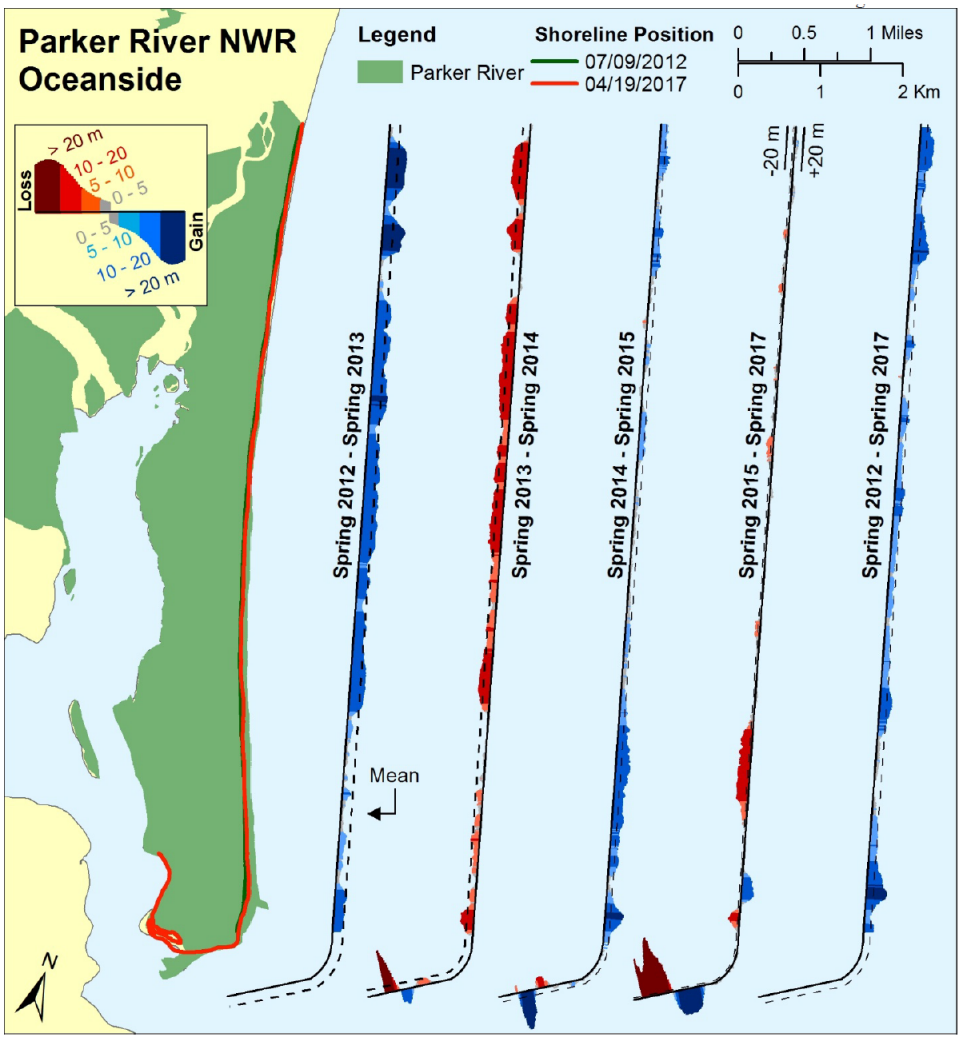

Figure 2-12 Seasonal shoreline change (mean low tide) at Parker River NWR from 2012 to 2017.

Note: Blue indicates accretion, and red indicates erosion.

Coastal habitats such as marshes and beaches may be able to accommodate moderate changes in sea level rise, at least to some extent, by migrating inland or increasing in elevation through accretion. The lands around Parker River NWR provide some of the best opportunities (~1,300 acres) for marshes to migrate inland (Runkle et al. 2022) (Figure 2-13). However, human infrastructure, such as berms, dams and roads may limit the ability of these marshes to migrate.

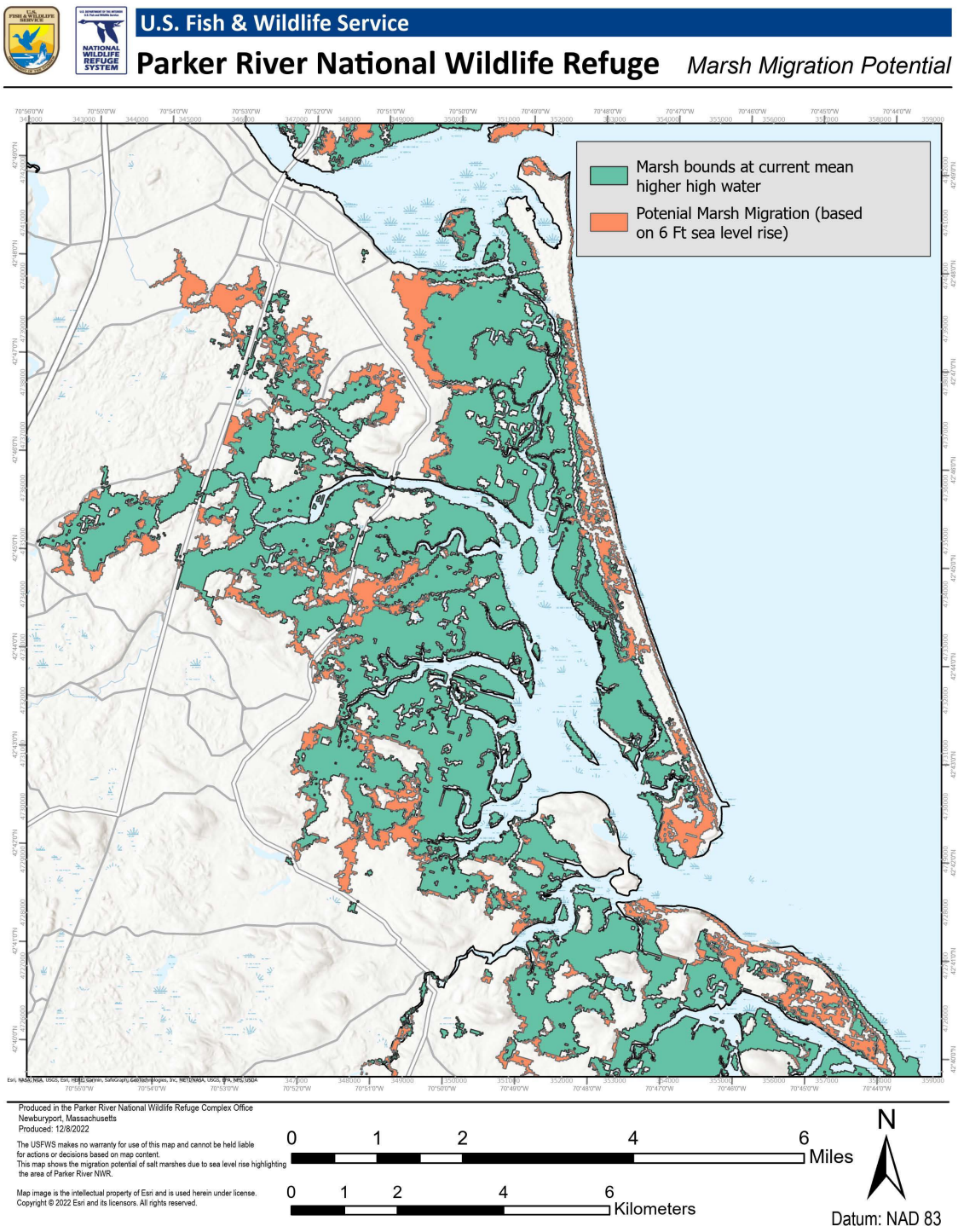

Figure 2-13 Map of existing salt marsh, showing potential future marsh migration. Credit: TNC Coastal Resiliency mapping tool.

Note: The marsh migration potential is based on landforms, and do not consider man-made barriers, like hardened structures, road and train tracks that restrict tidal flow.

Increasing sea level rise is expected to alter the extent and composition of coastal marshes within the refuge. The Plum Island salt marsh sits high on the tidal elevation range, with 82% of the marsh classified as high marsh (flooded once a month) and 10% classified as low marsh (flooded twice daily) in 2011 (Langston et al. 2020). Low marshes accrete two to five times faster than high marshes, driven by higher biomass production (*Spartina alternilfora* growth) and sediment capture (more frequent flooding). Langston's model (2020a) predicts that high marsh will persist in Plum Island Estuary until 2070, when it will rapidly convert to low marsh. Langston's model predicts that as sea level increases, accretion rates in the salt marsh will increase proportionally (7.02 mm per year by 2100), but ultimately not sufficiently to keep up with sea level rise. However, her model does not incorporate the haying infrastructure (embankments and ditches) (Adamowicz et al. 2020), which is impounding water in some areas and causing subsidence in other areas, accelerating the conversion of high marsh to low marsh or open water. Ganju et al. (2020) estimates that the Plum Island Estuary has one of the longest life spans on the East Coast (~1,100 years), due to its high current elevation. The ability of the marsh to keep up with sea level rise is largely dependent on its sediment supply. Human infrastructure, such as roads, dams, and berms may limit natural sources of sediments flowing into the estuary, reducing the ability of salt marshes and beaches to adapt.

Photo 2-7 Example of salt marsh erosion at Plum Island Sound, MA. Credit: Nicoletta Leonardi and Lacopo Carnacina.

Continued sea level rise threatens ecologically important salt marshes and estuaries that serve as breeding habitat for endemic Saltmarsh Sparrows, Clapper Rails, Seaside Sparrows, and Common Terns, migrating and wintering habitat for waterfowl and shorebirds, and nursery habitat for many marine fish species (Erwin et al. 2006). The most severe losses of intertidal habitat for shorebirds are likely to occur where habitats are unable to move inland due to natural or human barriers (Galbraith et al. 2002). This region's narrow, low-profile barrier islands are likely to experience a high degree of storm-induced change, including overwash events and erosion caused by wind and waves. Seavey et al. (2011) predict increasing storms to increase more favorable habitat for coastal species such as nesting Piping Plover, when natural sand movement is allowed to occur. The five-year average of nesting pairs on 6 miles of the refuge beach has increased from 16.6 pairs in 2012 to 43.3 pairs in 2022, seemingly supporting this prediction (Kirkey & Pau 2022).

Climate change is also likely to have an impact on the habitat quality and management of coastal impoundments throughout the Atlantic Coast, including those at Parker River NWR (i.e., North Pool, Bill Forward Pool, and Stage Island Pool). The current elevations of the impoundments are 1 foot to 1.5 feet below their adjacent salt marsh counterparts (Fitzgerald et al. 2017). This elevation deficit will increase and is expected to make drawdowns difficult or infeasible in the future. As the salt marsh bordering the impoundment dikes shrink or flood, the dikes are more vulnerable to breaching in major storms. Such unplanned breaches cause dramatic change in marsh elevation and massive die-off of vegetation and aquatic resources, as documented at Bombay Hook NWR during Hurricane Sandy (Neckles et al. 2019). A more detailed assessment of the Refuge impoundments is described in Chapter 4.

Our management strategies need to be flexible to accommodate any future ecosystem alterations due to climate change. Climate change impacts and ways to address them through management have been considered throughout this HMP and are incorporated into the habitat goals, objectives and strategies outlined in Chapter 4 and Chapter 5.

Increased ocean temperatures

Increased ocean temperatures have been shown to affect some species' abundances, distributions, productivity, and phenology (Dupigny-Giroux et al. 2018). The warming trend is causing some fish and invertebrate species to move northward and to greater depths within the ocean (Pershing et al. 2015). Species such as Atlantic Cod, American Lobster, and Rainbow Smelts are undergoing range shifts towards the north, while more southern species, such as Black Bass, Smooth Hammerhead Shark, Fiddler Crab, Blue Crab, and the invasive Lion Fish are establishing populations in the Gulf of Maine and its estuaries (Dupigny-Giroux et al. 2018; Johnson 2014).

Warming ocean temperatures can affect marine species distributions and disrupt the fisheries industries. Scopel et al. (2019) found sea birds shifted their diets because of warming ocean temperatures in the Gulf of Maine, resulting in poorer productivity of young. Welch (2015) found similar diet shift and lower productivity in tern colonies on offshore islands. These distributional shifts have resulted in communities of marine organisms changing substantially, impacting species interactions and trophic transfer.

Several studies have also noted that the composition and timing of phytoplankton blooms are shifting, and dominant algal species are changing, potentially resulting in bottom-up changes in food web structure (Pershing et al. 2015; Barton et al. 2016; Chivers et al. 2017). Additionally, researchers have also found that warming ocean temperatures have been linked to increased disease incidence and parasite loads in some taxa (Burge et al. 2014; Maynard et al. 2016).

Combined effects

As coastal areas face rising sea levels, storm surges, and temperature changes, human responses to such changes could lead to reduced adaptive capacity of these natural systems. For example, if warmer, drier summers contribute to shortages of water for human consumption, increased withdrawals upstream may reduce available water resources for fish and wildlife. In addition, rising sea levels and more-intense coastal storms may compel coastal property owners to armor their shorelines, which would limit the adaptive capacity of coastal habitats by exacerbating erosion and reducing important sources of sediment that could help in the adaptation of both beach and marsh habitats.

Fitzgerald et al. (2017) suggest that as sea level rise overtakes marsh accretion, leading to lower elevation and smaller marshes, the increasing tidal prism will increase the size of the tidal inlets. These geomorphological processes will increase wave energy in the back barrier, change sediment flux between front barrier and back barrier systems, and may lead to fragmentation of the stable barrier island system. The conceptual model below captures inter-related processes between the front and back barrier, such as sediment movement, shoreline erosion, and tidal exchange (Figure 2-14).

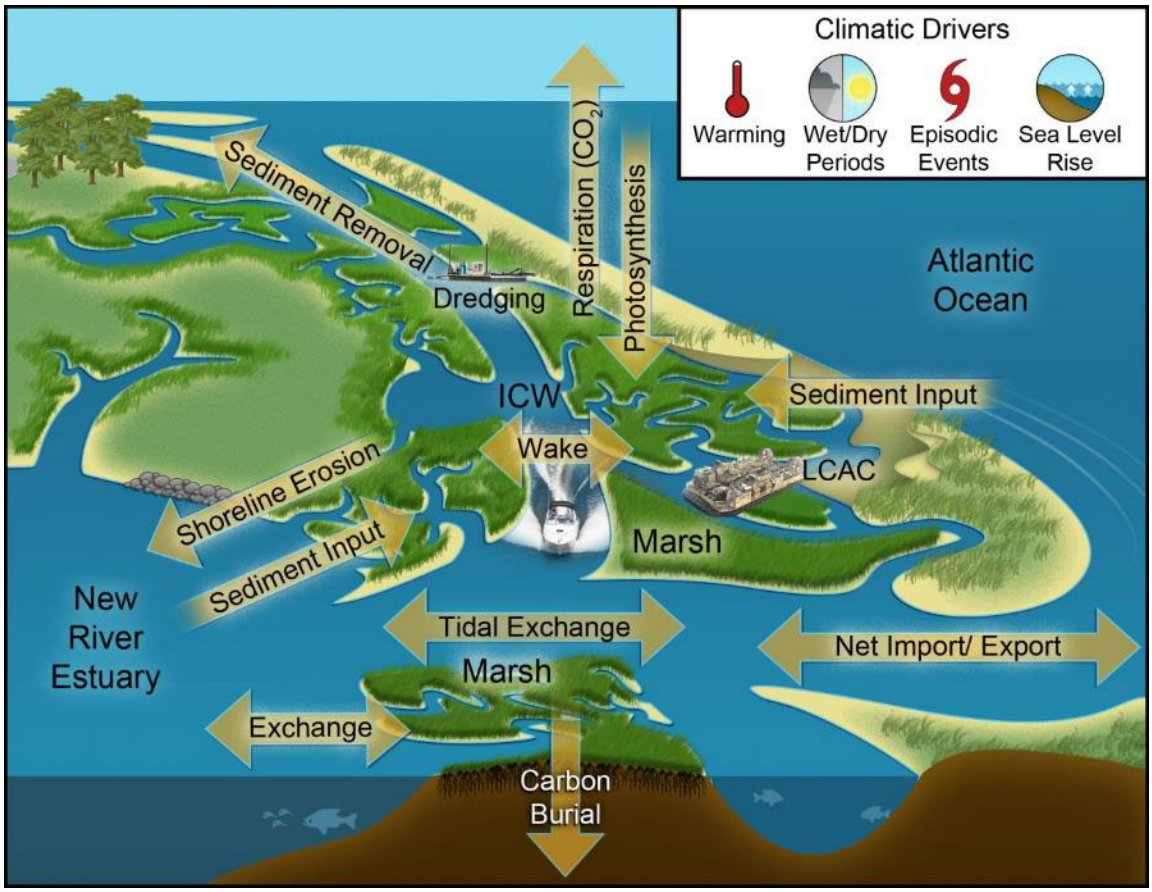

Figure 2-14 Conceptual model of a barrier island developed for Marine Corps Base Camp Lejeune ecosystem. Credit: Christensen (2021).

Chapter 3. RESOURCES OF CONCERN

BIOLOGICAL INTEGRITY, DIVERSITY, AND ENVIRONMENTAL HEALTH

The *Refuge System Improvement Act of 1997* states that, in administering the Refuge System, the Service shall "…ensure that the biological integrity, diversity, and environmental health of the System are maintained".

The Service defines biological integrity, diversity, and environmental health (BIDEH, Service Manual 601 FW3) as:

> ***Biological Diversity*** *- the variety of life and its processes, including the variety of living organisms, the genetic differences between them, and the communities and ecosystems in which they occur*
>
> ***Biological Integrity*** *- biotic composition, structure, and functioning at genetic, organism, and community levels comparable with historic conditions, including the natural biological processes that shape genomes, organisms, and communities*
>
> ***Environmental Health*** *- composition, structure, and functioning of soil, water, air, and other abiotic features comparable with historic conditions, including the natural abiotic processes that shape the environment*

Fulfilling the BIDEH policy requires consideration and protection of a broad suite of native plants and animals, as well as the habitats and ecosystem functions that sustain them. The native wildlife, plants, and habitats found on the Parker River and Thacher Island NWRs serve as the representative elements of BIDEH.

We consulted a variety of sources to assemble a holistic picture of the refuges' historic conditions, current conditions and site capabilities, species distributions, and predicted future conditions. Together, this information provided the basis for cataloging the elements of BIDEH, which are summarized in Tables 3-1 (Parker River) and 3-2 (Thacher Island). We list the major habitats found on the refuge, along with the names of the corresponding Massachusetts Natural Communities and National Vegetation Classification System (NVCS) Associations for each refuge. Each habitat is described by its component plant and animal populations and attributes, and the relevant natural processes and limiting factors and threats.

Table 3-1 Habitat types and associated natural communities that represent BIDEH at Parker River NWR, including attributes, natural processes, and limiting factors.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Rocky Intertidal Shore	Marine Intertidal Gravel / Sand Beach / (S4)	Yellow Tang – Black Tang Tidal Algal Nonvascular Vegetation [CEGL006341]	Occurs within the intertidal zone with a rocky or cobble substrate and is characterized by alternating tidal submergence. Dominated by rockweed, blue mussels, and brown algae. Protected areas of shoreline may include other species such as *Spartina alterniflora*. These are biologically diverse features that support a variety of marine life.	Large boulders and rocks deposited by the last glaciation. Most are edges of eroding drumlins. Subject to daily inundation of salt water and constant pounding by waves.	Shoreline exposed to the ocean receives high energy wave action, causing erosion. Sea level rise will reduce exposure at low tide.
Sandy Beach	Maritime Beach Strand (S3)	Northern Maritime Beach Strand [CEGL006106] North Atlantic Upper Ocean Beach [CEGL004400]	Strand: Sparsely vegetated sandy habitat seaward of the foredune but above the low tide. Vegetative cover is variable and seasonally dynamic. Above the high tide line, vegetation includes annuals and biennials including American beachgrass, sea-rocket, seabeach saltwort, dusty miller, and seabeach orache.	Semi-diurnal tides sustain this habitat. Wind and wave action constantly shift sand within this foredune habitat. Larger storms and Nor'easters transport large sand volumes, and change the shape, slope, width, and elevation of the beach. Generally, the winter season brings erosive forces while the summer season brings sand accretion.	Jetties and groins disrupt the natural processes of erosion and sand deposition. Climate change may influence habitat abundance as the sea level rises and increased storm frequency reshape this habitat with increasing frequency. Human structures such as stairs, overlooks and paths can alter the sand movement.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
			Upper Beach: This upper beach supports nesting habitat for Piping Plover and Least Tern. Expansive sandy beach and strands of wrackline support abundant invertebrate populations and provides vital feeding areas for a variety of shorebirds. Below the high tide line, the beach is composed of unvegetated sand that is flooded twice daily. This intertidal zone supports sand burrowing clams and other invertebrates.		
Dune Grassland	Maritime Dune (S3)	Northern Beach Heather Dune Dwarf-Shrubland [CEGL006143] Northern Beachgrass Dune [CEGL006274]	Beachgrass Dune: This community occurs west of the foredunes. Wind deposited sands are the primary substrate and vegetative composition is variable and patchy; exposed bare sand is common. Much of this habitat is dominated by American beachgrass with associated species of beach pea, dusty miller, seaside goldenrod, and rarely seabeach needlegrass. Heather Dune: Beach heather can form sporadically dominant patches, and where it occurs it will stabilize sands, helping other species to establish in low numbers. Associated species can include coastal jointweed, beach pinweed, bunchgrasses, and seaside sandmat. Reindeer lichen can be found throughout.	Wind and salt spray, especially during large storms, facilitates the movement of sand. Sandy soils, along with exposure to persistent winds and salt spray will limit succession and stunt the growth of many species, particularly woody vegetation. Variations in topography and wind constantly shifts sand, maintaining the sparse vegetation found in this habitat.	Invasive plants such as spotted knapweed and beach rose. Current and future visitor infrastructure can inhibit the free movement of sand, including the westward migration of the dunes across the refuge access road. Visitor trespass causes erosion and vegetation die-offs.

Habitat Type	**Massachusetts (State Rank)***	**NVCS****	**Populations and Habitat Attributes**	**Natural Processes**	**Limiting Factors & Threats**
Sandplain Grassland	Sandplain Grassland (S1)	North Atlantic Coast Backdune Grassland [CEGL006161] Sandplain Grassland [CEGL006067]	This community may intermix with the dune grassland habitat but is usually located in more sheltered areas. Older successional stages of this habitat can include shrubs and stunted trees, comprised of small bayberry, beach plum, and pitch pine. Field sagewort, little bluestem, beach pinweed, Pennsylvania sedge, and reindeer lichen are common. There are multiple robust populations of the State-listed species seabeach needlegrass. This habitat also supports rare and endemic Lepidoptera and other insects.	Dry, nutrient-poor sandy substrate prohibits growth of other species. The stabilized sands where this habitat persists allow for development of graminoid and soil crust communities that differ from the adjoining dune grassland community.	Susceptible to invasion by spotted knapweed, cypress spurge, Morrow's honeysuckle, black locust, Japanese knotweed, and beach rose. Historically, fire has set back succession, allowing sandplain grasslands to expand. Fire suppression has eliminated this mechanism for proliferation, allowing shrubs to encroach.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Interdunal Swale	Interdunal Swale (S2)	Northern Interdunal Shrub Swale [CEGL006339] Northern Interdunal Cranberry Swale [CEGL006141]	Interdunal depressions within the dune system that range from unvegetated freshwater pools to seasonally flooded shrublands. These swales may have a shallow layer of peat overtopping the sandy substrate; vegetation will vary depending on soil and hydrology. Large cranberry tends to dominate this habitat along with various rushes, sedges, clubmoss, and *Sphagnum* species. Shrub dominated swales may include small bayberry, winterberry holly, highbush blueberry, speckled alder, and willow species. Open areas between the shrubs will contain herbaceous species such as Virginia marsh-St. John's-wort and woolgrass. Some of these swales act as vernal pools and support amphibians and reptiles including the State-listed Eastern Spadefoot Toad, and support rare plants (sundews, dragon's mouth) and insects.	Flooding duration varies, and some swales may remain permanently inundated, but the water table always intersects the ground surface for at least part of the growing season. Cranberries and *Sphagnum* moss perpetuate acidic and inundated conditions that impede succession. Infrequent storms that breach the foredune create new swales by eroding sand down to the groundwater.	Swales are susceptible to invasion by *Phragmites*, purple loosestrife, glossy buckthorn, and rusty willow. Well-developed foredunes prohibit breaching thus new swale creation. This may change with an increase in storm intensity predicted with climate change. If breaches do occur, saltwater intrusion in existing swales will likely cause diebacks of the less salt tolerant vegetation. Drought has the potential to reduce the health and extent of swale habitat.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Maritime Shrubland	Maritime Shrubland (S3)	Northern Bayberry Dune Shrubland [CEGL006295] Northern Tall Maritime Shrubland [CEGL006379] North Atlantic Coastal Plain Dune Vine [CEGL003886]	This self-sustaining shrubland occurs in the interface between stabilized dunes and salt marsh on protected slopes and hollows of dry, stabilized maritime backdunes. Dominant species include small bayberry, beach plum, serviceberry, chokeberries, winterberry holly, arrowwood, eastern red cedar, and staghorn sumac. Typical vine associates are greenbrier, Virginia creeper, and poison ivy. The herbaceous layer tends to be sparse and low, particularly where shrub growth is dense, and can include dune grassland or adjacent upland species such as American beachgrass, seaside goldenrod, beach heather, beach pinweed, beach sedge, coast jointweed, annual saltmarsh aster, common yarrow, northern evening primose, Gray's flatsedge, little bluestem, and others. High-stem density associated with this habitat provides important cover for breeding and migratory songbirds and other wildlife. The dominant shrub species are heavy producers of berries, which are a vital food source for fall migrating landbirds.	Development of organic duff layer allows the development of woody vegetation. Infrequent wind and salt spray inhibits succession to tall forest. Groundwater levels vary and have a strong influence on vegetation composition and structure.	Exposure to wind and salt spray prevents expansion of this habitat seaward, and succession to forest limits expansion westward. Depth of freshwater lens is strongly correlated with barrier island and constrains this habitat. Continued invasion by multiple species, including glossy buckthorn, Morrow's honeysuckle, common barberry, and Asiatic bittersweet. Dense invasive understory has probably eliminated wildflower species that are present at several sparser shrub habitats and pitch pine forests on the refuge.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Successional Maritime Forest	Maritime Forest / Woodland (S2)	Northeastern Maritime Forest [CEGL006145] Northern Tall Maritime Scrub Forest [CEGL006379]	In more protected areas, maritime shrubs succeed to tall forest and allow the establishment of tree species such as black cherry, serviceberry, eastern black oak, quaking aspen, and the occasional sassafras and eastern red cedar. Stratification of the understory layers include shrub species such as blueberry, small bayberry, Virginia creeper, and arrowwood. The herbaceous layer includes wild sarsaparilla, Canada mayflower, and false Solomon's seal. In the Hellcat area, the substrate tends to remain saturated for extended periods, especially through the growing season. Red maple and blackgum are the dominant canopy species and often differ from the surrounding upland habitat. The shrub layer contains winterberry holly, highbush blueberry, and others. *Sphagnum* species are a typical component of this system.	Additional protection from wind and salt spray allows the establishment of tree species. Micro-topography and variation in groundwater levels create a mosaic of dry and wet forest patches. The red maple-blackgum swamp is influenced by spring floods and high groundwater. This community probably expanded with the creation of the North Pool, which holds freshwater. If impoundment is removed this community will likely shrink, and there may be some tree die-off.	Tidal flooding from adjacent salt marsh and the amount of salt spray from the ocean limit the expansion of this habitat. Sea-level rise and increased flooding may further restrict this habitat. Habitat is susceptible to already established invasive species such as honeysuckle, glossy buckthorn, common barberry, and black locust.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Dune Pine Forest	Maritime Pitch Pine Woodlands on Dunes (S1)	Pitch Pine Dune Woodland [CEGL006117] Black Pine	The maritime pitch pine woodland community occurs on stabilized backdunes influenced by wind and salt spray. The substrate is dry, acidic, nutrient-poor sand. There is generally a significant cover of bare sand, but where more stabilized, species diversity tends to increase. Pitch pine is the dominant canopy tree, with occasional eastern black oak and eastern red cedar. The shrub layer when present includes beach heather, small bayberry, black huckleberry, or blueberry. Scarce vines include greenbrier, Virginia creeper, and poison ivy. The herbaceous layer is sparse but can include wild sarsaparilla, goldenrod, beach pinweed, bracken fern, starflower, Canada mayflower, crinkled hairgrass, and common bearberry. Densely planted non-native black pines form a second pine community that contains little to no understory. Pitch pine communities support the highest concentration of rare and endangered Lepidoptera in Massachusetts. Forty one percent of state-listed moths and butterflies are associated with these communities, although studies have not yet been done on the refuge.	Storm winds, salt spray, and dry sandy soils maintain this habitat type and reduce species richness. Beginning in the 1950s non-native black pines were planted by refuge staff for erosion control and reforestation after an escaped fire burned through the dunes. The density of plantings prevents the development of an understory layer. Black pines are spreading through the dunes via wind dispersal of seeds.	Invasive black pine and honeysuckle continue to spread and outcompete native species. As the pitch pine community is fire adapted, fire suppression has likely limited the spread of this community. Pitch pines are outcompeted by other shrub and tree species on soils with increased nutrient levels. In the absence of fire, a thick duff layer precludes germination of pitch pine seedlings.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Old Fields	Cultural Grassland (NR)	Northeastern Old-field Meadow [CEGL006107]	This habitat is a remnant of old farm fields and historic refuge management for goose browse. The fields continue to be maintained for wildlife viewing opportunities. Soils support graminoid to shrubby species. Examples include Pennsylvania sedge, fescue species, little bluestem, creeping bentgrass, common timothy, quack grass, Virginia rose, poison ivy, and northern dewberry. Other patchy or scattered species vary by location and include common milkweed and goldenrod.	Annual mowing maintains the short vegetation and prevents succession to maritime shrubs and forest.	As these are not natural habitats, they are limited by refuge management. Due to disturbance, these areas are highly susceptible to invasive species that already occur on or surround the site including glossy buckthorn, Morrow's honeysuckle, Asiatic bittersweet, spotted knapweed, cypress spurge, multiflora rose, black swallowwort, and Canada thistle.
Impoundments	Deep Emergent Marsh (S4)	Eastern Reed Marsh [CEGL004141] Eastern Cattail Marsh [CEGL006153]	Emergent, lacustrine, marsh systems with a mucky substrate; likely covering thick salt marsh peat. Cattail and *Phragmites* form monotypic stands in shallowly flooded brackish to freshwater areas. Other species present in the impoundments include sedges, bulrushes, grasses such as creeping bentgrass, switchgrass, and red fescue, dwarf spikerush, saltmarsh aster, beggarticks, marsh orach, red goosefoot, salt sandspurry, marsh fleabane, fireweed, and others. Aquatic vegetation includes common duckweed and pondweed.	Flooding regime and soil salinity influence vegetation composition. Areas closer to the water control structures have higher salinity levels. Maintaining full-pool conditions early in the growing season slows the spread of cattail and *Phragmites* into shorebird and duck foraging areas. If invasive control is successful, water level drawdowns in May through August expose mudflats, allowing for the germination and growth of short-lived annual plants.	Conflicts with clammers limits draw down ability in Stage Island Pool. Subsidence and rising seas threaten future management capabilities and restoration potential. The altered system creates conditions that promote invasion by non-natives such as *Phragmites* and purple loosestrife. Forging habitat for shorebirds and water is difficult to achieve with existing resources and invasive persistence.

Salt Marsh	Salt Marsh (S3)	North Atlantic Low Salt Marsh [CEGL004192] North Atlantic High Salt Marsh [CEGL006006] Salt panne [CEGL004308] Salt panne pool [CEGL006370] Eastern Tidal Salt Shrubland [CEGL006848] Northern Brackish Meadow [CEGL006368]	Strongly influenced by diurnal tides, this habitat occurs in the protected back barrier between astronomical low and high tides. The plant community is determined by tidal inundation and micro-topography. Low salt marsh is diurnally flooded by tides, occurring between mean high tide and mean sea level. *Spartina alterniflora* forms nearly monotypic stands. Brown algae can form extensive mats at the bases of the grass. High salt marsh occupies the irregularly flooded zone extending from mean high tide landward to the limit of spring tides. Vegetation is typically dominated by *Spartina patens*, with patches dominated by spikegrass and black grass. Other characteristic associates that occur in low abundance include saltmarsh aster, sea lavender, seaside goldenrod, bushy knotweed, silverweed, marsh orach, sea milkwort, seaside plantain, northern seaside arrow-grass, and seaside gerardia. Prominent within the high marsh are salt pannes and pools, which are characterized by poor drainage creating hypersaline conditions. Salt pannes are very shallow depressions dominated by glasswort and short-form *S. alterniflora*. Bare peat and/or mucky soils are prevalent with a variable vegetative cover, ranging from near total absence to a dense cover. Micro-algal mat	Soil salinity levels and fluctuating hydroperiod limits marsh system to halophilic (salt tolerant) species. Tidal flooding dictates the extent and type of salt marsh habitat. The low marsh is dominated by *S. alterniflora* due to its ability to withstand longer submergence compared to other salt marsh grasses. It is outcompeted by *S. patens* in the higher marsh, which sees less flooding from daily tides. Formation of salt pannes and pools may result from ice-scouring, rafting flotsam, peat compaction, mosquito ditch levees, or lack of sedimentation associated with distance to creek. Salt panne depressions and salt pools are regularly to irregularly flooded by high tides. Some pools or pannes are legacies of deteriorating embankments and ditches from the salt hay era, holding water on the marsh surface and causing vegetation dieback or conversion to *S. alterniflora*.	Marsh migration is constrained by steep changes in topography further inland. Some marsh migration is possible both westwards and eastwards from the refuge marsh in some areas. Human infrastructure, such as roads, culverts, dams, and sea walls, that restrict tidal flooding and sediment flow significantly impede marsh accretion potential. Extensive ditches and embankments have replaced the natural creek hydrology in many of these marshes. Subsequent abandonment and clogging of these ditches and the embankments have caused impounding of flood waters on the marsh, accelerating conversion to *S. alterniflora* marsh, and creation of open water and mudflats. Many of these densely ditched marshes have subsided artificially, creating high marshes at lower elevations. Expansion of the invasive perennial pepperweed and *Phragmites* threaten the ability of the marsh to adapt to rapidly changing conditions.

Habitat Type	Massachusetts (State Rank)*	NVCS**	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
			communities are common and diverse. Salt pools are deeper than pannes, remaining permanently or semi permanently flooded. Vegetation is characterized by aquatic widgeongrass. Pools provide habitat for "marsh minnows" including Mummichog and sticklebacks. Two communities lie between the high salt marsh and the upland. The northern brackish meadow occurs as a narrow band where the marsh is irregularly flooded by spring tides and storm surges. This allows for the colonization by oligohaline or mesohaline vegetation, including creeping bentgrass, New York aster, red fescue, prairie cordgrass, and salt marsh bulrush in addition to high marsh plants.		

*Note: *Natural Communities of Massachusetts. Swain (2020); State Rank: Ranking reflects the community's rarity and threat within Massachusetts.*

- *S1 = Critically imperiled in the state due to extreme rarity. Typically, 5 or fewer occurrences, very few remaining acres or miles of stream, or especially vulnerable to extirpation in Massachusetts for other reasons.*
- *S2 = Imperiled in the state due to rarity. Typically, 6-20 occurrences, very restricted range, few remaining acres, or miles of stream, or very vulnerable to extirpation in Massachusetts for other reasons.*
- *S3 = Vulnerable in the state due to a restricted range, relatively few occurrences (typically 21-100), limited acreage or miles of stream, recent and widespread declines, or vulnerable to extirpation in Massachusetts for other reasons.*
- *S4 = Apparently secure in Massachusetts. Uncommon, but not rare.*
- *S5 = Demonstrably secure in Massachusetts. Common, widespread, and abundant.*
- *SU = Status unknown in Massachusetts.*
- *SNR = Status not ranked in Massachusetts.*

***National Vegetation Classification System (Associations), available via NatureServe Explorer (NatureServe 2020).*

Table 3-2 Habitat types and associated natural communities that represent BIDEH at Thacher Island NWR, including attributes, natural processes, and limiting factors.

Habitat Type	*Massachusetts 2020 (State Rank)	**NVCS	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Rocky Intertidal Shore	Marine Intertidal Rocky Shore	Yellow Tang – Black Tang Tidal Algal Nonvascular Vegetation [CEGL006341]	Occur on ocean shores between the high tide splash zone and the subtidal limits of light penetration. Intertidal communities consist of non-vascular plants and invertebrates. Marine brown algae (seaweed), especially bladder wrack and rockweed, dominate. Sea-lettuce, a green alga, is common throughout. Irish moss, a red alga, is common in tide pools.	Occurring on high-stress environment along exposed ocean shores, this community is alternately covered by tides and exposed to desiccation and thermal stress.	Shoreline exposed to the ocean receives high energy wave action. Sea level rise will reduce exposure at low tide.

Habitat Type	*Massachusetts 2020 (State Rank)	**NVCS	Populations and Habitat Attributes	Natural Processes	Limiting Factors & Threats
Maritime Shrubland	Maritime Shrubland (S3)	Northern Bayberry Dune Shrubland [CEGL006295] Northern Tall Maritime Shrubland [CEGL006379]	Occur along the coast within direct influence of the ocean and salt spray, such as on barrier beach dunes, next to tidal marshes or on bluffs or rocky headlands. Dominant species include small bayberry, beach plum, serviceberry, chokeberries, winterberry holly, arrowwood, eastern red cedar, and staghorn sumac. Typical vine associates are greenbrier, Virginia creeper, and poison ivy. The herbaceous layer tends to be sparse and low, particularly where shrub growth is dense. High stem density associated with this habitat provides important cover for breeding and migratory songbirds and other wildlife. The dominant shrub species are heavy producers of berries, which are a vital food source for fall migrating landbirds.	Development of organic duff layer allows the development of woody vegetation. Infrequent wind and salt spray inhibits succession to tall forest. Groundwater levels vary and have a strong influence on vegetation composition and structure.	Exposure to wind and salt spray prevents the succession to forest. Depth of freshwater lens may constrain this habitat. Continued invasion by multiple species, including glossy buckthorn, Morrow's honeysuckle, common barberry, and Asiatic bittersweet.

*Note: *Natural Communities of Massachusetts. Swain (2020); State Rank: Ranking reflects the community's rarity and threat within Massachusetts.*

- *S1 = Critically imperiled in the state due to extreme rarity. Typically, 5 or fewer occurrences, very few remaining acres or miles of stream, or especially vulnerable to extirpation in Massachusetts for other reasons.*
- *S2 = Imperiled in the state due to rarity. Typically, 6-20 occurrences, very restricted range, few remaining acres, or miles of stream, or very vulnerable to extirpation in Massachusetts for other reasons.*
- *S3 = Vulnerable in the state due to a restricted range, relatively few occurrences (typically 21-100), limited acreage or miles of stream, recent and widespread declines, or vulnerable to extirpation in Massachusetts for other reasons.*
- *S4 = Apparently secure in Massachusetts. Uncommon, but not rare.*
- *S5 = Demonstrably secure in Massachusetts. Common, widespread, and abundant.*
- *SU = Status unknown in Massachusetts.*
- *SNR = Status not ranked in Massachusetts.*

***National Vegetation Classification System (Associations), available via NatureServe Explorer (NatureServe 2020).*

POLICY AND DEFINITIONS

Congress entrusts the Service to conserve the entire suite of biodiversity and natural processes occurring within the refuge system. In addition, there is direction to protect migratory birds, federally listed threatened and endangered species, inter-jurisdictional fishes, and certain marine mammals. Further, each refuge has one or more purposes for which it was established; these purposes guide its management goals and objectives. These species are collectively known as Resources of Concern.

Resources of Concern are a central aspect of an HMP. The HMP policy (620 FW 1) defines Resources of Concern as:

> *All plant and/or animal species, species groups, or communities specifically identified in refuge purpose(s), System mission, or international, national, regional, state, or ecosystem conservation plans or acts. For example, waterfowl and shorebirds are a resource of concern on a refuge whose purpose is to protect "migrating waterfowl and shorebirds." Federal or State threatened and endangered species on that same refuge are also a resource of concern under terms of the respective endangered species acts."*

Because the development of Resources of Concern is a highly effective way to prioritize the species and habitats of greatest management concern, they are a focus of this HMP. Identifying Resources of Concern allows us to identify management units and refuge-wide objectives aimed at maintaining, increasing, and/or improving the habitats required by the species or habitats identified in the refuges' purpose. Concurrent with the Inventory and Monitoring Plan (IMP) process, the Resources of Concern selection process facilitates a targeted approach to identify priority areas and gaps in management that may require additional resources, such as information (data collection and monitoring) or staff and equipment. Resources respond to habitat management differently; identifying Resources of Concern allows us to focus management activities at the level that yields the greatest benefit to trust resources, maintains biological diversity, integrity, and environmental health, and fulfills the refuge purposes.

What follows is a description of the process that Parker River and Thacher Island refuge staff used to identify priority Resources of Concern and develop habitat goals, objectives, and strategies to benefit these species.

RESOURCES OF CONCERN

From an operational standpoint, a large, diverse refuge requires managers to set priorities. The priority habitats and representative species that focus management effort are referred to as Priority Resources of Concern (ROCs).

The Priority ROC Selection Tool was employed to prioritize the comprehensive list of species and arrive at the priority ROCs for Parker River and Thacher Island (Casey et al. 2021). The Selection Tool considers several criteria such as the priorities set by federal and state agencies as well as taxa-specific working groups (e.g., Atlantic Flyway Shorebird Initiative). The species and species groups that received the highest scores on the following criteria in the Selection Tool were selected as priority ROCs:

- Species/species groups that are most in need of help (High Conservation Priority in Regional or National Conservation Plans or Initiatives)
- Species whose individuals are reliant on refuge resources
- Species whose individual fitness is likely to benefit from habitat management efforts
- Species whose fitness is strongly associated with overall ecosystem health

The priority ROCs for Parker River and Thacher Island NWRs represent a broad array of habitats and a suite of other species that will also benefit from the management of key habitats (Table 3-3 and Table 3-4).

Table 3-3 Priority Resources of Concern for Parker River NWR.

Proposed Habitat Objective Name	Priority Resources of Concern	Habitat Requirements	Life History Requirement	Other Benefitting Species
1.1 Beach and Rocky Shore	Piping Plover	Nest above the high tide line on open sand, gravel, or shell-covered beaches, especially on sand spits and blowout areas in the dunes. Forages in the intertidal zone, sand flats, along pool edges or the wrack line. Diet: invertebrates such as polychaete worms, fly larvae, beetles, crustaceans, and mollusks.	Breeding, Migrating	Least tern; Migrating shorebirds (e.g., Sanderling, Black-bellied Plover, Ruddy Turnstone, Red Knot)
1.1 Beach and Rocky Shore	Semipalmated Sandpiper	Uses sandy beaches, foraging in intertidal zones and in wrack. Roosts on upper beach and wrackline in the hundreds. Diet: amphipods, small crustaceans, polychaete worms, small mollusks, and other insects.	Migrating	Least tern; Migrating shorebirds (e.g., Sanderling, Black-bellied Plover, Ruddy Turnstone, Red Knot)
1.2 Dune Grassland, Sandplain Grassland, Interdunal Swales	Eastern Spadefoot Toad	Breeds in vernal pools; rest of year in sandy or loose soils in sparse shrub or tree growth and sparse leaf litter; nocturnal; fossorial. Diet: Adults–a wide variety of arthropods, earthworms, snails, and small vertebrates. Larvae–phytoplankton, zooplankton, periphyton, dead plants and animals (e.g., earthworms, tadpoles), and anuran eggs.	Breeding	Ipswich Savannah Sparrow; migrating and wintering raptors (e.g., Northern Harrier, American Kestrel, Merlin, and Peregrine Falcon); rare beetles; breeding amphibians; rare plants (e.g., seabeach needlegrass)
1.2 Dune Grassland, Sandplain Grassland, Interdunal Swales	Rare Lepidoptera (e.g., Sandplain Euchlaena, Dune Noctuid Moth, Coastal Heathlands Cutworm)	Inhabit open coastal habitats, including sandplain grasslands, dune grasslands, and heathlands. Moth flight period from late May through August. Diet: larval host plants are undocumented, although low growing shrubs such as blueberry and shadbush are suspected.	Year Round	Ipswich Savannah Sparrow; migrating and wintering raptors (e.g., Northern Harrier, American Kestrel, Merlin, and Peregrine Falcon); rare beetles; breeding amphibians; rare plants (e.g., seabeach needlegrass)

Proposed Habitat Objective Name	Priority Resources of Concern	Habitat Requirements	Life History Requirement	Other Benefitting Species
1.3 Maritime Shrubland and Maritime Forest	Eastern Towhee	Dense, brushy dry areas, pitch pine-scrub oak forests; nests on or near ground in well-developed litter layer. Diet: insects and fruit.	Breeding, Migrating	Shrub-nesting songbirds (e.g., Willow Flycatcher, Blue-winged Warbler); migrating songbirds; New England Cottontail; migrating tree bats (e.g., Hoary and Silver-haired Bats).
1.3 Maritime Shrubland and Maritime Forest	Brown Thrasher	Dry thickets, brushy areas, forest edges; Low, dense, woody vegetation. Diet: insects, fruit, and seeds.	Breeding, Migrating	Shrub-nesting songbirds; American Woodcock; migrating songbirds; New England Cottontail
1.3 Maritime Shrubland and Maritime Forest	Eastern Red Bat	Migrants use coastal sites in the fall when performing long-distance migrations. Often feeds among forest trees and in open areas adjacent to forests and can migrate along barrier island on the East Coast during fall. Breeding has been documented at Parker River NWR. Diet: insects.	Breeding, Migration	Tree nesting songbirds (e.g., Eastern Kingbird, Baltimore Oriole); New England Cottontail; migrating songbirds; migrating tree bats (e.g., Hoary and Silver-haired bats).
1.4 Dune Pine Forest	Eastern Whip-poor-will	Prefers dry deciduous or mixed (evergreen-deciduous) forests with little or no understory growth, near open areas. Avoids large, uninterrupted forest with dense canopy. Diet: insects.	Breeding	Rare Lepidoptera
2.1 Old Fields	Bobolink	Requires a minimum of 5-10 acres; nests in mixed grass (8- 12”) fields with tall forbs and scattered shrubs; nest placed on the ground often at the base of large forbs. Diet: insects, spiders, and seeds.	Breeding, Migrating	American Woodcock, Northern Harrier, Short-eared Owl, Whimbrel, Savannah Sparrow.

Proposed Habitat Objective Name	Priority Resources of Concern	Habitat Requirements	Life History Requirement	Other Benefitting Species
2.1 Old Fields	Pollinators (e.g., Monarch butterfly, native bees)	Nectar sources are vital to Monarchs during fall migration, providing carbohydrates to fuel flight and to convert to the lipid reserves that support individuals during the winter. Important nectar plants include goldenrods, climbing hempweed, smooth bur-marigold, groundsel-tree, and horsemint. Critical night-roosting sites are in thickets of northern bayberry, groundsel-tree, and eastern red cedar. The larval stage of Monarchs is exclusive to milkweed plants. Native bees use a wide variety of flowering plants.	Breeding, Migrating, Wintering	American Woodcock, Northern Harrier, Short-eared Owl, Whimbrel, Savannah Sparrow.
2.2 Impoundments	Migrating shorebirds (e.g., Semipalmated Sandpiper, Red Knot, Black-bellied Plover)	Shallow (< 15 cm water depth) to mudflat habitat with sparse to no vegetation (<15% cover), at the time of peak shorebird migration (late May and mid-August).	Migrating	Foraging areas for breeding waterfowl (e.g., Gadwall, Mallard, Canada Goose), secretive marsh birds (e.g., Virginia Rail, American Bittern, Least Bittern), Marsh Wren.
2.2 Impoundments	Migrating waterfowl (e.g., American Black Duck, Northern Pintail, Green-winged Teal)	Shallow flooded (< 12" water depth) seed producing moist soil vegetation *(Cyperus, Echinochloa, Polygonum, Bidens*) during peak migration (late Oct). Diet: seeds, roots, tubers, stems, aquatic invertebrates, mollusks, crustaceans, small fish.	Migrating	Foraging areas for breeding waterfowl (e.g., Gadwall, Mallard, Canada Goose), secretive marsh birds (e.g., Virginia Rail, American Bittern, Least Bittern), Marsh Wren.

Proposed Habitat Objective Name	Priority Resources of Concern	Habitat Requirements	Life History Requirement	Other Benefitting Species
2.3 Salt Marsh	Saltmarsh Sparrow	Restricted to tidal salt marshes throughout the year. For nesting, they generally prefer higher-elevation, drier portions farthest removed from the reach of the tide. Nests are built just above the ground in *S. patens*, short-form *S. alterniflora,* saltmarsh rush, or saltgrass. Prefers dense vegetation cover (> 100%), with thatch layer. Diet: opportunistic-- insects, amphipods, spiders.	Breeding, Migrating	Nesting birds (e.g., Nelson's Sparrow, Seaside Sparrow, Black Rail, Clapper Rail, Willet); migrating shorebirds (e.g., Greater Yellowlegs, Short-billed Dowitcher, Least Sandpiper); foraging wading birds (e.g., Snowy Egret, Glossy Ibis); migrating and wintering raptors (e.g., Northern Harrier, Snowy and Short-eared Owls, Bald Eagle, Peregrine Falcon).
2.3 Salt Marsh	American Black Duck	Uses marshes for nesting, brooding, and molting. Open water and emergent vegetation are important for migration and wintering. In New England, uses tidal habitats exclusively in winter. Dabbles for food at surface and tips in shallow waters. Diet: seeds, roots, tubers, stems, aquatic invertebrates, mollusks, crustaceans, small fish.	Breeding, Migrating, Wintering	Nesting birds (e.g., Nelson's Sparrow, Seaside Sparrow, Black Rail, Clapper Rail, Willet); migrating shorebirds (e.g., Greater Yellowlegs, Short-billed Dowitcher, Least Sandpiper); foraging wading birds (e.g., Snowy Egret, Glossy Ibis); migrating and wintering raptors (e.g., Northern Harrier, Snowy and Short-eared Owls, Bald Eagle, Peregrine Falcon).

Table 3-4 Priority Resources of Concern for Thacher Island NWR.

Proposed Habitat Objective Name	Priority Resources of Concern	Habitat Requirements	Life History Requirement	Other Benefitting Species
3.1 Rocky Intertidal Shore	Roseate Tern (currently absent)	Colonial nester, almost exclusively on islands. Nest typically sheltered by tall, rank vegetation or structure (<30% visibility from above). May nest under debris or rocks. Diet: primarily American Sand Lance.	Breeding, Migrating	Common and Arctic Terns; Common Eider

Proposed Habitat Objective Name	Priority Resources of Concern	Habitat Requirements	Life History Requirement	Other Benefitting Species
3.1 Rocky Intertidal Shore	American Oystercatcher	Nests are primarily on sand and shell beaches, dunes, salt marsh, and occasionally rock or other surfaces. Typical nests are placed in areas with little to no vegetation well above mean high water. Diet: Bivalves, mollusks, crustaceans, worms, and other marine invertebrates that inhabit intertidal areas.	Breeding	Common and Arctic Terns; Common Eider
3.2 Maritime Shrubland	New England Cottontail (extirpated)	Live in dense areas of shrubs and young forests, which are necessary for predator avoidance. Winter survival requires a stem density of more than 20,234 stems per acre. Diet: herbaceous plants in summer; bark, twigs, and buds of woody plants in winter.	Breeding	Willow Flycatcher; Eastern Kingbird; migrating songbirds

PRIORITY HABITATS

With a limited budget and staff time, the refuge also needed to prioritize the habitats for planning and management purposes. Each habitat was classified as a Priority I or Priority II habitat on the Parker River (Table 3-5) and Thacher Island (Table 3-6) NWRs. Priority 1 habitats are either:

- sufficient in extent and/or quality to contribute to the refuge's highest priority ROCs, or
- are experiencing a high threat or urgent need for management to support the refuge's highest priority ROCs (Casey et al. 2021)

Table 3-5 Priority habitats for Parker River NWR.

Habitat Objective Name	**Priority Level**	**Reasons for Ranking**	**Limiting Factors and Threats**	**Management Needs**
1.1 Beach and Rocky Shore	I	Presence of nesting federally listed species; Importance to fall migrating shorebirds including highest priority species in BCR 30; Active management results in positive, measurable impact on trust resources.	Human disturbance. Climate change (sea-level rise, increased storm intensity). Erosion. Jetties, groins, dredging, beach nourishment.	Limit human-caused erosion. Work with towns to decrease impacts from human-made structures and sediment augmentation projects. Allow for dynamic movement of habitat spatially.
2.3 Salt marsh	I	Salt marsh habitat is limited within the northeast; high potential for greatest refuge contribution; presence of several highest priority birds in BCR 30 (Saltmarsh Sparrow, Seaside Sparrow, and Am. Black Duck); At 2,660 acres, it is the largest habitat type on the refuge and part of Great Marsh, the largest contiguous salt marsh north of Long Island.	Historic human alterations impacting natural hydrology. Impediments to sediment input and transport. Invasive species. Climate resiliency from sea level rise and increased inundation. Mercury contamination. Human disturbance.	Invasive plant management. Management to restore natural hydrology and sediment transport. Monitor ecosystem process changes in response to climate stressors. Monitor habitat suitability changes for species of concern.

Habitat Objective Name	Priority Level	Reasons for Ranking	Limiting Factors and Threats	Management Needs
1.2 Dune Grassland, Sandplain Grassland, Interdunal Swales	II	Sandplain Grasslands and Interdunal Swales are both rare (S1) natural communities in Massachusetts and host locally rare plants. Sandplain Grasslands support rare moths and beetles, and Interdunal Swales host vernal pool species. The extent of these habitats is limited on the refuge, while management of these, along with Dune Grasslands, is very limited.	Climate change (sea-level rise, increased storm intensity). Human disturbance/recreation. Invasive species. Succession. Requires periodic disturbance.	Limit recreational access. Allow natural processes to reset succession and create new habitat. Invasive plant management. Fire or mowing to reduce encroachment from shrubs.
1.3 Maritime Shrubland and Maritime forest	II	Many high priority bird species in BCR 30 in this habitat; potential habitat for New England Cottontail; important for fall migrating songbirds; requires little management.	Saltwater impacts from salt marsh and salt spray. Invasive plants.	Invasive plant management. Explore the role of prescribed fire in controlling invasive and promoting native plant regeneration.
1.4 Dune Pine Forest	II	Supports uncommon plant species, but the refuge contains only a small portion of this community type, scattered throughout the dunes. Much of this habitat is dominated by non-native black pine, which was planted by the refuge in the 1970s.	Lack of disturbance (i.e., fire). Invasive plants.	Invasive plant management (e.g., remove black pine). Prescribed fire.

Habitat Objective Name	Priority Level	Reasons for Ranking	Limiting Factors and Threats	Management Needs
2.1 Old Fields	II	Cultural habitat type that supports nesting Bobolinks, Monarchs, and other pollinating insects, foraging raptors, and migrating birds; managed mainly for wildlife viewing opportunities. Field sizes are too small to support many BCR 30 high priority species.	Requires regular mowing or other management to deter succession to woody vegetation. Invasive plants.	Annual mowing, burning, or grazing. Invasive plant management
2.2 Impoundments	II	Supports breeding wading and marsh birds, breeding and migrating waterfowl, and migrating shorebirds in BCR 30. Many species of waterfowl and shorebirds would benefit from the conversion of this habitat to salt marsh. Restoration to salt marsh would also benefit BCR 30 species of highest priority, including the Saltmarsh Sparrow.	Requires intensive management and maintenance. Invasive plants. Subsidence. Sea level rise and increased storm intensity threaten the integrity of the impoundment, increasing the chances of a catastrophic failure. Water quality issues (e.g., anerobic conditions). Restoration to salt marsh would create a healthier, resilient habitat with reduced management needs.	Manage water levels. Maintain water control structure (WCS) and dike. Invasive plant management. Monitor changing processes (accretion rates, dike vulnerability, WCS capability) and plan to restore prior to vulnerability threshold. Develop detailed restoration design.

Table 3-6 Priority habitats for Thacher Island NWR.

Habitat Objective Name	Priority Level	Reasons for Ranking	Limiting Factors and Threats	Management Needs
3.1 Rocky Intertidal Shore	II	Historically supported large colony of Common, Arctic, and Roseate terns. Nesting habitat for American Oystercatcher.	Human disturbance. Expanding Great Black-Backed and Herring Gull populations.	Gull population management.

Habitat Objective Name	Priority Level	Reasons for Ranking	Limiting Factors and Threats	Management Needs
3.2 Maritime Shrubland	II	Potential habitat for New England Cottontail breeding colony; important for fall migrating songbirds; requires little management.	Saltwater impacts from salt spray. Invasive plants.	Invasive plant management.

Chapter 4. HABITAT GOALS AND OBJECTIVES

This chapter's intent is to describe the habitat management direction for the refuge, and to provide links between habitat objectives and the refuge's priority ROCs (see Chapter 3) that are expected to benefit from management. Further, it outlines specific objectives for each habitat type, which will guide refuge staff to create conditions needed by the ROCs.

CREATING HABITAT GOALS

The planning team developed habitat management goals that are intentionally broad, descriptive statements of purpose, with greater specificity deferred to the objectives. The Goals and Objectives are organized by the barrier island ecosystem setting: front barrier and back barrier. In general, front barrier habitats are more exposed to ocean forces (wind spray, storms), and plant community succession is limited by these forces. Habitats included in front barrier ecosystems include beach, dunes, maritime shrublands and forests, interdunal swales and dune grasslands. Back barrier ecosystems are not directly exposed to ocean forces but are influenced by tidal hydrology and dune roll-over events. Habitats included in the back barrier ecosystems include fields, impoundments, and salt marsh. In general, the refuge road, which runs between the maritime shrubs and the salt marsh, separates the front barrier and back barrier ecosystems.

> **Goal 1. Front Barrier Ecosystems** – Protect, enhance, and restore the BIDEH of Parker River NWR's front barrier beach habitats to support native wildlife and plant communities, including species of conservation concern.
>
> **Goal 2. Back Barrier Ecosystems** – Protect, enhance, and restore the BIDEH of Parker River NWR's back barrier habitats to support native wildlife and plant communities, including species of conservation concern.
>
> **Goal 3. Rocky Shore and Shrubland** – Perpetuate the BIDEH of coastal habitat on Thacher Island NWR to sustain native wildlife and plant communities, including species of conservation concern.

DEVELOPING SMART OBJECTIVES

Nested under these goals, we developed objectives and strategies for each of the ecosystems present throughout the refuge.

The refuge's priority ROCs were used to develop a set of biological goals and objectives for each habitat type. In addition, five fundamental management objectives are defined for each habitat where they apply. The fundamental objectives are:

- Sustain the habitat or ecosystem and natural processes over time.
- Support migratory bird populations.
- Support recovery of federally threatened and endangered species.
- Support refuge priority ROCs.
- Maintain BIDEH.

Each objective is described by a set of SMART (Specific, Measurable, Attainable, Results oriented and Time-fixed) attributes that provide clarity about the desired future conditions for the respective objective (Powell & Casey 2019; USFWS 2021b). Each attribute has a measurement unit (e.g., 4 miles of beach) and a direction of preference (more, less, or within a range), which then guide the development and selection of management strategies (chapter 5) and monitoring tools (Inventory and Monitoring Plan). The objective statements describe what the refuge hopes to achieve and are 'aspirational' (i.e., they represent the desired future condition of the habitats, not necessarily what they look like today).

Each objective begins with a set of *desired conditions* that will sustain the ecosystem and natural processes over time and help meet the other fundamental objectives.

SMART objectives facilitate the development of habitat work plans that direct specific management activities, including adaptive management strategies for the year. The format of the habitat goals and SMART objectives is standardized across all national wildlife refuges, which provides consistency when identifying future inventory and monitoring needs.

We use the terms habitat, natural community, plant association, ecosystem, and natural process to describe different levels of ecological complexity or condition, defined as follows:

- National Vegetation Classification (NVCS) Association – NatureServe Explorer (2020) references the NVCS as a standardized hierarchical system to provide a common language for the management and conservation of plant communities. The most fine-grained level is the Association, based on the diagnostic or dominant species and composition reflecting local environmental factors.
- Natural Community – a recurring assemblage of species found in specific physical environments. Most states, including Massachusetts, have created a classification of natural communities (Swain 2020), which are analogous to the NVCS Association.
- Habitat – a set of environmental conditions (abiotic, biotic, ecological interactions) that an organism needs to survive throughout its life processes, often described as food, water, cover, and space. We crosswalk habitat types with the Massachusetts natural community classifications and the NVCS Associations (see Chapter 3).
- Ecosystem – a community of organisms interacting with the physical environment. An ecosystem can be an assemblage of habitats or natural communities, or a given habitat may be considered an ecosystem. At times, the term is used interchangeably with habitat.
- Natural Processes – a complex mix of interactions among plants, animals, and their environment that contributes to the maintenance of an ecosystem's full range of biodiversity. Examples include succession, predator-prey interactions, nutrient cycling, and shifting beach extent.

Figures 4-1 and 4-2 show the desired future conditions for Parker River and Thacher Island NWR management units. In the case of Thacher Island, the desired condition is for the current habitat to remain the same. For more detailed maps of specific habitat types and management units, refer to the maps in sections 1.1 to 3.2.

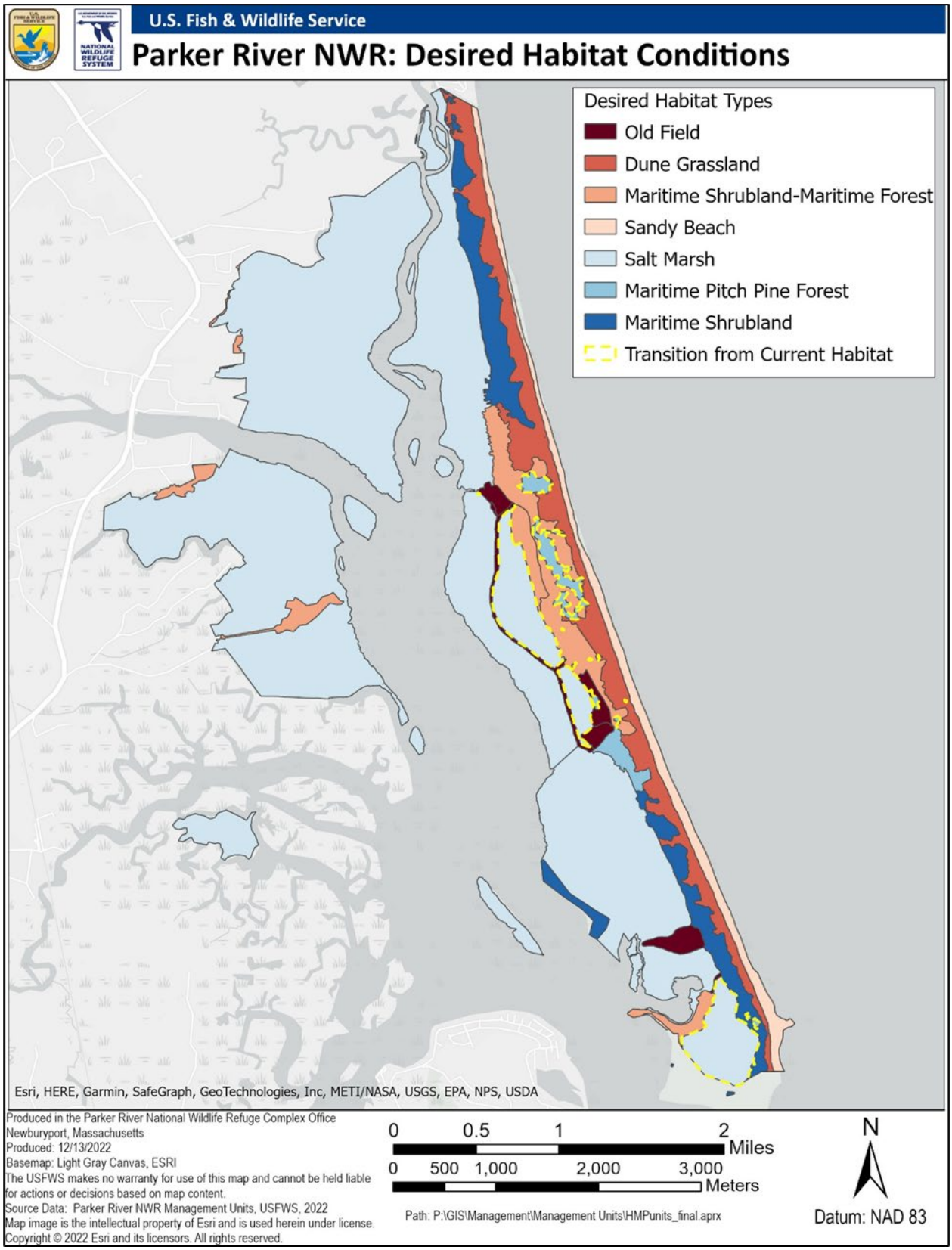

Figure 4-1 Desired future habitat conditions for management units at Parker River NWR.

Figure 4-2 Current and future habitat conditions at Thacher Island NWR.

GOALS AND OBJECTIVES

Goal 1—Parker River NWR: Front Barrier Ecosystems

Protect, enhance, and restore the BIDEH of Parker River NWR's front barrier ecosystem to support native wildlife and plant communities, including species of conservation concern.

Objective 1.1 Beach and Rocky Shore

Manage 6.7[1] miles of beach and rocky shore habitat on Parker River NWR by maintaining the natural processes (e.g., total extent, geomorphic stability, and transgression) over time, to support migratory shorebird populations (Semipalmated Sandpiper), restore populations of federal threatened and endangered species (e.g., Piping Plover, Red Knot), and maintain native (e.g., eradicate invasive species), with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- A range of intact dynamic geomorphic settings, including foredunes, dune slopes, upper beach, wrack, intertidal zones, and washovers.
- Maintain a minimum of 4 miles of upper beach habitat (highest high tide to base of dunes) communities greater than 50 feet in width, with < 30% native vegetation, including American beachgrass, sea-rocket, seabeach orache, seaside sandwort and seaside sandmat.
- Primary dune face (top of primary dune to the foot of the dune) is 30 to 70% vegetated with American beach grass and native forbs (including beach pea and seaside goldenrod).
- Allow for natural geomorphic changes to the Stage Island beach shoreline in response to climate change, including natural erosion and deposition cycles, and the development of a new salt marsh unit in response to sediment movement.

Restore breeding populations of federal and state listed threatened and endangered species

- Over a 5-year period, an average of 30 nesting pairs of Piping Plovers producing an average of 40 fledglings annually.
- Greater than 4 miles (out of a total of 6 miles) of suitable nesting habitat for Piping Plover and the state listed Least Tern comprised of sandy, shell, gravel, or cobble substrate, with sparse vegetation (less than 20% cover); located on the beach front, foredunes, washover, or backshore geomorphic setting.
- Minimize human-caused disturbance to federal and state threatened and endangered species, including breeding shorebirds and terns (e.g., Piping Plover, Least Tern), with visitors along 6 miles of available breeding habitat.
- A wrack line consisting of a variety of plant matter (e.g., seaweeds) and shells is present over 90% of the beach shoreline from March through November.

Support migrating shorebirds and wintering waterfowl

- Minimal disturbance to migrating shorebirds (early July through November 15), with minimal foot traffic (< 3 per hour) along 3.5 miles of the refuge beach between Lot 3 and Lot 6.

[1] *All numbers, including 1-9, are written as numerals in the objective statements.*

- Minimal disturbance for wintering waterfowl from Nov 15 to March 15.

Maintain BIDEH

- Eradicate and prevent establishment of any invasive plant species that colonize refuge or Plum Island beaches. Early Detection species include Asian sand sedge, yellow horn-poppy, and saltwort.

Rationale

The refuge beach is important nesting habitat for the federally listed Piping Plover and State listed Least Tern (Kirkey & Pau 2022), and for foraging and resting by thousands of shorebirds, including the federally listed Red Knot, during fall and spring migration (Baker et al. 2020; USFWS 2019). The intertidal zone, wrack line, and unvegetated upper beach above daily high tide are used by shorebirds. Natural tidal fluctuations and wrack deposits are necessary to maintain this ephemeral foraging habitat for shorebirds.

Increased storm frequency in the last five years has often benefited shorebirds, as it creates new, high-quality nesting and foraging habitat by reshaping beach and dunes and from migration of the intertidal zone. A severe storm is a short-term phenomenon that may erode a sand spit or reduce or move a dune, a process that leads to continually shifting sands, reshaping of topography, and plant communities adapted to these dynamic conditions. The ability of beach to shift and migrate is critical to the persistence of this habitat (Zeigler et al. 2019a).

Beach habitat shaped by natural, dynamic processes is limited in coastal Massachusetts. The Parker River NWR barrier beach ecosystem (dune, maritime shrubs, and salt marsh) is wide and resilient to storm-related impacts. However, other activities threaten the resilience and integrity of these ecosystems in other locations. Dams on tributary rivers result in a steady decline of sand that reaches the coast. Infrastructure, such as jetties, groins, and seawalls, can magnify erosive forces and disrupt the transport of sediment to beaches. Raking, beach nourishment, and intensive recreational beach use on other beaches reduces their value as wildlife habitat. In other locations, including Plum Island north of the refuge, beach front houses or other infrastructure interferes with the natural processes of beach migration.

Human disturbance is a threat to both breeding and migrating shorebirds (Mengak & Dayer 2020; Mengak et al. 2019). Refuge studies found shorebirds using the beach were disturbed by visitors up to eight times an hour (Drilling & Harrington 1996) and 11 times an hour (refuge data 2009 to 2011, *unpublished*). Shorebirds rarely use an area if there are more than 15 people within 200 meters (Hunt et al. 2019). Parker River NWR hosts over 300,000 visitors annually. Due to the narrow beach and steep foredunes, the potential for visitor disturbance to wildlife is higher than on other nearby beaches (such as Crane Beach, Sandy Point, and the north end of Plum Island) where the beach is wider and the transition to back dunes is more gradual. Refuge area closures are effective in lowering visitor disturbance and increasing shorebird abundance and reproductive success (Hunt et al. 2019). The strategic location of beach access points to provide a long stretch of beach with lower visitor disturbance is important to migrating shorebirds.

Off-road vehicle (ORV) use for fishing was discontinued on the refuge beach in 2022. Detailed impacts of human disturbance and ORV use can be found in the 2022 Compatibility Determination for Fishing (USFWS 2022a).

We have documented significantly more frequent erosion and accretion cycles on the refuge beaches since 2011 and we expect these to increase based on climate projections (Psuty et al. 2017). The refuge may need to rebuild and adapt our recreational infrastructure (boardwalks, stairs, and viewing platforms) to accommodate these changes, but we do not anticipate major habitat alteration strategies to benefit wildlife, such as beach nourishment or sand fencing in the next 15 years. Future beach management actions off-refuge at the north end of Plum Island, such as nearshore dredging and seawalls, would affect the sediment supply and thus the natural resiliency of the refuge beach.

Objective 1.2 Dune Grassland, Sandplain Grassland, Interdunal Swales

Manage 516 acres of dune grassland, sandplain grassland, and interdunal swales on Parker River NWR by maintaining the natural processes (e.g., storm surges, fire) over time, to support ROCs (e.g., rare plants, Eastern Spadefoot Toad, rare Lepidoptera) and maintain native BIDEH, with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- 445 acres of dune grassland communities, with $>$ 95% dominance by native plants (American beachgrass, beach pea, seaside goldenrod, seabeach needlegrass, beach heather, coastal jointweed, beach pinweed, bunchgrasses, seaside sandmat, and reindeer lichen).
- 24 acres of sandplain grassland communities, with $>$ 95% dominance by native plants (small bayberry, beach plum, pitch pine, field sagewort, little bluestem, beach pinweed, Pennsylvania sedge, reindeer lichen, and seabeach needlegrass).
- 48 acres of interdunal swale plant communities, with $>$ 95% dominance by native plants (large cranberry, small bayberry, winterberry holly, highbush blueberry, speckled alder, and various rushes, sedges, and clubmoss).
- Maintain a range of intact dynamic geomorphic settings, including a mosaic of dune grasslands, sandplain grasslands, interdunal swales, and maritime shrubs, through maritime forces (storms, overwash, salt spray, winds).
- Disturbances (natural or managed, e.g., fire) occur frequently enough (e.g., every 3 to 5 years) to sustain a grass-dominated system.

Maintain BIDEH

- Eradicate and contain existing non-native invasive plants (black pine, spotted knapweed, beach rose), and prevent establishment of new invasives (perennial pepperweed, Japanese knotweed, cypress spurge).
- Sustain population of rare plants (seabeach needlegrass), lepidoptera, and Eastern Spadefoot Toad and reintroduce rare plants (dragon's-mouth), if feasible.
- Evidence of breeding activity by Eastern Spadefoot Toads in the interdunal swales.

Rationale

Dunes may occur as a single ridge or a series of parallel ridges that extend back through shrub and forest thickets to salt marsh (Swain 2020). The back dunes are sparsely vegetated with patches of herbaceous or low shrubby plants interspersed with areas of bare sand, and often grade into shrubland or woodland communities in more sheltered areas. Vegetation in wet areas between dunes supports vernal pools and unique wetland habitat. Natural dune grassland is limited in Coastal Massachusetts, New England, and the East Coast of the United States, with houses and other human infrastructure developed at or near the foredune along most of the coast.

Sandplain grassland occurs on protected back dunes as small openings within pitch pine or shrub communities, maintained by salt spray and coastal storms. Sandplain grassland is a rare vegetative community that supports rare plants, moths, and ground beetles. Interdunal swale communities are scattered throughout low depressions in the dunes and provide the only source of natural freshwater on the refuge in an otherwise saline environment. Many of the interdunal swales on the refuge support natural cranberry bogs.

Dune grasslands provide an important habitat for the Ipswich Savannah Sparrow, a subspecies of the Savannah Sparrow that breeds on Sable Island, Nova Scotia. It winters along the Atlantic Coast from Massachusetts south to Georgia (Wheelwright & Rising 2020). This subspecies overwinters in the dune grassland on the refuge, likely foraging on small seeds, fruits, and insects. Dune grasslands also provide habitat to the Massachusetts State-threatened seabeach needlegrass.

Other species of concern that use the refuge's dune grassland include the state-listed Dune Noctuid Moth, nesting Piping Plovers, and a diverse suite of native insects. In addition, several species of raptors migrate along the coast in large numbers including American Kestrel, Peregrine Falcon, and Northern Harrier, all listed as species of conservation concern in Massachusetts (MassWildlife 2022b). Parker River NWR supports the greatest concentrations of raptors during the spring migration for Massachusetts, with over 600 American Kestrels migrating through in April and May (EMHW 2022). They are commonly seen hunting the dune grasslands during their migration.

Some interdunal swales function as vernal pools, holding freshwater long enough to enable successful breeding of amphibians and invertebrates, including the Eastern Spadefoot Toad, a state-listed threatened species. Plum Island is at the northern limit of the toad's range (MassWildlife 2022b). With only 32 current populations verified in Massachusetts, the refuge hosts one of the more abundant and stable populations in the State (MassWildlife 2022b). This primitive amphibian exhibits colonial breeding that is initiated by heavy rain between April and September. During winter and dry summer periods the toads burrow up to eight feet below ground in dry sandy soils.

Beginning in the 1950s non-native black pines were planted by refuge staff for erosion control and reforestation after an escaped fire burned through the dunes (Pau 2017). In recent years, we noted the invasion of black pines into the dune grassland community. Mapping in 2017 identified 29 acres of mature black pine trees and six acres of seedlings and saplings. Over 600 individual infestations were found scattered throughout the dunes and maritime shrublands. Manual removal was piloted, and appears effective, but routine mapping and removal will be required to ensure that the black pine forests do not expand (see Objective 1.4 for details).

Barrier beach and dune communities occur in mosaics that shift location over time as the dunes move. The ability of dunes to move is an important disturbance process that maintains these ecosystems. Winds move and carry salt; wind-blown sands prune and bury plants. Together, the salt and shifting sand limit succession to climax communities, preventing trees and shrubs from dominating this landscape. Climate change may have some beneficial effects on dune grassland habitats, as increased storm forces will move sand and set back succession, helping to form new and maintain existing sandplain grasslands, dune grasslands, and internal swales. Negative impacts from climate change include increased invasive species vigor and disease outbreaks. Adaptation and mitigation strategies for sandplain grasslands include controlling invasive plants to increase resiliency and monitoring ecological processes and advance planning and outreach to allow natural processes to occur (e.g., prescribed, and natural fires, storm surges, etc.).

Objective 1.3 Maritime Shrubland, Maritime Forest

Manage 440 acres of maritime shrubland and forest on Parker River NWR by maintaining the natural processes over time, to support migratory birds (e.g., breeding Eastern Towhee and Brown Thrasher, migratory songbirds), support ROCs (e.g., Eastern Red Bat), and maintain native BIDEH (e.g., reduce invasive plant species), with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- In general, maritime shrubland has a more open canopy, with more berry-producing shrubs such as bayberry and roses, with serviceberry or black cherry as the dominant tree species. Maritime forests have more closed canopy (50 to 80%), with black cherry, red maple, and oaks as dominant tree species, and fewer berry-producing shrubs due to shading.
- A minimum of 221 acres of maritime shrubland with $>$ 70% cover of fruit-bearing native shrubs (small bayberry, beach plum, serviceberry, chokeberries, winterberry holly, arrowwood), with $<$ 25% tree canopy.
- A minimum of 218 acres of maritime forest with $>$ 70% native species composition (black cherry, serviceberry, eastern black oak, quaking aspen, sassafras, eastern red cedar (trees); blueberry, small bayberry, Virginia creeper, and arrowwood (shrubs); wild sarsaparilla, Canada mayflower, and false Solomon's seal (herbs).
- Maintain maritime processes (such as salt spray, winds, shifting sands, and fire) that sustain the primary and secondary dunes as an open, grass- and shrub-dominated system.
- Disturbances (natural or managed, e.g., fire) occur frequently enough to sustain a shrub-dominated system.
- Natural processes and invasive plant control are used to create the native plant community, rather than active management of forest/shrub layer composition.

Support migratory birds and other ROCs

- Brown Thrasher and Eastern Towhee will be present annually during the breeding season.
    - Shrub habitat with 4,000 to 12,000 woody stems per acre, tree canopy cover is 10 to 30%, and 80% of the litter layer is at least 1 inch deep for breeding Brown Thrashers.
- Eastern Red Bat will be annually present during summer (pupping) and fall (mating) season.
    - Retain large hardwood trees with relatively open understory as maternity roosts for bats.

- At least 250 acres of shrub consisting of > 75% native species (e.g., arrowwood, bayberry, black cherry) that produce fruits during fall migration (late August through October) for songbirds.

Maintain native BIDEH

- Less than 10% cover of invasive species in maritime shrubland (e.g., glossy buckthorn, Morrow's honeysuckle, common barberry, and Asiatic bittersweet) and less than 30% invasives (e.g., honeysuckle, glossy buckthorn, common barberry, black locust, black pine) in maritime forest.
- Eradicate early detection plant species, such as beach rose, autumn olive, rusty willow, and tree of heaven; These are plants that are not yet widely established, and thus more easily control with early detection and rapid response (EDRR).

Rationale

The loss and degradation of naturally self-sustaining shrublands has been extensive throughout the Northeast due to development. Parker River NWR supports persistent maritime shrublands that occur as a thin band of vegetation that transitions to salt marsh. Salt spray and constant ocean wind allow salt-tolerant shrub species to dominate and prevent the establishment of trees. Without regular disturbance, the community may succeed to maritime forest and invasive species such as honeysuckles, buckthorn, and Asiatic bittersweet can outcompete native shrubs.

Maritime shrubs and forests co-occur with other maritime communities (dune grasslands, salt marsh) in varying stages of succession. Although we expect these communities to shift over time due to succession and disturbance (fire, wind, storm), for the purposes of management, staff is differentiating maritime shrubs from maritime forests. Community compositions are described in the Objectives above. As noted under Objective 1.2, the refuge maritime shrublands and forests have imbedded within the interdunal swales and patches of sandplain grassland and pitch pine and black pine forests.

Maritime shrublands support a high concentration of fruit-bearing species (e.g., bayberry, beach plum, serviceberry, winterberry, chokecherry, Atlantic white cedar) that provide migrating birds easy access to a high energy food source (Parrish 2000). This habitat is particularly important for young birds, as, on average, more than 85% of the birds banded on the refuge at the joint Parker River NWR/Mass Audubon Banding Station during the fall migration are hatch year birds (Flemer & Moon 2019). More than 150 species of songbirds use shrub habitats on the refuge, such as Eastern Towhee and Brown Thrasher, two BCR 30 high priority species. Both species nest in low shrubs and in leaf litter of the shrubby habitat. Other BCR 30 species of concern using shrub habitat on the refuge, especially during migration, include Willow Flycatcher, Blue-winged Warbler, Canada Warbler, and Prairie Warbler.

Maritime forests are primarily located in more protected zones on either side of the refuge road, and west of Plum Island sound, between salt marshes and residential houses along the refuge boundary. Dominant tree species vary depending on location and include red and black oaks, black cherry, sassafras, and the invasive black locust. Wetter areas in the Hellcat Forest are dominated by black gum and red maple.

Maritime forests provide nesting and migratory stopover habitat for birds of BCR 30 conservation concern, including Baltimore Oriole, Brown Thrasher, Eastern Kingbird, and Eastern Whip-poor-will. Parker River NWR is also a significant migratory route for bats, including the federally endangered Northern Long-eared Bat, Small-footed Bat and Little Brown Bat, and three species of concern: Eastern Red Bat, Hoary Bat, and Big Brown Bat (Yates & Meattey 2010). All bats breed in the late summer or fall. Tree bats (e.g., Eastern Red Bat, Hoary Bat, Silver-haired Bat), being solitary in both the summer and wintering range, breed at coastal sites where they congregate in large numbers. Based on observations, we believe that Eastern Red Bats may breed and have maternity roosts on the refuge.

Predicted climate change patterns, such as hotter and drier summers, may lead to more frequent fires in maritime shrubs. More frequent and intense storms will also help set back succession for this community, which has not had a major disturbance in decades. These changes may result in increased vigor of invasive plants and increased disease outbreak. Shifts in phenology may also affect the synchrony of insect emergence and fruit production with bird nesting and migration (Mayor et al. 2017).

Objective 1.4 Dune Pine Forest

Manage 37 acres of dune pine forest on Parker River NWR by maintaining the natural processes (e.g., fire) over time, to support migratory bird species (e.g., breeding Eastern Whip-poor-will) and maintain native BIDEH (e.g., reduce invasive species), with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- A minimum of 37 acres of dune pine forest, dominated by pitch pine, eastern black oak, beach heather, small bayberry, blueberry, common bearberry, Pennsylvania sedge, Canada mayflower, reindeer lichen, and star-flowered Solomon seal.
- Forest densities typical of a dune pine forest, with $<$ 70% canopy and mid-canopy closure, allowing $>$ 30% sun exposure to ground layer.
- Transition non-native black pines to pitch pine forest over time.
- Disturbances (natural or managed, e.g., fire) occur frequently enough (e.g., every 3 to 5 years) to sustain the habitat.

Support migratory birds

- Eastern Whip-poor-will will be present annually during the breeding season.
    - Presence of early successional, dry deciduous or mixed forests (e.g., pitch pine, oak-northern hardwoods), with a sparse ($<$ 30% cover) understory and ground cover for breeding Eastern Whip-poor-will, with proximity ($<$ 65 ft) to open areas for foraging, such as roads, trails, and canopy gaps.

Maintain native BIDEH

- Sustain and restore pitch pine partial canopy cover to support desired habitat for rare Lepidoptera (e.g., Coastal Heathlands Cutworm, Sandplain Eucheana, Frosted Elfin) and pine snags for Northern Long-Eared Bat roost habitat during migration.
- Less than 30% cover of invasive species (e.g., black pine, Morrow's honeysuckle, black locust, glossy buckthorn) in dune pine forest.

- Sustain and restore native ephemerals (wild sarsaparilla, starflower, false Solomon's seal, Canada mayflower, and common bearberry) by removing non-native invasive plants and increasing canopy cover.

Rationale

The classic pitch pine dune woodland is dominated by scattered pitch pines often with little or no shrub layer (USDA FS 2020). The understory vegetation, if present, is typically beach heather, bearberry, lichen, or sandplain grassland species (Swain 2020). The refuge's pitch pine forest has a closed canopy and a mid-layer of non-native, invasive shrubs (e.g., honeysuckle, autumn olive) adjacent to existing trails.

Pitch pine communities support the highest concentration of rare and endangered Lepidoptera in Massachusetts (Wagner et al. 2003). Among the State-listed moths and butterflies, 41% are associated with these communities. Three state species of special concern (Sandplain Euchleana, Dune Noctuid Moth, and Coastal Heathlands Cutworm) were found within or adjacent to pitch pines on the refuge. The Eastern Whip-poor-will, a BCR 30 species of concern, prefers a dry forest with little or no underbrush and should thrive within the pitch pine forest; the species thus serves as an indicator of the integrity of the woodland.

Non-native black pines were planted in several refuge locations between 1953 and 1980 for erosion control and reforestation. In 1953, 6,500 black pine seedlings were planted in the dunes after an escaped prescribed fire burned a sizable portion of the dunes across from the North Pool. In 1958, 20,000 pines were planted in the Stage Island Pool area, and in 1980, 70 pines were planted on Grape Island. Today, black pines dominate 29 acres and seedlings have recently colonized another 6 acres of dune habitat, although some of the native plant community and ecological function is retained in these forests.

The refuge initiated a small pilot ($<$ 1 acre) in 2009 to remove black pine and restore a pitch pine dominated community. We removed 90% of the black pines and planted pitch pine seedlings. Seedlings had ~80% survival after 10 years, with smaller seedlings ($<$ 4 ft in height) having higher survival. Both native and invasive woody species germinated in the understory. Lack of funding and concerns about potential damage to a fragile ecosystem by heavy equipment have limited larger-scale restoration. Another small-scale effort was launched in 2017 to remove black pines through mechanical cutting and herbicide injection after mapping efforts showed a significant spread of the species into the dune system. Success using the injection system was low; it was successful on some large saplings but had no effect on mature trees. Preventing further spread of black pines has been identified as a priority through periodic mechanical removal.

Hotter and drier summers caused by climate change will likely result in natural fires, which are important for regeneration of pitch pines and promoting understory species. Negative impacts from climate change include increased invasive species vigor and disease outbreaks. Adaptation and mitigation strategies for pitch pine woodlands include treating invasives to increase resiliency, monitoring ecological processes, and advance planning and outreach to allow natural processes to occur (e.g., prescribed fires).

Goal 2—Parker River NWR: Back Barrier Ecosystems

Protect, enhance, and restore the BIDEH of Parker River NWR's back barrier habitats to support native wildlife and plant communities, including species of conservation concern.

Objective 2.1 Old Fields

Manage 69 acres of old fields on Parker River NWR, to support migratory birds, support ROCs, and maintain native BIDEH, with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- 60 to 80% of the habitat is dominated by grasses and forbs (< 2 ft in height) (e.g., Pennsylvania sedge, fescue species, little bluestem, creeping bentgrass, common timothy, quack grass, and scattered common milkweed, stiff aster, and goldenrod).
- 5 to 15% is dominated by shrubs (2 to 6 ft height) (e.g., bayberry, Virginia rose, poison ivy, chokeberry)
- Less than 5% is dominated by trees (6 to 16 ft height) (e.g., black cherry, serviceberry, eastern red cedar).
- Disturbances (mowing, fire) occur at least once a year to sustain the system as an open, grass and herbaceous dominated system.

Support migratory birds

- Bobolink will be present annually during the breeding season on all management units.
    - Presence of graminoid species (common timothy, hard fescue, meadow fescue, quack grass, and Canada bluegrass at Cross Farm Hill; Pennsylvania sedge and drooping brome grass at Sub-Headquarters Field; common timothy, spike-rush, and creeping bentgrass at Bill Forward Field) for nesting and feeding and >30% cover for resting during migration (September to October) for Bobolinks.
- Savannah Sparrows will be present (2 of 5 years, as they tend to be sporadic nesters from year to year) during the breeding season at the Cross Farm management unit.
    - Presence of graminoid (common timothy, hard fescue, meadow fescue, quack grass, and Canada bluegrass) and herbaceous plant (common milkweed and goldenrods) species that support invertebrate communities for feeding. The presence of graminoid species that develop a thick thatch layer for nesting. > 30% cover for resting during migration (September to October).

Support other ROCs

- Bill Forward Field, Dikes, Sub-HQ field with > 200 milkweed stems/acre and > 30% cover of nectar-producing forbs (e.g., violets, milkweeds, asters, goldenrods, yarrow) blooming from April through September for Monarchs and other lepidoptera and bees.
- Bare earth (5% open ground) and downed wood (> 2% ground cover) on all management units for shelter and nesting of native bees.

Maintain native BIDEH

- Containment of Asiatic bittersweet, Morrow's honeysuckle, and glossy buckthorn with no new areas occupied (2035 occupancy = 5%) and 70% of occupied areas not exceeding 10% cover. Reduce spotted knapweed and multiflora rose to less than 10% cover.
- Eradicate black swallowwort (i.e., zero areas occupied) from Cross Farm and HQ fields.

Rationale

Management of what had been traditional grasslands began almost immediately upon the refuge's establishment in 1941. Stage Island and Cross Farm Fields had been farmed prior to refuge ownership and were the first areas to be intensely managed (e.g., tilled, seeded, burned) as forage for geese. By 1961, 100 acres across five fields were under cultivation of rye, millet, buckwheat, or winter wheat. Beginning in 1968, the refuge began converting the fields from crop cover to grasslands. By 1996, all fields were established grasslands that were mowed annually with occasional seeding and fertilization. A 2006 assessment (Hoy 2006) found that the soils and hydrology in the Refuge fields supports maritime shrub species. With annual mowing, the % cover of shrubs was expanding over time, although they are stunted due to mowing. To reduce recurrent maintenance needs and support declining shrub-dependent bird species, the refuge started reverting some fields (North Pool, Stage Island, Nelson Island) with more mesic soils to shrubs from 2008 to 2014. These units are discussed under the Maritime Shrub objective.

The refuge currently manages three old field units (Cross Farm [Figure 5-7], Sub-HQ, and Bill Forward [Figure 5-8]) that provide nesting habitat for Bobolink and Savannah Sparrow, migration feeding areas for Eastern Meadowlark and Whimbrel, wintering foraging areas for Northern Harrier and Short-eared Owl, and habitat for Field Sparrow, Eastern Kingbird, and American Woodcock, among other high priority bird species. The dikes surrounding North Pool and Bill Forward Pool will also continue to be mowed and support nesting Bobolinks, Red-wing Blackbirds, and Willets.

These fields still require periodic disturbances (e.g., mowing, burning, grazing, herbicide) to maintain an open habitat and to increase the proportion of native grass and forb species that support pollinators. Invasive plant species are the major threat to old fields, especially colonization by multiflora rose, Asiatic bittersweet, glossy buckthorn, Morrow's honeysuckle, and black swallowwort.

The 15-acre Bill Forward Shrub Unit has historically been managed as an early successional grassland/shrub matrix. The vegetative composition is a mix of cool season grasses, broadleaf herbaceous plants, and small woody seedlings. This shrub encroachment dictates the current designation of "old fields" instead of traditional grasslands. Additionally, the small size of these units precludes optimal management for many grassland-obligate birds that require large habitat blocks. Instead, the Refuge maintains these areas for public wildlife-viewing opportunities and pollinator habitat.

Although old fields are human-created habitats in the northeast, they diversify wildlife viewing opportunities for visitors, and can have significant value to Bobolinks, Savannah Sparrows, other migratory birds, pollinators and other insects, including the Monarch butterfly (USFWS 2016b). Common milkweed (essential to Monarch larvae), goldenrods and asters (nectar sources for migrating Monarchs) are present in the old fields. Bumble bees are an important group of native pollinators, with significant range-wide population declines. Parker River NWR bee surveys from 2010 through 2012 documented 109 species (*USFWS 2012*), including seven species of bumble bee. The undeveloped and unmanaged nature of much of the refuge provides ideal habitat for native bees.

Cross Farm Hill (24 acres) has the greatest potential to support grassland nesting birds such as Savannah Sparrows and Eastern Meadowlarks. As a glacial drumlin surrounded on three sides by salt marsh, it provides the visual openness area-sensitive grassland nesting birds seek in suitable nesting habitat. This openness also provides expansive views for refuge visitors, and attracts other watchable wildlife, such as Northern Harriers and Short-eared Owls. Two invasive plant species, black swallow-wort and porcelain

berry are found in Cross Farm and nowhere else on the refuge. Preventing the spread of these two species is a large consideration in the management of Cross Farm.

Objective 2.2 Impoundments

Manage or restore 266 acres of impoundments on Parker River NWR across 3 units: North Pool (110 acres), Bill Forward (31 acres), and Stage Island Pool (105 acres), to support migratory bird species and restore ecological integrity and function of the system to be resilient to climate change in the long term.

The impoundments are not sustainable over time. Restore to salt marsh. The timing of restoration aims to balance benefits to bird use and wildlife observation opportunities with long-term sustainability. Post-restoration the *objectives* and *strategies* for salt marshes will apply.

Desired conditions after restoration

- By 2027, restore Stage Island impoundment to tidal estuary marsh; the current 1.5-meter culvert will be restored to a 40-meter opening.
- By 2035, restore Bill Forward impoundment to a tidal estuary marsh to support estuarine fish, wading birds, shorebirds, waterfowl, and rails; the current 1.5-meter culvert will be restored to a 6-meter opening.

  The following attributes will guide restoration of these two impoundments:

  - Tidal amplitude as close as possible to unrestricted marsh to promote sedimentation and marsh accretion.
  - A vegetated platform comprised primarily of *S. alterniflora* post restoration, with a gradual conversion to *S. patens* and other high marsh species as marsh platform gains elevation.
  - Single channel hydrology sufficiently sized to flood and ebb 90% of the management unit during a lunar cycle, and at equilibrium to the volume of water as to minimize erosion potential at tidal opening.
- By 2035, restore North Pool to tidal estuary marsh to support estuarine fish, wading birds, shorebirds, waterfowl, and Saltmarsh Sparrows the current 1.5-meter culvert will be restored to a 16-meter opening, with the following attributes guide restoration:
  - Tidal amplitude that promotes sedimentation and marsh accretion and restores a mix of high marsh and low marsh post-restoration.
  - A minimum of 25% high marsh, with increasing percentage of high marsh as marsh accretes elevation post-restoration.
  - Single channel hydrology sufficiently sized to flood and ebb 90% of the management unit during a lunar cycle, and at equilibrium to the volume of water as to minimize erosion potential at tidal opening.
- Note: Exact timing of North Pool and Bill Forward restoration may be adjusted based on results of the Stage Island restoration and vulnerability of the impoundments and relative elevation difference between the impoundments and adjacent salt marsh.

Desired conditions prior to restoration

Support ROCs

Prior to restoration, Bill Forward and Stage Island Impoundments will be managed to support migrating shorebirds (e.g., Semipalmated Sandpiper, Red Knot, Black-bellied Plover) and waterfowl, (e.g., American Black Duck, Northern Pintail, Green-Winged Teal) while optimizing native BIDEH (i.e., reduce invasive species).

- Shallow flooded (< 12 inches depth) habitat with 20 to 40% cover by native emergent wetland plants (sedges, bulrushes, dwarf spikerush, saltmarsh aster, beggarticks, marsh orach, red goosefoot, salt sandspurry, marsh fleabane, fireweed); and aquatic plants (common duckweed and pondweed; 10 to 30% cover) from September to November to support migrating waterfowl.
- Mudflat and shallow water (< 4-inch water depth) with sparse vegetation (< 15% cover) and food resources (e.g., aquatic invertebrates) are present once every 2 years for spring and fall-migrating shorebirds, mid-May to late September.

Maintain native BIDEH

- Less than 30% invasive *Phragmites* cover and minimize marsh subsidence.

Rationale

Three freshwater impoundments - North, Bill Forward, and Stage Island Pools, were constructed by installing berms in the salt marsh in the 1940s and 1950s to provide waterfowl breeding habitat, especially for American Black Duck and Canada Goose. The impoundments were intensely managed for many years to benefit breeding waterfowl, with prescriptions including discing, plowing, mowing, flooding, seeding, planting, burning, herbicide application, and drawdown. Nationally, the focus for nesting waterfowl habitat has shifted to the prairie pothole regions of the U.S. and Canada, though the Northeast remains important for nesting American Black Duck. The Atlantic flyway continues to provide important migration and wintering habitat for waterfowl.

Since creating the impoundments, refuge objectives have broadened to include migratory shorebirds and breeding marsh and wading birds. The refuge has been managing the three impoundments for migratory shorebirds and waterfowl since the 1990s. In the late-2000s, we started managing North Pool for breeding marsh and wading birds due to its importance to the State (USFWS 2007).

However, persistent problems in managing the impoundments, including aging water control structures, eutrophication, silting of channels and ditches, subsidence, poor water quality, lack of fresh water, and invasive plants, have prevented the refuge from achieving desired wildlife objectives. These issues are detailed in the *2007 HMP* and in the *North Pool Restoration Feasibility Study report.* The risk of catastrophic (unplanned) failure of Pool dikes during storm surges, ongoing maintenance issues, and the high habitat value of salt marsh has prompted the refuge to pursue decommissioning the impoundments and restoring them to salt marsh. Studies begun in the early 2000s that assessed existing conditions and vegetation and the creation of hydrological models deemed restoration feasible [Parker River NWR Annual Habitat Work Plan (*2007*)], (Louis Berger Group 2004; Konisky 2004).

In 2019, hydrological models were developed for all 3 impoundments to provide a range of alternatives for impoundment restoration to salt marsh (Fitzgerald et al. 2017; Woods Hole Group 2019b, 2018). To compare the cost and benefits of waiting to restore the impoundments, we selected North Pool to for modeling restoration on two timeframes: restore Immediately (2015) or restore in 2050. Based on these models, North Pool is more likely to retain high marsh if restored immediately compared to restoration initiated in 2050. With restoration, Bill Forward Pool will primarily become low marsh and Stage Island will be mostly low marsh with fringing high marsh (Woods Hole Group 2018, 2019b).

Restoring the impoundments to tidal estuaries will allow these systems to keep up with sea level rise, adapt to climate stressors and protect adjacent habitat and infrastructure (i.e., Hellcat Swamp and the refuge road). With the restoration of tidal flow, we expect a flush of sediment import, an increase in marsh elevation (Oosterlee et al. 2020; Oosterlee et al. 2018; Virgin et al. 2020), and a succession of low marsh to high marsh over time (Roman et al. 2002; Virgin et al. 2020). These restored marshes have the potential to provide important habitat for imperiled species, such as Saltmarsh Sparrow and Black Rail (Hartley & Weldon 2020; ACJV 2020a).

Restoration will result in a system better suited for adaptation and resilience in the face of climate change and sea level rise. The Refuge recognizes that the current values of the impoundments to wildlife and wildlife-viewing opportunities are important to the State and refuge visitors. To ensure the restoration is successful, we plan to first restore Stage Island, and use monitoring data from this restoration to inform subsequent projects. We will also learn from similar tidal restoration projects currently in Canada (Virgin et al. 2020), Belgium (Oosterlee et al. 2020), and the Herring River estuary restoration in Wellfleet and Truro, Massachusetts (*National Park Service 2018*). Bill Forward provides shorebird foraging during migration while North Pool is important to breeding marsh and wading birds. For these two impoundments, we will time restoration to balance the need for ecological function with current wildlife values.

The details of the restoration modelling and analysis are described in the Environmental Assessment (Appendix A).

Objective 2.3 Salt Marsh

Manage 3,001 acres of salt marsh (includes 266 acres transitioned from impoundments by 2037) on Parker River NWR by maintaining natural processes (e.g., total marsh extent, vegetation communities, vegetated and non-vegetated marsh, elevation relative to sea level rise, and migration) over time, to support migratory birds (e.g., Saltmarsh Sparrow and American Black Duck), and maintain native BIDEH (e.g., reduce invasive species), with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- 80% of marsh units will have a natural wetting and drying cycle associated with diurnal and monthly tides that provide needed sediment and hydroperiod.
- A shifting mosaic of habitats in response to changing tidal flooding, sedimentation rates, and marsh vegetation response.
- The ratio of un-vegetated (e.g., pools, pannes, creeks, and mudflats) to vegetated marsh is less than 0.15.
- By 2037, target composition of vegetation communities is as follows:

- Approximately 15% of the total marsh acreage is 'low marsh', typically dominated by *S. alterniflora* and regularly flooded twice on a daily cycle.
- Approximately 80% of the total marsh acreage is 'high marsh', typically dominated by *S. patens* (> 50%), co-dominated by *S. alterniflora* short-intermediate form, saltgrass, and blackgrass, and irregularly flooded on a daily cycle, with a thatch layer (dead standing plants underneath live plants) in > 50% patches, < 15% bare ground, and high peat strength.
- Approximately 5% of the total marsh acreage is 'upper salt marsh', typically dominated by marsh elder and seaside goldenrod, and flooded only on astronomic tides, with:
  - Approximately 90% vegetation cover, no bare ground, and no open water at low tide.
  - Migration of upper salt marsh zone into adjacent upland habitat, with minimal impediments from *Phragmites*, legacy agricultural berms, and road structures.

Support migratory birds

- At least 1,000 acres of suitable breeding habitat for Saltmarsh Sparrow, with at least 775 adults (median 5-year refuge-level abundance), with at least 45% annual nest success (i.e., at least 1 chick present before expected fledge date).
- American Black Ducks will be annually present during the non-breeding season (September to April) on all salt marsh management units.
- Migratory shorebirds (e.g., Greater Yellowlegs, Short-billed Dowitcher, Least Sandpiper, Red Knot) will be annually present in foraging habitat (e.g., salt pannes, mudflats) during spring (April to June) and fall migration (July to November) on all salt marsh management units.

Maintain native BIDEH

- Reduce perennial pepperweed in 8,000 acres of Great Marsh currently infested.
- Increase the portion of eradicated pepperweed in treatment area to 60% by 2037.
- Prevent the spread of pepperweed to the currently uninfested areas (22,000 acres) of Great Marsh and increase this area to 25,000 acres by 2037.
- Containment of *Phragmites* in the upper salt marsh, with no new spread of *Phragmites* from 2020 levels.

Rationale

Over one-third of the world's tidal marshes are located along the Atlantic and Gulf Coasts of the US (Greenberg et al. 2006). Salt marshes protect shorelines from erosion caused by strong wave dynamics and storm surges, provide areas for flood storage, filter water pollutants, and serve as nursery habitat for terrestrial and marine organisms (Greenberg et al. 2006). Flooding tides bring inorganic sediment to and promote vegetation growth in salt marsh (Langston et al. 2020; Morris et al. 2002); both are critical for vertical marsh accretion. This ability of salt marshes to maintain dynamic equilibrium with sea level rise has maintained this ecosystem for the past 4,000 years.

Bird populations

Eastern U.S. marshes support the highest level of vertebrate biodiversity of any tidal marsh region in the world, supporting 56% of the world's endemic salt marsh species (Greenberg et al. 2006). However, population trends for many salt marsh birds are declining and sea level rise threatens loss or conversion of much of this ecosystem (ACJV 2019).

Parker River NWR was established with the purpose of benefitting American Black Ducks and is one of their most important wintering habitats in New England, with more than 2,500 ducks at peak times. Coastal salt marshes, estuaries, and sheltered coves are especially important to migrating and wintering black ducks (Longcore et al. 2020).

The Saltmarsh Sparrow, a highest priority species in BCR 30 and a species of concern in Massachusetts, is an obligate tidal-marsh specialist. Parker River NWR hosts a large contiguous nesting site and a relatively large population of Saltmarsh Sparrows. The Great Marsh supports 5% of the global population and 50% of the State population, for a species that has declined more than 80% over 15 years, down to less than 30,000 individuals (ACJV 2022; Hartley & Weldon 2020). Trend analysis of the refuge population does not show the population decline seen throughout the *rest of the range* (Hartley & Weldon 2020; Walker & Pau 2021).

The Saltmarsh Sparrows at Parker River NWR also show elevated levels of blood mercury (Hg) (Lane et al. 2011; Lane et al. 2020). This is of particular concern as Parker River NWR appears to be an important source population to other New England sites (Walsh et al. 2012). Due to these population pressures, the Saltmarsh Sparrow is currently under review for potential federal listing (USFWS 2022c).

Tidal hydrology, elevation, and resilience

The salt marsh at Parker River NWR is part of the Great Marsh, the largest contiguous salt marsh (25,500 acres) north of Long Island, NY, extending from Gloucester, Massachusetts to Hampton, New Hampshire. Salt marsh is the largest ecosystem type at Parker River NWR with approximately 2,653 acres (60% of the total refuge acreage). An additional 247 acres of historical salt marsh were impounded in the 1950s, and the refuge plans to eventually restore these impoundments back to salt marsh (see *Objective 2.2 Impoundments)*.

Tidal hydrology and elevation strongly dictate the zones of salt marsh vegetation communities. The refuge salt marsh is roughly 82% high marsh platform, flooded by $<$ 20% of the tides during a monthly cycle, and dominated by *S. patens* and black grass. Low marsh habitat, dominated by *S. alterniflora*, is inundated daily by tides, and makes up less than 5% of the refuge marsh, mostly at the edge of large creeks or Plum Island Sound. Scattered throughout the saltmarsh are shallow pannes and deeper pools, which remain permanently or semi permanently inundated, and a network of tidal ditches.

Tidal creeks were the conduit for flooding water to the marsh platform. As a marsh floods, water rises in the creeks and ditches, eventually topping the banks and flooding the marsh surface. Throughout New England, tidal creek hydrology has been replaced by ditches (Burdick et al. 2020). In the 1700s and 1800s, farmers installed a network of berms, ditches, and culverts to facilitate the growth of "salt marsh hay" (*S. patens*), and these legacy structures continue to alter hydrology in salt marshes today (Adamowicz et al. 2020). Without regular maintenance, many ditches have collapsed, and the berms continue to hold water (Smith et al. 1989), resulting in conversion of high marsh (*S. patens* dominated habitat) to low form *S. alterniflora* and 'megapools.' Rising sea levels and increased inundation from storms has accelerated this marsh conversion process.

Through a series of pilot restoration projects, the refuge and partners have developed a set of restoration techniques to address the above-referenced legacy infrastructure and climate impacts. Our marsh management aims to restore flood-ebb tidal hydrology, reduce the impacts of past marsh alterations, and increase resilience to climate change and sea level rise. Current strategies include ditch plug removal, runneling, ditch remediation, and creating microtopography islands to increase sparrow nesting habitat. Ditch plug removal and runneling are restoration techniques involving the creation of narrow channels to mimic natural channels or breaches and drain areas with excessive pools. Ditch remediation involves cutting salt marsh grass and placing it in select ditches to encourage peat development and revegetation. These restoration strategies are used in combination to re-create single channel hydrology that will allow the entire marsh platform to flood and ebb, thereby increasing sediment capture, vegetation biomass, and marsh accretion.

The latest models indicate that the marshes on Plum Island may persist for many centuries due to its relatively high elevation in relation to mean sea level (Langston et al. 2020). Ganju et al. (2020) found that marshes on Plum Island are some of the most stable in the East Coast and will likely persist for over 1,000 years (Ganju et al. 2020). Langston et al. predict that the high marsh platform will persist until 2070 before rapid conversion to low marsh, while low marsh will persist well beyond 2100. Coastal Zone Management's Sea Level Affecting Marsh Model (SLAMM) (CZM 2023) finds a similar timeline for conversion, while identifying the highest marsh migration potential for the State just west of the Refuge. Plum Island has relatively high elevation relative to mean sea level, providing a higher buffer against marsh loss (Wasson et al. 2019; Kirwan et al. 2010).

Intertidal and subtidal habitats

The Refuge boundary extends to the Mean Low Water (MLW). Therefore, many of the tidal flats and submerged aquatic habitats are located within State waters, and not owned by the refuge. These habitats provide important habitats for clams, mussels, shorebirds, and waterfowl; and the refuge works with local towns and the State to minimize activities that may impact wildlife habitat or ecological health.

Eelgrass is a flowering underwater seagrass that serves as a vital food source and shelter for fish, crustaceans, and is strongly associated with waterfowl species. Eelgrass has been declining due to factors including disease, non-native crab herbivory, and pollution. According to the Eelgrass Habitat Suitability Model, the Nelson Island Marsh area is an ideal restoration site due to several factors, including historic presence of eelgrass beds, suitable substrate, adequate water quality and clarity, and lower wave energy (Novak & Short 2012). Experimental efforts to restore eelgrass have been successful in Essex Bay, but more challenging in Plum Island Sound (Novak & Short 2012).

Goal 3 – Thacher Island NWR: Rocky Shore and Shrubland

Perpetuate the BIDEH of coastal habitat on Thacher Island NWR to sustain native wildlife and plant communities, including species of conservation concern.

Objective 3.1 Rocky Intertidal Shore

Manage 12 acres of rocky intertidal shore habitat on Thacher Island NWR to sustain the ecosystem over time (e.g., community composition), support recovery of federally threatened and endangered species, and maintain native BIDEH, with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- Rocky, gravel substrate dominated by rockweed, blue mussels, and brown algae.
- Dense maritime shrubs with stem density > 20,000 stems per acre, 3 to 15 feet high, comprised of >70% native shrub species, and less than 30% tree cover.

Support recovery of federal threatened and endangered species

- > 10 acres of suitable nesting habitat (rocky areas with sparse vegetation) for breeding terns, with access to marine or estuarine open water foraging areas within 15 km.
- Island free of mammalian predators and rats.
- Establish a breeding population of New England Cottontails, such that rabbits can be removed annually to augment mainland wild populations.

Maintain native BIDEH

- Early detection of marine invasive species that have been observed on the mainland. These may include invasive tunicate species, European green and Asian shore crabs, and red algae (Wells et al. 2014).

Rationale

Thacher Island supports several colonial nesting species, including Double-crested Cormorant, Common Eider, Canada Goose, Herring Gull, Great Black-backed Gull, and American Oystercatcher. The Island historically supported breeding pairs of Common Tern, Arctic Tern, and Roseate Tern (Kress & Hall 2004), although no terns currently breed there. Past studies in the Gulf of Maine have shown declines in tern numbers and displacement of tern colonies can be attributed to increased egg and chick depredation by gulls (Drury 1973; Donehower et al. 2007). The presence of Common Terns appears to be the most important criteria for Roseate Tern nest site selection. The Roseate Tern is a federal- and state-listed endangered species (Nisbet et al. 2020); Common Tern is listed as a species of special concern in Massachusetts (MassWildlife 2022a).

Thacher Island is near the northern extent of the Roseate Tern breeding range (Nisbet et al. 2020). As of 2019, approximately 89% of the Atlantic Roseate Tern population is concentrated at just three nesting colonies: Great Gull Island, New York (2,200 pairs); Bird Island, Marion, Massachusetts (1,101 pairs); and Ram Island, Mattapoisett, Massachusetts (919 pairs) (USFWS 2020). The only other tern nesting colonies in Massachusetts are at Penikese Island, Gosnold (15 pairs), South Monomoy Island, Chatham (12 pairs), and Norton Point Beach, Edgartown [19 pairs; (Mostello et al. 2019)]. Nesting colonies north of Thacher Island include Seavey Island, Rye, New Hampshire (80 pairs) and Stratton Island, Portland, Maine (123 pairs) (USFWS 2020).

Given its geographic location between other tern nesting islands (Cape Cod nesting islands and coastal Maine islands), Thacher Island is an ideal tern restoration site. These active tern nesting islands offer source populations for the refuge. If re-established here, Thacher Island could then serve as a source population in the event of population declines elsewhere in the region.

Currently, the large population of gulls on Thacher Island is the greatest limiting factor to tern restoration. Population management since 2001 has reduced gull numbers on Thacher Island from approximately 1,735 nests in 2001 to 370 nests in 2019 (Refuge data 2001 to 2019, unpublished) (MassWildlife 2022b), and MassWildlife has indicated concerns for further gull depredation efforts.

Significant tern restoration efforts and gull population management at offshore islands like Thacher Island, in the Gulf of Maine and Long Island Sound, have increased tern numbers in the past 20 years (Elizabeth Craig, pers. comm., 2022). On White and Seavey Islands, 3,066 pairs of Common Terns, 147 pairs of Roseate Terns, and 1 pair of Arctic Terns were recorded during the 2022 breeding season; this represents a huge restoration success after the first 6 pairs of Common Terns settled there in 1997 (NHGF 2023). Similarly, in response to gull control beginning in the late 1990s and subsequent habitat management efforts at Monomoy NWR, Common Terns recolonized South Monomoy Island to such a degree as to now be the largest breeding colony of the species worldwide, exceeding 14,000 pairs, in addition to over a dozen nesting Roseate Terns (USFWS unpubl. data).

The limiting factor for reintroducing terns to Thacher Island is lack of consistent funding and staffing capacity. Once a tern breeding population is established, annual commitment of staffing is needed for 7 to 8 months to maintain and manage the population. It is difficult to implement this objective without confirmed long-term funding.

Objective 3.2 Maritime Shrubland

Collaboratively manage 27 acres of maritime shrubland habitat on Thacher Island (both on NWR and Town property) by maintaining the natural processes (salt spray, winds, storms) over time, to restore populations of ROCs (e.g., New England Cottontail), and maintain native BIDEH, with the following attributes (measurements) and aspirational targets (values):

Desired conditions

- 50 to 70% is dominated by shrubs (2 to 6 ft height) (e.g., small bayberry, beach plum, serviceberry, chokeberries, winterberry holly, arrowwood, and staghorn sumac).
- 20 to 30% is dominated by young trees (6 to 16 ft height) (e.g., eastern serviceberry, black cherry, eastern red cedar).
- Maritime forces (salt spray, winds, storms, etc.) to sustain the system as shrub-dominated.

Restore populations of ROCs

- Establish an island breeding colony of New England Cottontails to support population augmentation in other parts of New England.
- Maintain the island free of mammalian predators.
- Assess Norway rat population and control and eradicate if needed.

Maintain native BIDEH

- Containment of invasive plant species (bush honeysuckle, rusty willow, glossy buckthorn, and barberry), with 50 % of occupied areas not exceeding 10 % cover.
- Containment of invasive plant species (purple loosestrife and *Phragmites*) in wet swale habitats, with no new areas occupied and less than 25% cover where occupied.

Rationale

Located 1.5 miles off the coast of Rockport, MA, the maritime shrub community at Thacher Island is maintained by constant maritime wind and salt spray, preventing the succession to forest. Coastal islands are important resting locations for migratory songbirds and, if adequate resources are available, provide an opportunity to replenish their energy reserves (Ferretti et al. 2021). Maritime shrublands and forests support a high concentration of fruit-bearing species (e.g., bayberry, beach plum, serviceberry, winterberry, chokecherry, Atlantic white cedar), providing migrating birds easy access to a high energy food source (Parrish 2000). The island supports breeding birds as well, but no formal surveys have been conducted to date.

The New England Cottontail is a species endemic to New England and eastern New York and was a candidate for Federal listing. The New England Cottontail's range has contracted by more than 75%; where they persist, the populations are extremely small and fragmented by roads and development. They also face competition from the introduced Eastern Cottontail. Without intervention, the population is at high risk for extirpation in many parts of its remaining range (e.g., southern Maine, New Hampshire, Rhode Island).

In 2015, the FWS precluded listing under the Endangered Species Act due to a strong partnership of organizations and agencies committed to specific conservation actions to halt range-wide population declines (USFWS 2023). Although the cottontail is not listed, it is a species of high conservation concern for USFWS, and we work diligently with partners to restore shrub habitat and restore and increase wild populations through a captive rearing program. The current captive rearing facilities include two zoos, two outdoor breeding pens, and two offshore island facilities. To date, the existing facilities have the capacity to provide 90 rabbits annually for augmentation and reintroduction. The goal for the regional captive program is 250 rabbits annually (Holman 2022). The working group is actively seeking to add facilities to slow the population decline throughout NEC's range.

Thacher Island is a good candidate for establishing a breeding colony of New England cottontails due to its self-sustaining shrub habitat, lack of mammalian predators, and reliable access to the island. Early results from the Regional Captive Breeding Workshop group have suggested that zoos and enclosed breeding pens are not sufficient to provide the 250 rabbits per year needed to augment wild populations. Island nesting colonies in Rhode Island and Massachusetts have seen significantly higher breeding success, with researchers able to remove young for augmentation within 3 to 5 years of reintroduction (USFWS 2023).

Evaluating Thacher Island as a breeding colony for New England Cottontails would involve assessment and discussion with the NEC Captive Rearing Working Group and discussions with Thacher Island Association.

Chapter 5. MANAGEMENT UNITS AND STRATEGIES

This chapter describes how refuge staff intend to achieve the management objectives described in Chapter 4. A comprehensive literature review was conducted to identify all potentially useful strategies (e.g., burning, water-level manipulation, mowing, restoring, or allowing natural processes, etc.). In consultation with other refuge biologists, managers, and experts, we selected the most effective strategies for accomplishing the habitat objectives. Management techniques that are shared across multiple refuges and employed to restore and enhance the biological integrity of priority habitats are described in *General Strategies for HMPs* (Knutson 2021).

Being a 15-year plan, the prescriptions included in this document are broad and include all potential actions, even those that are not currently prioritized. Staffing levels, new priorities, environmental factors (e.g., weather), and logistics affect what management actions are employed each year. Therefore, more specific prescriptions (i.e., details of when, where, and how treatments will be applied) will be described in detail in Habitat Work Plans, where we evaluate the effectiveness of past management and adapt strategies as needed. Habitat Work Plans are completed every 2 years due to staffing constraints and the multi-year cycle of most biological projects.

CURRENT AND DESIRED HABITAT CONDITIONS

To meet the Objectives described in Chapter 4, some habitats at Parker River NWR will transition to different habitat types over 15 years, due to sea level rise, forest and shrubland succession, or planned management actions.

Table 5-1 and Figure 4-1 highlight the changes in habitat types at Parker River NWR from the 2007 HMP to today (2023), and what's proposed in this HMP (ending in year 2038). The acres used in the tables are derived from Geographic Information System (GIS) calculations of the habitat map and are not exact. Also note that incorrect acreage was recorded in the 2007 HMP. Table 5-1 shows the acreages used in the 2007 HMP, and the correct acreages in parenthesis underneath. Table 5-2 and Figure 4-2 highlight those for Thacher Island NWR, although no changes are proposed there.

Table 5-1 Current and desired habitat types for Parker River NWR.

Objective	*Habitat Type*	*2007 HMP Acres*	*Current Acres (2023)*	*Desired Acres (2038)*	*Notes on Change in Acres*
1.1	Sandy Beach, Rocky Shore	182	182	182	No change
1.2	Dune Grassland	540 (444)	444	444	No change
1.2	Sandplain Grassland	24	24	24	No change
1.2	Interdunal Swale	48	48	48	No change
1.3	Maritime Shrubland and Forest	333 (372)	440 (Gain 68 acres)	440	Fields (see below) left to naturally succeed to shrubland
1.4	Dune Pine Forest	37	37	37	No change
2.1	Old Fields	130 (137)	69 (Lose 68 acres)	69	Ceased mowing of North Pool, Stage Island and Nelson Island fields between 2008 and 2012
2.2	Impoundments	266	266	0	Restore all 3 impoundments
2.3	Salt Marsh	2,660	2,735	3,001	Acquired 75 acres in 2011. Gain 266 acres from impoundment restoration

Table 5-2 Current and desired habitat types for Thacher Island NWR.

Objective	*Habitat Type*	*2007 HMP Acres*	*Current Acres (2023)*	*Desired Acres (2038)*	*Difference between Current and Future Acres*
3.1	Rocky Intertidal Shore	12	12	12	0
3.2	Maritime Shrubland	10	10	10	0

MANAGEMENT UNITS AND PRIORITIES

The refuge is divided into management units (MU) to facilitate the planning and implementation of management actions, and to document and monitor outcomes. Management units are based on location, ecologically recognizable features, roads, trails, and other features. They closely correlate to habitat types, but many MUs contain multiple habitat types. As such, the sum of MU acres under each habitat objective does not equal the total habitat acreage in the table above. In Chapter 3 (Table 3-5), refuge staff prioritized the habitats to help guide annual work plans and provide flexibility for changes in staffing and resources. These priorities are carried through to the MUs below.

The highest priority units are those that provide the greatest opportunity for conservation of the ROCs (priority species and habitats) highlighted in Chapter 3 while considering the goals and objectives in Chapter 4. Ranking is based upon consideration of numerous factors, including (in general order of priority):

- Determined habitat priority.
- Value or contribution to ROC.
- Management capabilities, including access challenges.
- Use by federal and state-listed species.
- Habitat quality and potential.
- Spatial patch size and connectivity to similar habitat types.
- Intensity, frequency, and the type of management needed.
- Personnel availability and operating costs.

Factors such as the effects of climate change or the addition of resources for habitat management could shift the priority of these units.

Priority 1

These units will receive more management effort because they have higher value for ROCs, support the highest priority species in the region as well as federally endangered or threatened species, provide strong public opportunities for connection with nature, have larger habitat blocks, and require time-sensitive restoration to adapt to the effects of climate change. The land is under Service jurisdiction and management actions (e.g., invasive species control or vegetation management) are expected to have a beneficial impact or connect prioritized habitats.

Priority 2

These units still receive management attention but at a reduced level due to staffing and funding constraints. The reasons for lower priority vary. These units may have lower value for ROCs or they tend to be smaller and not spatially connected to larger habitat blocks (e.g., in the case of grassland nesting birds). Others have logistic challenges (difficult access) or high costs for recurrent management (old field habitat and black pine forests). Some units have intact, self-sustaining habitats and primarily require stewardship (such as dune grasslands). Priority 2 units still support many nesting bird species as well as regionally and locally rare habitats. If funding and staff become available to address logistic challenges or management capabilities, these units could be reclassified as Priority 1.

INVASIVE SPECIES

Invasive species threaten the biological diversity, integrity, and environmental health of refuge habitats and the wildlife they support. The threat to habitats and ROCs from invasive species varies by species and habitat condition, but affects all habitats and MU discussed below. The strategies below describe the priority invasive species by habitat and some specific parameters for success. Specific control methods for invasive plants are described in detail in *General Strategies for HMPs* (Knutson 2021). Invasive management strategies and priorities generally follow the process described in *Picking Our Battles*, a publication by University of New Hampshire Extension (Stevens et al. 2015).

Invasive management efforts at Parker River NWR generally focus on strategies that have long-term success, including:

(1) Focusing on species that are in early stages of invasion on the refuge or adjacent areas, as it provides the highest likelihood of success for eradication. These are referred to as early detection and rapid response (EDRR) species, and at Parker River NWR, include perennial pepperweed, rusty willow, beach rose, black swallowwort, Japanese knotweed, tree-of-heaven, and porcelain berry.
(2) Restoring natural processes and plant communities to provide natural resilience against new invasions. Examples include restoring hydrology in salt marsh habitats to control *Phragmites* or restoring native plant communities in shrub habitats to outcompete invasive plants.
(3) Reducing invasive pressure in sensitive habitats (pitch pine or interdunal swales) where they are likely to have negative consequences on rare species.

Table 5-3 describes the distribution, priorities, strategies, and history of invasive plant control on Parker River and Thacher Island NWRs.

Table 5-3 Distribution and treatment history of invasive plants at Parker River NWR.

Species	*Location*	*Priority (H, M, L or EDRR)*	*Spread (S, E, U)*	*Treatment History*
Asian sand sedge *Carex kobomugi*	No known established stands; may be found on sandy beaches	EDRR	-	EDRR species for refuge beaches. If found, eradicate.
Asiatic bittersweet *Celastrus orbiculatus*	Parker River (PKR): Mapped in 2003 (111 ac); Maritime shrublands and old fields including management units: North Pool Shrub, Dikes, Stage Island, Sub HQ, Cross-Farm, Nelson Island, Pink House, Pitch Pine Shrub	M	U	Occasional cutting and spot treatment (Garlon, Rodeo, or Escort) by the side of roads or trails; foliar and basal treatments in reverting fields, 2015-2017; 2018: Pink House treated with Escort/Rodeo mix

Species	*Location*	*Priority (H, M, L or EDRR)*	*Spread (S, E, U)*	*Treatment History*
Autumn olive *Elaeagnus umbellata*	PKR: Maritime shrublands and forests including along Refuge Road and in pitch pine forest	EDRR	S	Mechanical removal: In 2004 bulldozed all autumn olives mapped near the main road; monitoring regrowth along road and other disturbed areas; treat as needed
Beach rose *Rosa rugosa*	PKR: Mapped in 2003 (18 ac); Lot 1 Sandplain grasslands and dunes are susceptible to invasion	M	S	Spot treatment with Rodeo and Escort mix; Substantially controlled on refuge; yearly maintenance necessary; 2023 HMP proposes to eradicate within 10 years using mechanical, chemical, and fire strategies and educate public
Black locust *Robinia pseudoacacia*	PKR: Mapped in 2003 (35 ac); Maritime shrublands, successional maritime forests, pitch pine forest, and sandplain grasslands; Most found along Refuge Road	M	U	Girdle and treat with Garlon; In 2004, treated a small area (0.6 acres) across from the Salt Panne Observation Area; Extended treatment to 30 acres throughout the refuge in 2005 to 2012; 2023 HMP proposes to selectively treat in sandplain grasslands
Black pine *Pinus thunbergii*	PKR: Mapped in 2017 (29 ac mature, 6 ac seedling, 583 locations of seedlings); Maritime shrublands, maritime forests, dune grasslands, dune pine forests, and old fields including management units: Black Pine Forest, Bill Forward Shrub, Hellcat, Dune Grasslands	M	E	Pull seedlings, cut young trees, inject large trees with herbicide (E-Z Ject and Rodeo); Tree removal in small patch in 2009 and 2010; Seedlings pulled in 2011 and 2012; Cutting of young trees and injection with herbicide of large trees in 2017; 2023 HMP proposes to contain to existing areas and begin transitioning to pitch pine forest
Black swallowwort *Cynanchum louiseae*	PKR: Old fields including management units: Headquarters, Cross Hill Farm	H	S	Treated with herbicide since 2010; herbicides previously used include Garlon, Rodeo, and Roundup; most recently treated with Roundup Custom in 2022; 2023 HMP proposes to eradicate this species within 10 years using herbicide treatment

Species	*Location*	*Priority (H, M, L or EDRR)*	*Spread (S, E, U)*	*Treatment History*
Climbing nightshade *Solanum dulcamara*	PKR: Mapped in 2003 (12 ac); Shrub thickets and open ground including at Sub HQ Field.	L	U	None to date.
Common barberry *Berberis vulgaris*	PKR: Mapped in 2003 (6 ac) Thacher Island: Maritime shrublands.	L	U	None to date.
Common reed *Phragmites australis*	PKR: Mapped in 2003 (34 ac); Old fields, impoundments, interdunal swales, and salt marshes including in management units: North Pool, Bill Forward Pool, Stage Island Pool, Sub HQ Field, Cross Farm Field. Thacher Island: Wet swales	H	E	Treating since the 1960's using several methods: herbicide spray (aerial, ground), discing, mowing, and flooding in impoundments; targeted control (cut stem and drop) in interdunal swales; herbicides previously used are Rodeo, Habitat, and Polaris. Recent treatment: Creeks, Pine Island, Parker River treated in 2015; 2.5 acres (Sub HQ, Cross Farm) in 2016; 12 acres (Refuge Road, Sub HQ, Cross-Farm) in 2017 with Rodeo/Habitat; 50 acres (Newbury/Rowley) in 2019 and 2020 (Polaris). 2023 HMP proposes to continue using herbicides to reduce expansion and to control infestations in interdunal swales, while working to pilot innovative treatment that focuses on hydrology restoration as a long-term control method.
Cypress spurge *Euphorbia cyparissias*	PKR: Mapped in 2003 (12 ac); Old fields including management units: Sub HQ Field, Stage Island. Sandplain grasslands are susceptible to invasion	L	E	Garlon and hand pulling; Attempted treatment in 2005, but it was not effective; Very small treatment window; Incidental mowing occurs during maintenance of main road and grasslands

Species	*Location*	*Priority (H, M, L or EDRR)*	*Spread (S, E, U)*	*Treatment History*
Japanese barberry *Berberis thunbergii*	PKR: Mapped in 2003 (40 ac); Headquarters and Hellcat.	L	U	Present in multiple places on the refuge, mainly at Hellcat. No treatment has occurred.
Japanese knotweed *Fallopia japonica*	PKR: Mapped in 2003 (0.06 ac); currently not found on the refuge portion of Plum Island but is north and south (Sandy Point SP) of the refuge. Is found at at Headquarters site. Sandplain grasslands are susceptible to invasion.	H	S	Repeated cutting; Stem-injection and spot treatment; herbicides previously used include Escort, Habitat, and Rodeo; Treated at headquarters and Sandy Point State Reservation in 2017.
Mile-a-minute weed *Persicaria perfoliate*	No known established stands; however, has been documented in Essex County	EDRR	-	EDRR species for refuge beaches. If found, eradicate.
Morrow's honeysuckle *Lonicera morrowii*	PKR: Mapped in 2003 (324 ac); Maritime shrublands, successional maritime forests, dune pine forests, and old fields including management units: North Pool Shrub, Bill Forward, Stage Island, Sub HQ, Cross Farm, Hellcat, Pitch Pine Shrub, Nelson Island. Sandplain grasslands are susceptible to invasion. Thacher Island: Maritime shrublands	M	U	Herbicide treatment (foliar spray with Rodeo and Escort); Foliar and basal treatment in reverting fields in 2015 to 2017
Multiflora rose *Rosa multiflora*	PKR: Mapped in 2003 (< 0.01 ac); Old fields including management units: Cross Farm, Stage Island, Nelson Island, Headquarters, Sub HQ, North Pool Shrub, Bill Forward, Dikes. Thacher Island: Maritime shrublands	M	S	Spot treatment with Rodeo and Escort mix; Largely controlled on refuge; Maintenance spray of few roadside stands and in reverting fields

Species	*Location*	*Priority (H, M, L or EDRR)*	*Spread (S, E, U)*	*Treatment History*
Perennial pepperweed *Lepidium latifolium*	PKR: Mapped annually (~100 acres in 2022); To the west of Refuge Road in high marsh from Stage Island to Gatehouse; Nelson Island; Parker River marshes in Newbury and Rowley; headquarters	H	S	Annual monitoring and mapping; Annual spot treatment with herbicide (Escort XP) and hand pulling; Treating populations in the Great Marsh for watershed-wide control and eradication.
Porcelain-berry *Ampelopsis glandulosa*	PKR: Cross Farm	EDRR	S	Rodeo and Habitat mix; Single plant found and sprayed in 2017 in Cross Farm Field; 2023 HMP proposes to eradicate this species within 10 years using herbicide treatment
Purple loosestrife *Lythrum salicaria*	PKR: Mapped in 2003 (52 ac); Interdunal swales and impoundments	L	S	From 1996 to 2001, *Galerucella* and *Hylobrius* beetles were released in the Refuge impoundments to biologically control the species; Monitoring was completed from 1997 to 2000; 2023 HMP proposes to treat infestations in interdunal swales and to monitor impoundment infestations
Reed canary grass *Phalaris arundinacea*	PKR: Mapped in 2003 (6 ac); Bill Forward Dike	L	U	None to date.
Rusty willow *Salix cinerea*	PKR: Old fields, interdunal swales, and maritime shrublands including in management units: Cross Farm Field. Thacher Island: Maritime shrublands	EDRR	S	E-Z Ject system; A half-acre patch across from Cross Farm Field was treated with E-Z Ject system in 2017
Saltwort *Salsola kali*	PKR: Has been previously documented in refuge, but currently there are no known established stands May be found on sandy beaches	EDRR	-	EDRR species for refuge beaches. If found, eradicate.

Species	*Location*	*Priority (H, M, L or EDRR)*	*Spread (S, E, U)*	*Treatment History*
Spotted knapweed Centaurea stoebe	PKR: Old fields and dunes, including management units: Stage Island, North Pool/Bill Forward Dike, Sub HQ, Cross Farm, Dune Grasslands, Lot 1 Sandplain grasslands are susceptible to invasion	M	U	Spot treatment with herbicides Garlon, Escort, or Rodeo and hand pulling smaller infestations; Treated in 2011 to 2012 with 1.5% Garlon 4 solution; Treated in 2018 with Escort/Rodeo mix
Toringo crabapple Malus sieboldii	PKR: North Pool Field; roadside individuals near Lot 1, Sub HQ, Lot 6, Hellcat Thacher Island: Present in maritime shrublands	M	U	Rodeo and Escort mix or E-Z Ject system; Treatment in North Pool Field with Rodeo and Escort mix in 2017; E-Z Ject system used to treat roadside individuals and a dozen stem patch north of Hellcat parking lot
Tree-of-heaven Ailanthus altissima	PKR: Stage Island	EDRR	E	Spraying with Garlon; About 0.5 acres treated at former Goodwin Camp with Garlon in 2017; Saplings observed again in 2020
White poplar Populus alba	PKR: Mapped in 2003 (6 ac); Stage Island	L	S	Treatment in 2017 in the western part of field using herbicides Garlon and Escort
Wild garlic Allium spp.	PKR: Cross Farm Field	EDRR	-	None to date.
Yellow flag iris Iris pseudacorus	PKR: Stage Island	L	U	Herbicide treatment (Rodeo); Spot treatment in 2011 off Stage Island Overlook tower
Yellow horn-poppy Glaucium flavum	No known established stands; May be found on sandy beaches	EDRR	-	EDRR species for refuge beaches. If found, eradicate.

Notes: Priority rating: management priority based on level of spread, ecological threat, and management difficulty. If treatment is planned, treat High and Medium species first. High (H): High priority for treatment; Medium (M): Medium priority for treatment, treat High species first; Low (L): Low priority for treatment, little to no treatment planned; Early Detection, Rapid Response (EDRR): Vigilant observation for new infestations and rapid removal of plant.

Spread is the rate at which the species' infestation is expanding. Stable (S): The infestation is not expanding due to site conditions or slow growth, and/or is not entering new areas; Expanding (E): The infestation is increasing and/or spreading to other areas; Unknown (U).

CLIMATE CHANGE ADAPTATION

The effects of climate change on wildlife and habitats are expected to be location- and species-specific, with a predicted general trend of species' ranges shifting northward and sea level rise pushing habitats and the associated species inland, where possible. It is also possible that some habitat types will undergo transformation or total loss if conditions do not allow for adaptation or inland migration. For more specific climate change projections, see Chapter 2.

General strategies for adapting to climate change include maintaining genetic diversity, restoring ecological function and connectivity, manipulating disturbance regimes (e.g., fires, floods), and reducing other stressors (Mawdsley et al. 2009). Management strategies that reduce non-climatic stressors (e.g., habitat loss or fragmentation, altered hydrology or soils, human disturbance of wildlife, pollution, and invasive species) will increase the capacity of ecosystems and associated species to adapt to a changing climate. The Service and other conservation entities use a range of tools to implement these strategies such as land and water protection, ecological restoration, species translocation, invasive control, captive propagation, public education, and regulation. At Parker River NWR, where many ecological processes are still intact, our best climate adaptive strategy is to preserve or restore ecological function (hydrology, soils, sediment transport, natural plant communities) where feasible. We will continue to apply these tools in novel and innovative ways to meet the unprecedented challenges posed by climate change (Carroll & Noss 2021).

Managers at Parker River and Thatcher Island NWR will use adaptive management (e.g., monitoring outcomes, adjusting strategies, and updating management objectives) to maintain healthy ecosystems in the face of uncertainty about the future effects of climate change (Nichols et al. 2011). Climate change adaptation strategies are described below under the general category of Mitigate or Adapt to Climate Change.

MANAGEMENT STRATEGIES – PARKER RIVER NWR

This section focuses on the major habitat types found on the refuge and the general management direction for each priority habitat type, including proposed habitat improvements and increases or decreases in the acreage of a particular habitat. Each habitat type is represented by one or more management units (MU) with specific strategies listed.

1.1 Beach and Rocky Shore

- Habitat Priority 1 (Figures 5-1 to 5-4)
- ROCs: Piping Plover, Semipalmated Sandpiper
- Other benefitting species: Least Tern; migrating shorebirds (e.g., Sanderling, Black-bellied Plover, Ruddy Turnstone, Red Knot)
- No planned change in acreage

Sandy Beach and Rocky Shore MU (182 acres)

This unit encompasses the entire Parker River NWR beach from mean low tide up to and including the primary dunes. Constantly changing due to oceanic forces, it currently consists of bare intertidal sand and beach strand. Beach strand is a sparsely vegetated, long, narrow community occurring between the wrack line of the daily high tide and the foredunes. Beach strands are subject to overwash during storms and spring tides. Vegetation is lacking across much of this MU, except along the primary dune, where American beach grass begins to take root. Other salt-tolerant species may also be present, including beach pea, beach wormwood, and seaside goldenrod.

There are five beach parking lots and boardwalks that allow the public to access the beach. Between Lot 3 and Lot 6, there is over 3 miles of beach with no direct beach access. This long stretch with limited beach access is important to reduce disturbance pressure on migratory shorebirds and other species.

Three shoreline stretches are characterized by rocky boulders left by eroding glacial drumlins: Emerson Rocks north of Lot 6, Barhead at the southern border with Sandy Point, and Stage Island shoreline, protruding into Plum Island Sound. These rocky substrates provide habitat for blue mussels, fish, and diving ducks.

Sustain natural processes

- Allow the unrestricted and continual deposition and erosion of sand due to natural geological processes. The refuge will construct infrastructure (only when necessary) such that it will not interfere with the shifting of the barrier beach and dunes but will repair existing infrastructure as necessary and appropriate.
- If erosional hotpots develop, consider reestablishing geodetic beach surveys.
- At Stage Island, provide shoreline access for fishing and public viewing in a way that minimizes erosion.
- Study marsh formation and blue mussel reef development at Stage Island shoreline.

Support migratory birds, ROC, and T&E species

- Maintain natural dynamic shoreline that supports foraging habitat for sea ducks and other diving ducks, and fish, including Atlantic Sturgeon along the rocky shores.
- Allow natural erosion and accretion that maintain high-quality nesting habitat for Piping Plover and Least Tern. Monitor long-term trend of available nesting habitat on refuge beach and regionally.
- Consider habitat enhancement strategies, such as reducing dune vegetation or creating blow-out areas, only when New England plover population is below recovery goals and declining for 3 to 5 years, and available habitat is a limiting factor.
- Annually increase productivity of nesting birds:
    - Monitor Piping Plover and Least Tern activity along the refuge beach 2 to 3 times a week from April to August to assess productivity and monitor predator activity around nests.
    - Manage potential nest predators using non-lethal means first. Management methods include behavior modification, trapping, and shooting. When deemed necessary and when funding allows, contract with outside organizations to target problem individuals and reduce predation.

    - Install predator exclosures around plover nests using multiple designs and non-clustering approach. Coordinate with staff from adjacent beaches, including Crane Beach, to respond rapidly to avian predators targeting adult plovers at exclosed nests.
    - When practical, install an electric fence around Least Tern nesting colony to protect colony from mammalian predators.
- Minimize human disturbance and intrusions:
    - Beach closures April to August during peak shorebird breeding. Most of the refuge beach is closed during the plover nesting season, starting April 1; sections of the beach start opening in July or August, as plovers complete breeding in these sections. The entire beach typically opens in mid- to late August, at the peak of shorebird migration.
    - Keep Lot 1 open for public use, but close beach access if: (a) a 50-meter buffer for plover nests is not possible while maintaining beach access from Parking Lot 1, (b) chicks from nests in closed areas move onto the open beach, in which case we would monitor chick activity and provide for a maximum buffer by moving closure signs accordingly if chicks are disturbed more than four times per hour when foraging, and/or (c) chicks are not able to feed in closed areas due to competition from gulls.
    - Continue to maintain the beach between Lot 3 and Lot 6 (4.1 miles) as a low-disturbance beach use area for shorebirds by limiting beach access points. Install signs and increase outreach focused on ways visitors can reduce disturbance to shorebirds in this section (e.g., Walk around Flock campaign).
    - Recruit and train volunteer shorebird stewards to monitor human activity on the beach and educate the public about the closure and beach-nesting birds.
    - Develop and implement education and interpretive programs to foster stewardship among beach users for plovers and other beach wildlife and reduce the frequency and intensity of human disturbance.
    - Provide environmental education programming and informal outreach on the importance of the refuge as a migratory stopover for shorebirds, using local refuge data.
    - Continue to partner with other organizations to develop and implement effective outreach strategies that engage diverse beach users, with the goal of changing behavior to minimize shorebird disturbance (e.g., Walk Around Flock campaign).
    - Continue to work with FWS and other organizations to increase diversity and representation among staff that implement beach conservation and outreach, to ensure effective communication to an increasingly diverse beach audience.
    - Install symbolic fencing and seasonal signage with direct, positively framed guidance, and continue to monitor disturbance impact to migratory shorebirds.

Restore and maintain Biological Diversity, Integrity, and Environmental Health (BIDEH)

- Eradicate any new invasive plant species that may colonize refuge or Plum Island beaches. Early detection species include Asian sand sedge, yellow horn-poppy, and saltwort.
- Educate Town beach managers, Audubon plover monitors, and MA DCR on identification of these early detection species, and coordinate control and eradication if found on any Plum Island beach.
- Guide plant succession at the Stage Island bluff and remove invasive plants (tree of heaven, honeysuckle, etc.) to restore native plant community, while maintaining viewscapes.

Figure 5-1 Parker River NWR management units for beach, dune, maritime shrubland, and maritime forest habitats. This map shows the northern-most quarter of the refuge.

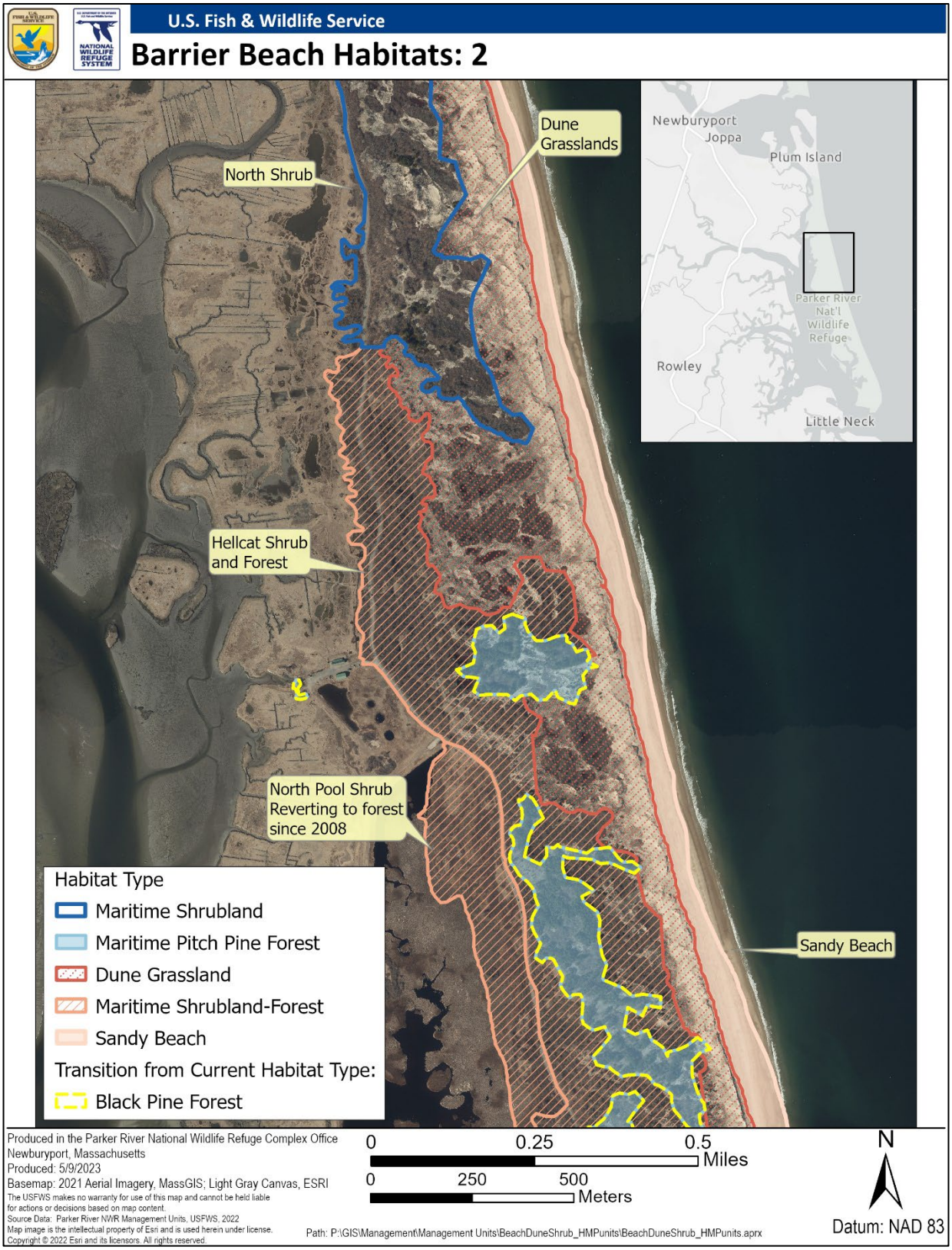

Figure 5-2 Parker River NWR management units for beach, dune, maritime shrubland, and maritime forest habitats. This map shows the north-central quarter of the refuge.

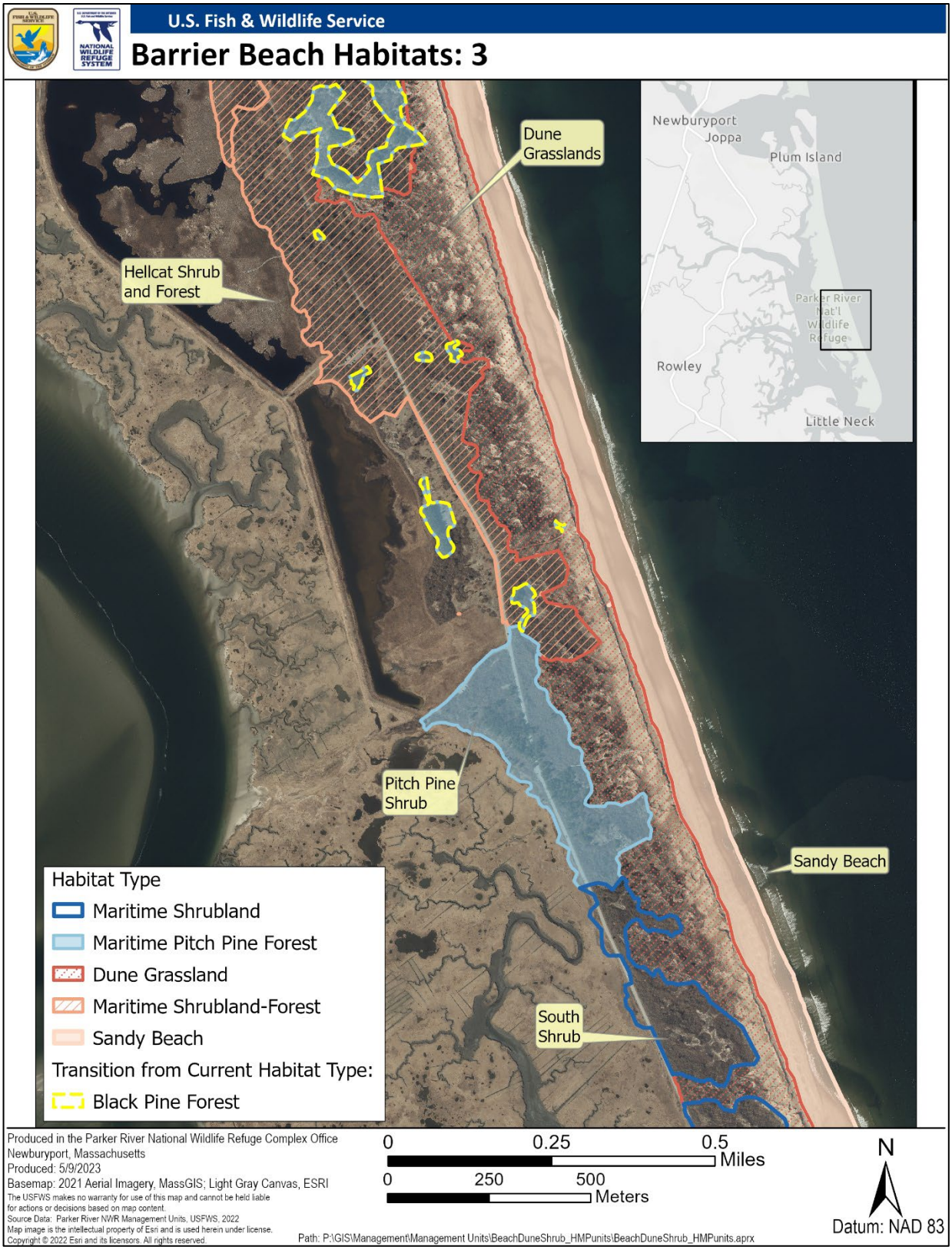

Figure 5-3 Parker River NWR Management Units for beach, dune, maritime shrubland, and maritime forest habitats. This map shows the south-central quarter of the refuge.

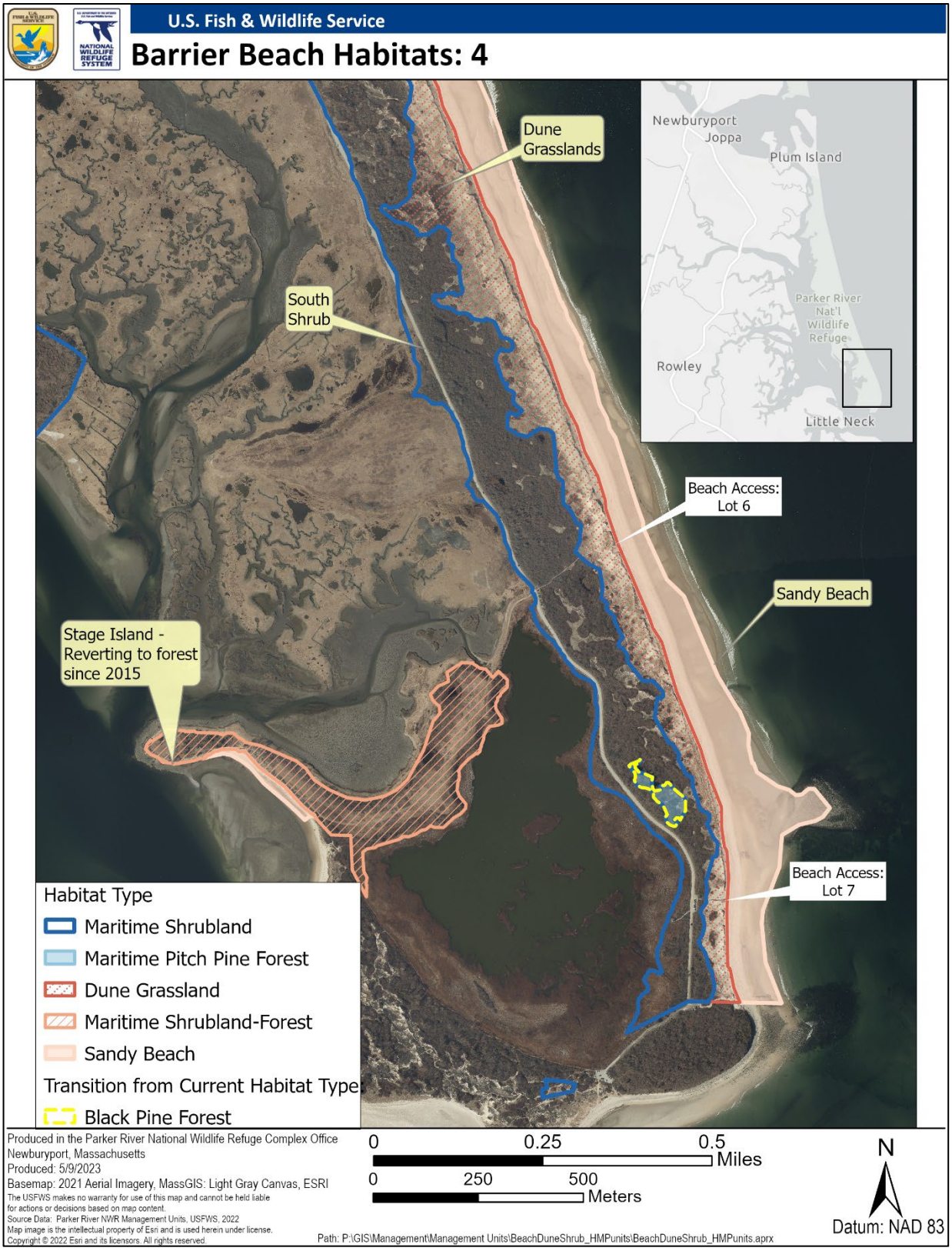

Figure 5-4 Parker River NWR management units for beach, dune, maritime shrubland, and maritime forest habitats. This map shows the southern quarter of the refuge.

1.2 Dune Grassland, Sandplain Grassland, Interdunal Swales

- Habitat Priority 2
- ROCs: Eastern Spadefoot Toad, rare Lepidoptera (e.g., Sandplain Euchlaena, Dune Noctuid Moth, Coastal Heathlands Cutworm)
- Other benefitting species: Ipswich Savannah Sparrow; migrating and wintering raptors (e.g., Northern Harrier, American Kestrel, Merlin, and Peregrine Falcon); rare beetles; breeding amphibians; rare plants (e.g., seabeach needlegrass)
- No planned change in acreage

Sandplain grasslands (24 acres) and interdunal swales (48 acres)

Sandplain grasslands and interdunal swales do not have their own management units because they are embedded within multiple other habitat types and management units. These rare natural communities primarily occur within maritime shrublands but can also be found within dune grasslands and maritime forests (Figure 5-5). While mainly located in maritime shrublands, these communities are biologically closely associated with dune grasslands as they all provide important resources to rare lepidopterans and the Eastern Spadefoot Toad. Although these habitats are included in many MUs, including North Shrub, Dune Grasslands, Hellcat Shrub and Forest, Pitch Pine Shrub, South Shrub, Black Pine Forest, and Bill Forward Shrub, the management strategies for sandplain grasslands and interdunal swales are listed here.

Dune Grasslands MU (444 acres)

The Dune Grasslands MU is a matrix of dune grasslands and interdunal swales with isolated patches of short, salt-tolerant maritime shrubs. There are 21 interdunal swales in this MU, some of which are cranberry bogs.

The dune grassland community occurs on windswept dunes within the salt spray zone, just behind the primary dunes. The salt spray and infrequent storms inhibit the growth of shrub species, so this habitat is dominated by grassland species such as beach grass, beach pea, seaside goldenrod, and beach heather. Populations of seabeach needlegrass (State threatened) are found in twelve different locations within this MU. While some of these populations remain relatively large (>10,000 individuals), all known seabeach needlegrass sites have decreased in size since 2004, and several subpopulations now contain less than 100 individual plants.

Sustain natural processes

- Allow the unrestricted and continual deposition and erosion of sand due to natural geological processes. The refuge will not inhibit such beach dynamics and will not construct infrastructure that may interfere with the shifting of the barrier beach and dunes but will repair existing infrastructure as necessary and appropriate.
- Reintroduce fire as a tool for creating disturbance and managing shrub encroachment within sandplain grasslands.

Support migratory birds, ROC, and T&E species

- Assess human disturbance levels associated with populations of sensitive species (e.g., seabeach needlegrass, Eastern Spadefoot Toad) and employ signage, trail closures or rerouting, as needed.

- Assess human disturbance associated with public use (e.g., cranberry picking, educational programs), and adjust use as needed through Compatibility Determinations.

Restore and maintain BIDEH

- Monitor rare plants (dragon's mouth orchid) and animal populations (Eastern Spadefoot Toad) and enhance or reintroduce if determined necessary.
- Selectively treat glossy buckthorn, black locust, Morrow's honeysuckle, and other invasive plants in the sandplain grasslands using mechanical, chemical, and fire strategies.
- Treat invasive plants in interdunal swales, including rusty willow, glossy buckthorn, *Phragmites*, and purple loosestrife using mechanical, chemical, and fire strategies.
- Eradicate beach rose on the refuge within 10 years using mechanical, chemical, and fire strategies. Educate the public on native and invasive roses.
- Treat spotted knapweed around Lot 1 using herbicide applications to prevent spread.
- Monitor to prevent and detect new infestations of invasive plant species.

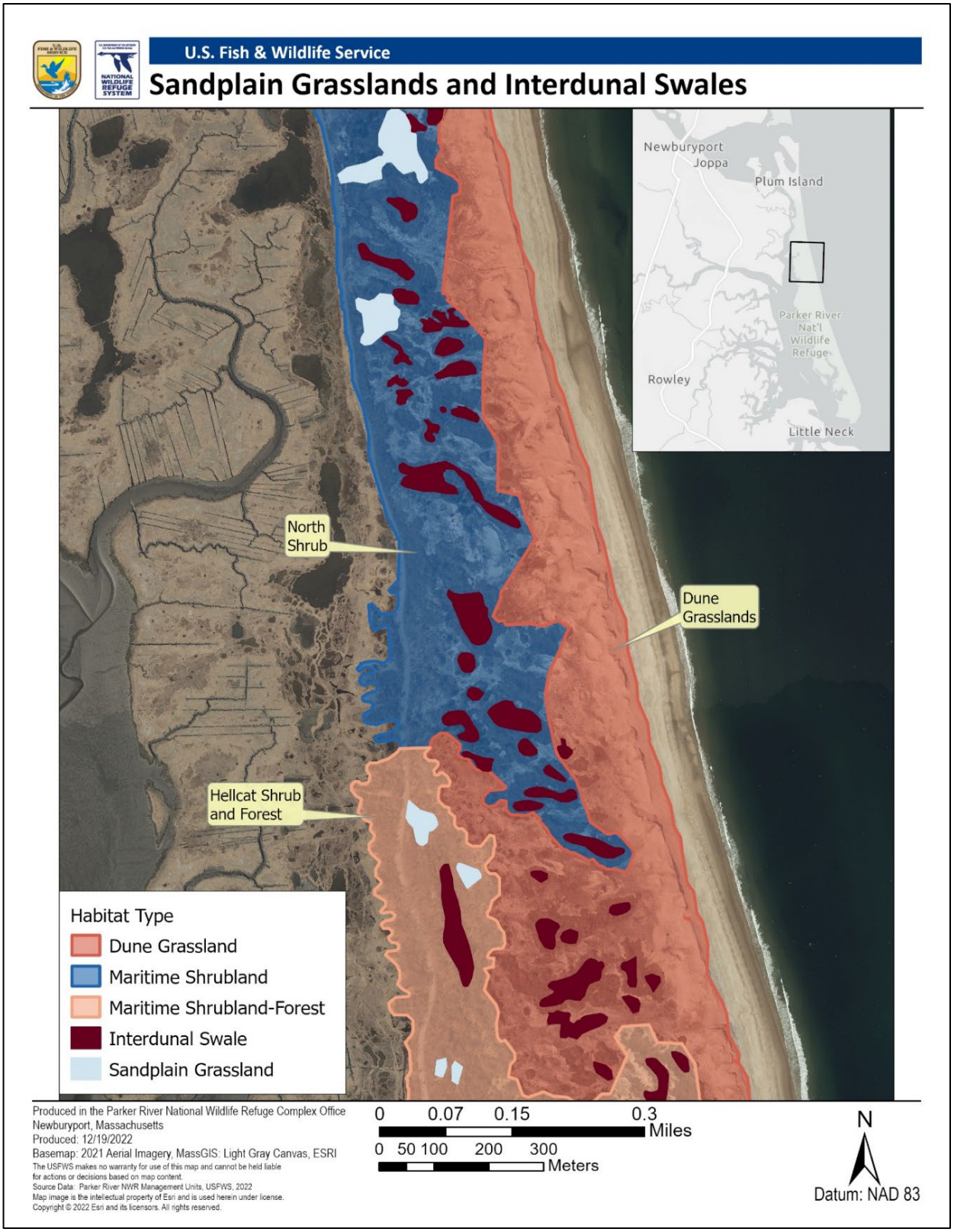

Figure 5-5 Example of how sandplain grasslands and interdunal swales intermingle with maritime shrubs and dune grasslands at Parker River NWR.

1.3 Maritime Shrubland, Maritime Forest

- Habitat Priority 2
- ROCs: Eastern Towhee, Brown Thrasher, Eastern Red Bat
- Other benefitting species: Eastern Kingbird; Baltimore Oriole; American Woodcock; migrating songbirds; New England Cottontail; migrating tree bats (e.g., Hoary, and Silver-haired Bats.
- No planned change in acreage (62 acres currently reverting from old field to Maritime Forest).

North Shrub MU (135 acres)

Maritime shrublands and forests, sandplain grasslands, interdunal swales

- The North Shrub Unit stretches from the northern boundary to the OMWM gate, an administrative entrance to the marsh located approximately 0.5 miles north of Sub-headquarters (Figures 5-3, 5-4, 5-7). It is located west of the dune grasslands and east of the salt marsh. The area is largely maritime shrublands intermixed with small amounts of dune pine forests, dune grasslands, sandplain grasslands and interdunal swales. Over time, the shrub density has increased within this MU. As of the last survey in 2017, this area had no invasive black pines. There are 44 cranberry bogs, including the largest, which is about one acre in size, and four sandplain grasslands in this MU.

Hellcat Shrub and Forest MU (170 acres)

Maritime shrublands and forests, sandplain grasslands, interdunal swales

The Hellcat Shrub and Forest unit stretches from the OMWM Gate (an administrative entrance to the marsh located approximately 0.5 miles north of Sub-headquarters) to the Lot 5 Pines Trail (Figures 5-1, 5-2, 5-5). It consists of maritime shrubland, and forest interspersed with 34 interdunal swales and four sandplain grasslands. The largest forest block on Plum Island lies within the heart of this MU, with mature tree species such as black gum, red maple, black cherry, and quaking aspen.

This unit surrounds the largest black pine forest, which is managed separately, and discussed below in Dune Pine Forest. A pilot project in 2009-2010 removed black pines from 1-acre area and planted pitch pine seedlings. Although successful, restoration is slow. Untreated, this stand of black pines provides the seed source for invasion of the adjacent dune grassland and maritime shrubs. This MU also hosts a long-term bird banding station, administered by Mass Audubon, which has operated since 1998.

South Shrub MU (106 acres)

The South Shrub Unit extends from the Pitch Pine Shrubs by Lot 5 to the southern boundary (Figures 5-3, 5-4). This MU is largely maritime shrubland punctuated by small patches of dune grasslands and interdunal swales. There is a small section of sandplain grasslands near the old Beach Buggy 2 access trail and two additional pockets bordering the Grape Island Marsh Unit. This unit has more mature trees than the North Shrub Unit, with more shrubs and forest patches and less open dune grasslands. There are 15 interdunal swales in this unit; they are small and spaced further apart, but some still support cranberry bogs.

Grape Island MU (23 acres)

Maritime shrublands and forests

Grape Island is a long, narrow strip of upland along the southwest edge of Plum Island (Figure 5-7). To the east, salt marsh separates Grape Island from other upland portions of Plum Island; to the west lies Plum Island Sound. A small farming settlement operated on the island beginning in the 1670s until the last resident passed away in 1984. All structures have since been removed, and the vegetation has succeeded to maritime forest and shrubland. Vegetation includes black pines, which refuge staff planted in 1980. Due to the difficulty in accessing the island (by boat or on foot through the salt marsh), no recent invasive mapping or treatment has been done.

Newbury Forest MU (21 acres)

Maritime shrublands and forests

The Newbury Forest consists of multiple small forest patches located along the western edge of the refuge (Figure 5-6). These patches are part of larger forest blocks that continue onto adjacent privately owned property. Four patches, including one 5-acre tract, are located adjacent to the Hunt Area A salt marsh. The largest patch (16 acres) is located within Hunt Area B. A small parking lot is located at the end of a private road in this unit, primarily to allow duck hunters to access the marsh. This MU receives little management due to its small size and access difficulties. There is potential for salt marsh migration within these forests as sea levels rise and salt water encroaches inland.

North Pool Shrub MU (33 acres)

Maritime shrublands and forests

In 2008, the refuge started restoration of the south portion of the North Pool Field (7 acres) to shrub habitat as part of a multi-refuge adaptive management project (Figures 5-2, 5-3). Restoration of the remaining 19 acres began in 2014. We treated invasive shrub species (e.g., glossy buckthorn and honeysuckle) in the southern portion in 2009 and in the full field in 2015-2017, and 2021. Monitoring indicates that the field has transitioned to the desired young shrub habitat with many berry-producing shrubs, including bayberry, winterberry holly, chokecherry, arrowwood, blueberry, and black cherry. Pervasive poison ivy in this unit currently makes invasive treatment very challenging.

Nelson Island MU (27 acres)

Maritime shrublands and forests

Nelson Island is a drumlin located on the western side of the refuge and is surrounded by salt marsh (Figure 5-6). A dirt road connects the drumlin to the nearest upland, crossing the salt marsh. Since the early 2000s, the frequency of road flooding has progressively increased, leaving some sections of the road permanently flooded. As a result, refuge management abandoned the road in 2013. Without a drivable access road, mowing ceased after 2012. Management shifted toward restoring Nelson Island to a maritime shrubland and forest. The distance from the drumlin to the nearest upland has reduced seed dispersal, leading to a slow recolonization of woody vegetation. Woody invasive plants like glossy buckthorn, honeysuckle, and multiflora rose were treated in 2015, 2016, and 2021 (Groves 2021).

Stage Island MU (25 acres)

Maritime shrublands and forests

Stage Island is a linear old field drumlin between the human-made Stage Island Pool and salt marsh, with Plum Island Sound along the western extent (Figures 5-4, 5-7). In 2014, the decision was made to restore this field to Maritime Shrub. The soil at this unit supports climax community dominated by oaks, hickory, red maple, sugar maple, birches, and white pine. As of 2020, this unit is comprised of a shrub/tree border around the edge of the drumlin, and dense patches of native species, such as bayberry and sumac, colonizing the field from the edges. The field is approximately 30% shrub cover, with black cherry and honeysuckle colonizing the middle, and an understory of Virginia rose, grape, poison ivy, bedstraw, vetch, and spurge. Woody invasive plants like glossy buckthorn, honeysuckle, multiflora rose, and Asiatic bittersweet were treated in 2015, 2016, and 2021. In 2016, the last privately-owned house on the refuge was removed from the western tip, allowing for the extension of the Stage Island Trail through the full MU to the point overlooking the Ipswich Bluffs. A small patch of tree-of-heaven was found by the bluffs and treated in 2017, but it persists.

Strategies for Maritime Shrubland and Forest

Sustain natural processes

- Reintroduce fire as a tool for creating disturbance and controlling invasive plants.
- Allow the North Pool Shrub MU, Stage Island MU, and Nelson Island MU to succeed to maritime forest.
- Assess potential for marsh migration within the Newbury Forest MU, including establishing marsh migration transect per Tiner et al. (2002).

Support migratory birds, ROC, and T&E species

- Continue to partner with Massachusetts Audubon Society to monitor landbird use during spring and fall migration via the banding program.
- Monitor berry-producing plants and abundance using established or new protocols to ensure high-quality foraging habitat for fall migrating songbirds.

Restore and maintain BIDEH

- Treat invasive plants, such as bush honeysuckle, buckthorns, barberry, Asiatic bittersweet, rusty willow, multiflora rose, tree-of-heaven, and beach rose, using mechanical, chemical, and fire strategies, to restore native habitats, including pollinator plants.
- Map and remove invasive black pines using mixed approaches of cutting and spraying. Investigate additional methods of control.
- Monitor succession of North Pool Shrub MU, Stage Island MU, Nelson Island MU, to ensure recovery of native plant communities as described in Objectives. Monitoring should include the detection of new invasive species. If found, employ EDRR tactics to eradicate.

Figure 5-6 Parker River NWR management units: Newbury Forest and Nelson Island.

1.4 Dune Pine Forest

- Habitat Priority 2 (Figures 5-2 to 5-4)
- ROCs: Eastern Whip-poor-will
- Other benefitting species: Rare Lepidoptera
- No planned change in acreage

Pitch Pine Shrub MU (28 acres)

Dune pine forests, sandplain grasslands, interdunal swales

This unit is dominated by pitch pines, often with little or no shrub layer (Figure 5-3). The understory vegetation is composed of beach heather, bearberry, lichen, or Pennsylvania sedge with extensive amounts of invasive honeysuckle present. From the lack of fire in the unit, the duff layer is thick. This has resulted in the roots of the pitch pines to be shallow. It also prevents further seed germination. There is a small patch of sandplain grassland on the western edge and two interdunal swales on the southern end.

Black Pine Forest MU (48 acres)

Black pine forest, maritime shrubland and forest, dune grasslands, sandplain grasslands, interdunal swales

This unit encompasses the largest black pine infestations, with approximately 29 acres dominated by mature trees and an additional 6 acres of seedlings (Figures 5-2 to 5-4). The infestations are primarily within maritime shrublands and maritime forests but are also spreading into the dune grasslands. An area of sandplain grassland and seven interdunal swales are scattered throughout this management unit.

Strategies for Dune Pine Forest

Sustain natural processes

- Collaborate with fire program to develop strategy to reduce duff layer and shrub cover while preventing damage to the pitch pine root system.
- Monitor the response of invasives to a fire treatment.

Restore and maintain BIDEH

- Restore the pitch pine forest habitat using prescribed fire and control of invasive plants to create the desired open understory typical of this habitat.
- Transition black pine dominant forests to pitch pine forests by cutting and treating black pines with herbicide and planting pitch pines.
- Investigate additional control methods for black pines.
- Update black pine mapping to track black pine spread and treatment success.
- Reduce or eliminate non-native honeysuckles, buckthorn, and Asiatic bittersweet using mechanical, chemical, and fire strategies.

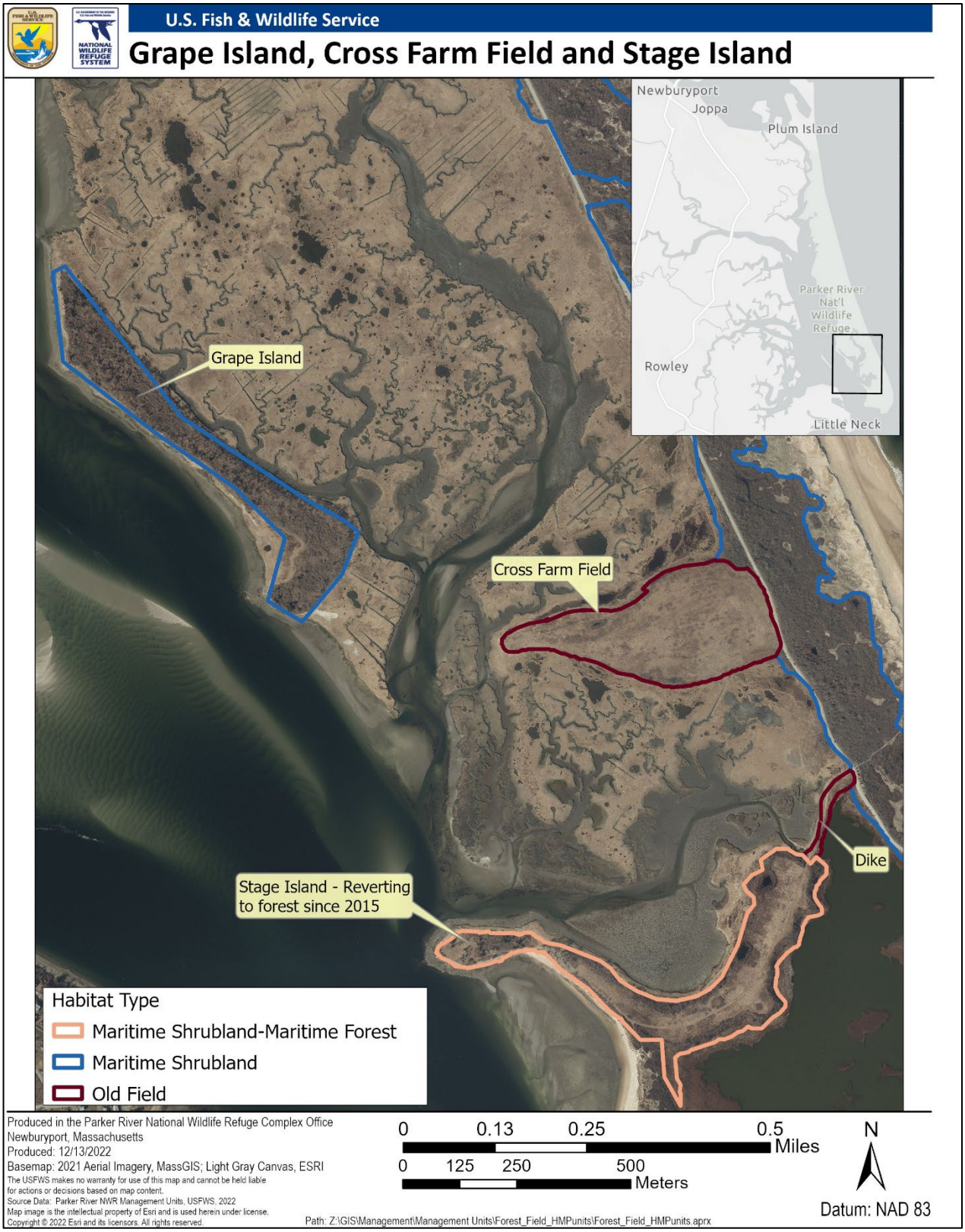

Figure 5-7 Parker River NWR management units: Grape Island, Cross Farm Field, and Stage Island.

2.1 Old Fields

- Habitat Priority 2 (Figures 5-7, 5-8)
- ROCs: Bobolink, pollinators (e.g., Monarch butterfly, native bees)
- Other benefitting species: American Woodcock, Northern Harrier, Short-eared Owl, Whimbrel, Savannah Sparrow
- No planned change in acreage

Cross Farm Field MU (24 acres)

Old field

Cross Farm Hill is a drumlin that was farmed prior to refuge ownership (Figure 5-7). Currently, it has virtually no native plants other than poison ivy, milkweed, and goldenrods. The upper part is covered with a mix of grass-leaved stitchwort and grasses, including quack grass, hard fescue, meadow fescue, common timothy, and Canada bluegrass. Interspersed among the mixed grasses are patches of common milkweed, Asiatic bittersweet, Canada thistle, wild garlic, and poison ivy. Several small patches of black swallowwort have been treated periodically with herbicide since 2010. In 2017, one invasive porcelain berry and seven rusty willows were found and treated. A patch of spotted knapweed was found in the southeast corner in 2011 but has not been treated.

According to Weare (1996), topsoil was removed from the top of this hill to build the road, which explains the shallow depth to the dense layer in the Windsor soil in this part of the field. This unit will likely succeed to coastal forest/woodland if unmanaged. Cross Farm Field has good potential to support grassland nesting birds due to its relatively large size and proximity to open habitat with the adjacent salt marsh. Refuge staff have confirmed breeding Savannah Sparrow and Bobolink as recently as 2021. Historically, this unit supported breeding Eastern Meadowlark.

A significant management consideration is to contain and eradicate black swallow-wort and porcelain berry to prevent spread of these invaders to other habitats and units. Both these species will invade shrub and forest habitats. Allowing a field to revert prior to eradicating these species may make control and eradication more difficult.

Bill Forward Field MU (11 acres)

Old field

The drier areas of the Bill Forward Field (near the road) grade into the shrub and grass mosaic north of the field (the Bill Forward Shrub MU) (Figure 5-8). They meet in a weedy area that harbors Canada bluegrass, drooping brome grass, English plantain, common king devil, rabbit-foot clover, common timothy, and Asiatic sweet clover. Wet areas support mainly non-native vegetation, with single species stands of curly dock, foxtail barley, and common plantain. Two native species are present in these wet areas: one-glumed spikesedge and sensitive fern. The northwest corner of the field closest to Bill Forward Pool was historically planted with a seed mixture of annuals and weedy perennials.

Sub-headquarters Field MU (12 acres)

Old field

The Sub-headquarters Field is dominated by Virginia rose, poison ivy, and Pennsylvania sedge, with patches of hair fescue, hairy hudsonia, and dune reindeer lichen (Figure 5-8). It is largely uninvaded and supports a dwindling population of seabeach needlegrass. Located ~150 ft east of the northernmost pond within the MU on a small, sandy dune area, this population now includes less than fifty individual plants - a significant reduction from a population size of 1,000 plants in 2004. The lower areas and pool edges support freshwater cordgrass and other native species as well as a large patch of climbing nightshade, an invasive plant. On the edge of this MU is the refuge's historic burn pile, where vegetation refuse was dumped and burned annually until 2010. The transported vegetation and soil disturbance may be responsible for nearby patches of invasive plants, including Morrow's honeysuckle, drooping brome grass, and leafy spurge. This unit is mowed annually to limit encroachment of woody vegetation.

North Pool/Bill Forward Dike MU (23 acres)

Old field

This unit includes the earthen berms that separate the human-made North and Bill Forward Pools from the salt marsh and each other (Figure 5-8). Annually mowed to prevent the growth of shrubs and trees, these long, narrow grassland units are characterized by a level top with a two-track path down the middle and sloping sides. Although the dike is narrow, it abuts the salt marsh and the impoundments, increasing its appeal for grassland nesting birds. Willet, Bobolink, and Savannah Sparrow nest along the dike. The dike is being invaded by spotted knapweed, leafy spurge, and Phragmites. No treatment has been applied thus far.

Bill Forward Shrub MU (15 acres)

Maritime shrubs, sandplain grasslands, old fields

This sandplain shrubland is a mosaic of sandplain grasslands and shrub islands (Figure 5-8). The area north of the Bill Forward Blind is approximately 50% shrubs. An additional 25% cover consists of small shrubs interspersed with graminoids, held in check by mowing every three to five years. Small patches of beach grass, Pennsylvania sedge, little bluestem, and other native grasses and forbs are interspersed in stands of shining sumac, beach plum, northern bayberry, and pasture rose. South of the blind there are fewer shrubs (20% cover) and more graminoids and forbs. Beach grass, poison ivy, Pennsylvania sedge, beach plum, beach heather, and little bluestem are more prevalent here than the north portion.

This unit is managed through mowing every three to five years to reduce encroachment by woody vegetation, allowing for the continuation of native grasses and forbs used by native pollinators. The patchy shrubland also provides habitat for American woodcock.

Stage Island Dike MU (1 acre)

Old field

While a majority of Stage Island has reverted to shrubland, the dike (Figure 5-7) continues to be mowed for dike maintenance and pedestrian safety. The most common species are Canada bluegrass, common timothy, Rhode Island bentgrass, red fescue, redtop, quack grass, and goldenrods. There are populations of invasive leafy spurge, spotted knapweed, Asiatic bittersweet, and drooping brome grass distributed in localized patches. Purple loosestrife and *Phragmites* are found in the wetter areas. A patch of perennial pepperweed at the toe of the dike was eradicated in 2019 and has been cleared since. Annual inspections are necessary to ensure no re-invasion as this marsh edge is across the way from large infestations in Ipswich.

Strategies for Old Fields

Support migratory birds, ROC, and T&E species

- Experiment with timing of mowing, grazing, fire, soil restoration, and native plants to restore plant communities more conducive to nesting grassland birds and pollinators.
- Mow Cross Farm Field, Bill Forward Field, Sub-Headquarters Field, and the North Pool/Bill Forward dike annually after August 15 to prevent shrub growth and encourage grasses. Leave patches of nectar and host plants (e.g., milkweed, asters, goldenrod) for Monarch and other pollinators.
- Evaluate the importance of Plum Island for migrating Monarchs and develop strategies for management.
- Mow the Bill Forward Shrub MU every 3-5 years to reduce shrub encroachment and create a habitat mosaic for species such as American Woodcock.

Restore and maintain BIDEH

- Treat invasive plants, such as bush honeysuckle, buckthorns, barberry, Asiatic bittersweet, multiflora rose, and beach rose, using mechanical, chemical, and fire strategies, to encourage native plant communities, including pollinator plants.
- Continue to use herbicide treatments for invasive black swallowwort and porcelain berry within Cross Farm Field and at Headquarters with the goal of eradication within the next 10 years.
- Monitor fields for new invasive species. If found, employ EDRR tactics to eradicate.
- Restore Cross Farm Field to more native and graminoid plant composition to support grassland nesting birds and to eradicate black swallow-wort and porcelain berry.
- If Cross Farm is not restored to more native grassland by 2030, consider letting this unit revert to maritime shrub and forest to support migratory birds and to reduce maintenance.

Figure 5-8 Parker River NWR management units: Sub HQ Field, Dikes, and Bill Forward Field.

2.2 Impoundments

- Habitat Priority 2 (Figures 5-11, 5-12)
- ROCs: Migrating shorebirds (e.g., Semipalmated Sandpiper, Red Knot, Black-bellied Plover), migrating waterfowl (e.g., American Black Duck, Northern Pintail, Green-winged Teal)
- Other benefitting species: Breeding waterfowl (e.g., Gadwall, Mallard, Canada Goose), secretive marsh birds (e.g., Virginia Rail, American Bittern, Least Bittern), Marsh Wren
- Reduce by 266 acres

North Pool MU (114 acres)

Impoundment

North Pool is a human-made impoundment created in 1948 by building an earthen dike through the salt marsh (Figure 5-11). North Pool is currently brackish to freshwater marsh habitat. Precipitation provides its sole source of fresh water, and water levels can be managed by adding or releasing water through a single water control structure along the dike. In the past, management was limited by an inability to adequately lower and raise water level. The impoundment is managed to support breeding marsh and wading birds, although marsh and wading breeding numbers have been declining. The static water level regime for marsh and wading birds has led to the development of undesirable monotypic plant communities, primarily invasive *Phragmites.* The aging dike will be subject to continued sea level rise and increased storm frequency, putting its long-term security in question. Hydrological and vegetative models predicted that restoration to a mix of high and low marsh is feasible (WHG 2018, 2019).

Interim strategies prior to restoration

- Maintain high water levels (6-24" above marsh) through the breeding season (April – August), until decommissioning.
- Every five years, conduct a gradual drawdown beginning August 15 to allow for aerobic activity in benthic areas. Water levels during drawdown should be low enough to expose as much undecomposed organic matter as possible while still maintaining refugia (e.g., pools capable of supporting aquatic invertebrates, amphibians, reptiles, and fish). Water levels must be sufficient to allow relatively rapid recolonization of the impoundment when full water is restored.
- Drawdowns may occur sporadically for invasive *Phragmites* control and for other administrative or biological needs, such as overwintering *Galerucella* beetles that control purple loosestrife, and certain monitoring needs.
- In early October, flood as necessary to get water close to marsh surface, allowing precipitation to raise water level thereafter. Leave the pool full throughout the winter.
- Continue to collaborate with MassWildlife to improve habitat conditions to support marsh and wading bird breeding habitat in North Pool, seek funding to control *Phragmites*, and monitor breeding marsh and wading bird populations.
- Work with MassWildlife to conduct periodic water chemistry testing to track the effects of drawdowns on oxygen, salinity, phosphorous and nitrogen levels, and nutrient composition.

Bill Forward Pool MU (34 acres)

Impoundment

Bill Forward Pool is the smallest of the three impoundments at 34 acres (Figure 5-11). Bill Forward Pool and North Pool were created concurrently in 1948 and share the same main dike separating them from the salt marsh. A second shorter dike, perpendicular to the first, splits the area into the two pools. Bill Forward Pool currently has the most effective water management to benefit shorebirds and waterfowl due to its gradually sloping elevations. Sediment core samples (Fitzgerald et al. 2017) indicated that much of the substrate in this impoundment is sand and muddy sand, with very little organic peat matter. The refuge simultaneously manages for the competing needs of waterfowl (open water) and shorebirds (mudflats) in this impoundment. *Phragmites* has expanded into what were once mudflats, decreasing the amount of habitat available for shorebirds. This impoundment has subsided the most relative to the adjacent salt marsh, with an elevation difference of 69 cm. Climate change will also impact Bill Forward Pool in the future, as the aging dike will be subject to sea level rise and increased storm frequency.

Interim strategies prior to restoration

- Create high water conditions in spring to suppress *Phragmites* and other robust perennial plants (fireweed, marsh fleabane, cattail, etc.)
- Alternate spring and fall drawdowns with Stage Island impoundment each year, such that optimal shorebird habitat (shallow water and mudflats with an abundance of invertebrates) is provided from May to September each year, and each impoundment is flooded during the growing season every other year to promote moist soil annual plants.
- Flood up in late August (Spring Drawdown) to October (Fall Drawdown) to provide habitat for fall waterfowl migration.
- Manage robust vegetation (cattail, *Phragmites*) to promote species favorable to feeding shorebirds and waterfowl.

Stage Island Pool MU (118 acres)

Impoundment

Stage Island Pool was created in 1957 at the southern end of the refuge, about four miles from the other two impoundments (Figure 5-12). Fifty-three acres of the impoundment can be managed as a moist soil unit due to its gradual sloping pool bottom elevations; the remainder of the impoundment (65 acres) is dominated with robust vegetation. Water level management for this unit is constrained by the need to avoid impacts to clamming in the tidal channel outside the water control structure. Typically, this restricts drawdowns to Sunday or when clam flats are closed due to weather events. Shorebird use in Stage Island has decreased in recent years compared to 2010 to 2011 numbers (USFWS 2012), potentially because of limitations on a drawdown schedule. The refuge plans to restore tidal flow to Stage Island Pool, which has subsided more than a foot relative to the adjacent marsh since impoundment (Fitzgerald et al. 2017). Restoration would convert Stage Island Pool to salt marsh, help control invasive plant species, and increase climate resilience in the future.

Interim strategies prior to restoration

- Create high water conditions in the spring to suppress *Phragmites* and other robust perennial plants (fireweed, marsh fleabane, cattail, etc.).

- Alternating Spring or Fall drawdown with Bill Forward each year, such that optimal shorebird habitat (shallow water and mudflats with an abundance of invertebrates) is provided from May to September each year, and each impoundment is flooded during the growing season every other year to promote moist soil annual plants.
- Flood up in late August (Spring Drawdown) to October (Fall Drawdown) to provide habitat for fall waterfowl migration.
- Manage robust vegetation (cattail, *Phragmites*) to promote species favorable to feeding shorebirds and waterfowl.

Strategies for Impoundments

Mitigate or adapt to climate change

- Continue to monitor the relative elevation of impoundments in relation to adjacent salt marsh using established surface elevation tables.
- Add additional elevation transects using Real Time Kinetic GPS equipment.
- Develop monitoring protocols to understand uncertainties related to restoring to a salt marsh ecosystem for Stage Island Pool. Uncertainties include initial elevation loss with conversion from fresh to saline system, sediment accretion, natural restoration of geomorphological features with the new tidal regime, shifts in vegetation community after equilibrium has been reached and with continued sea level rise.
- Work with partners to plan and implement restoration of Stage Island Pool by 2027.
- By 2035, initiate restoration of North Pool and Bill Forward Pool with updated restoration predictions and timeframe for restoring North and Bill Forward Pools based on information learned from Stage Island Pool and the latest climate science.
- Explore alternatives (e.g., bridge, open bottom culverts) to provide continued access to Stage Island Trail post-restoration to support public use, habitat management, and maintenance.

Restore and maintain BIDEH

- Using a combination of water level manipulation, herbicide application, mowing, and biological control, and fire to manage for desired vegetation and control of invasive plants.
- Monitor plant species composition and response to water level management using established vegetation plots.
- Continue to assess and implement strategies for *Phragmites* control.
- Monitor the populations of purple loosestrife.

2.3 Salt Marsh

- Habitat priority 1 (Figures 5-9 to 5-13)
- ROCs: Saltmarsh Sparrow, American Black Duck
- Other benefitting species: Nesting birds (e.g., Nelson's Sparrow, Seaside Sparrow, Black Rail, Clapper Rail, Willet); migrating shorebirds (e.g., Greater Yellowlegs, Short-billed Dowitcher, Least Sandpiper); foraging wading birds (e.g., Snowy Egret, Glossy Ibis); migrating and wintering raptors (e.g., Northern Harrier, Snowy and Short-eared Owl, Bald Eagle, Peregrine Falcon)
- Increase by 266 acres

Plum Island River Marsh MU (395 acres)

Salt marsh

The Plum Island River Marsh is located primarily on Plum Island, extending from the northern refuge boundary to Sub-headquarters (Figure 5-9). Several small marsh islands are located within the Plum Island River, which forms the unit's western boundary. To the east is the refuge road and associated upland. It contains one of the refuge's most notable features, the large salt pannes. This popular birding spot attracts a variety of shorebirds, wading birds, and dabbling ducks. The marsh surrounding the salt pannes is favored by the Saltmarsh Sparrow.

Due to its accessibility and high habitat value, the Plum Island River Marsh has been the primary focus of marsh restoration pilot projects, including ditch plug removal, runneling, and OMWM modification. A summary of these pilot projects can be found here (Pau et al. 2022). Historically, the area has received a host of human alterations, including the construction of agricultural embankments and ditches in the 1700s to 1800s and OMWM mosquito control treatment in the 2000s.

Area A Marsh MU (904 acres)

Salt marsh

The Area A Marsh Unit covers the area south of Little Pine Island Creek to the Parker River and is one of the three waterfowl hunt areas on the refuge (Figure 5-9). The area to the north is largely owned by Essex County Greenbelt. The refuge has no direct foot access to this unit, with most access occurring via boat, or via adjacent private land. Three large tidal creeks (Pine Island, Jericho, and Hason's Creeks) meander through this unit. This unit has a high density of breeding Saltmarsh Sparrow and Marsh Wren populations. The marsh north of Pine Island Road has higher occurrences of invasive *Phragmites* and perennial pepperweed. The initial runnel project was piloted in this unit from 2015-2017 (Burdick 2017).

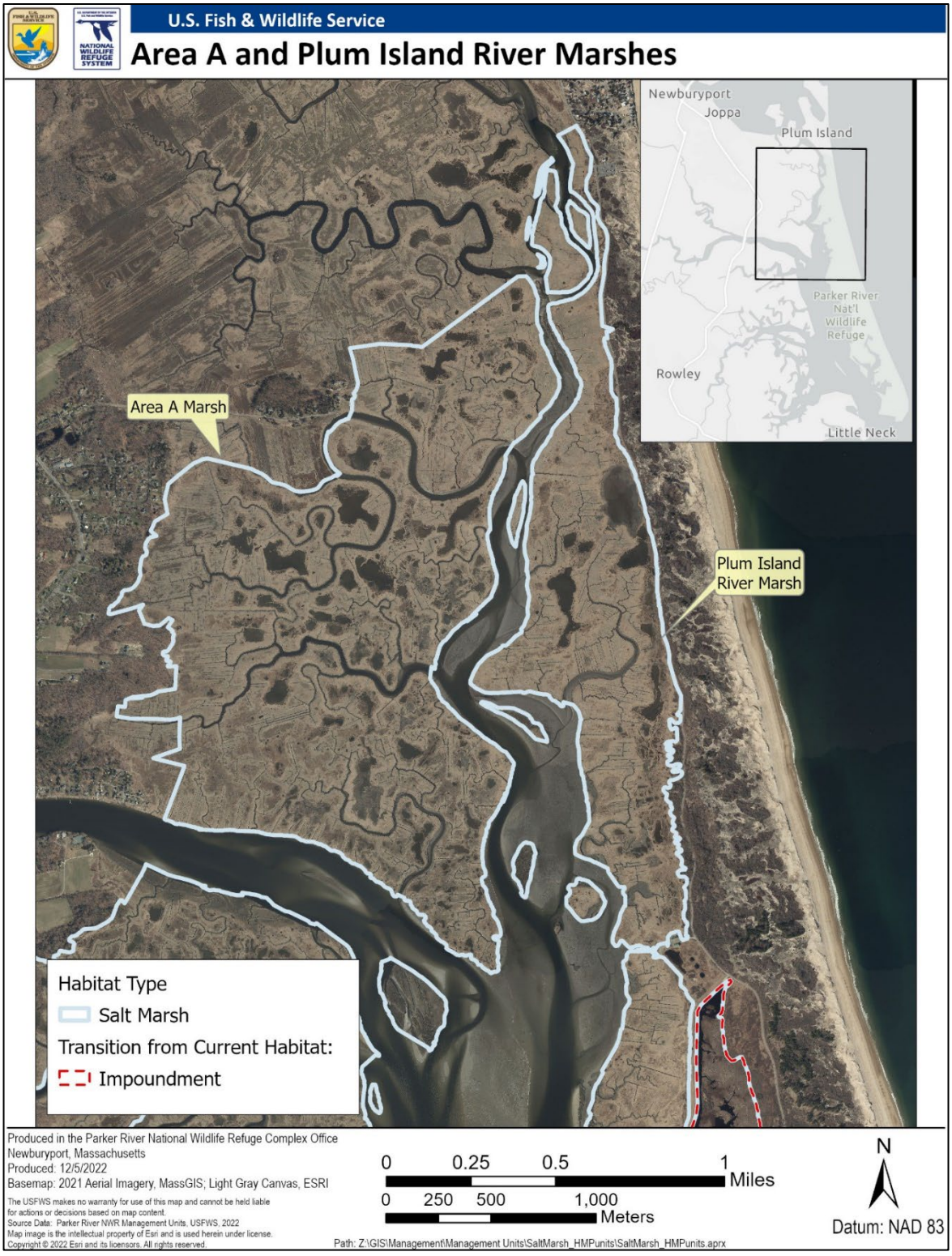

Figure 5-9 Parker River NWR management units: Area A and Plum Island River Marshes.

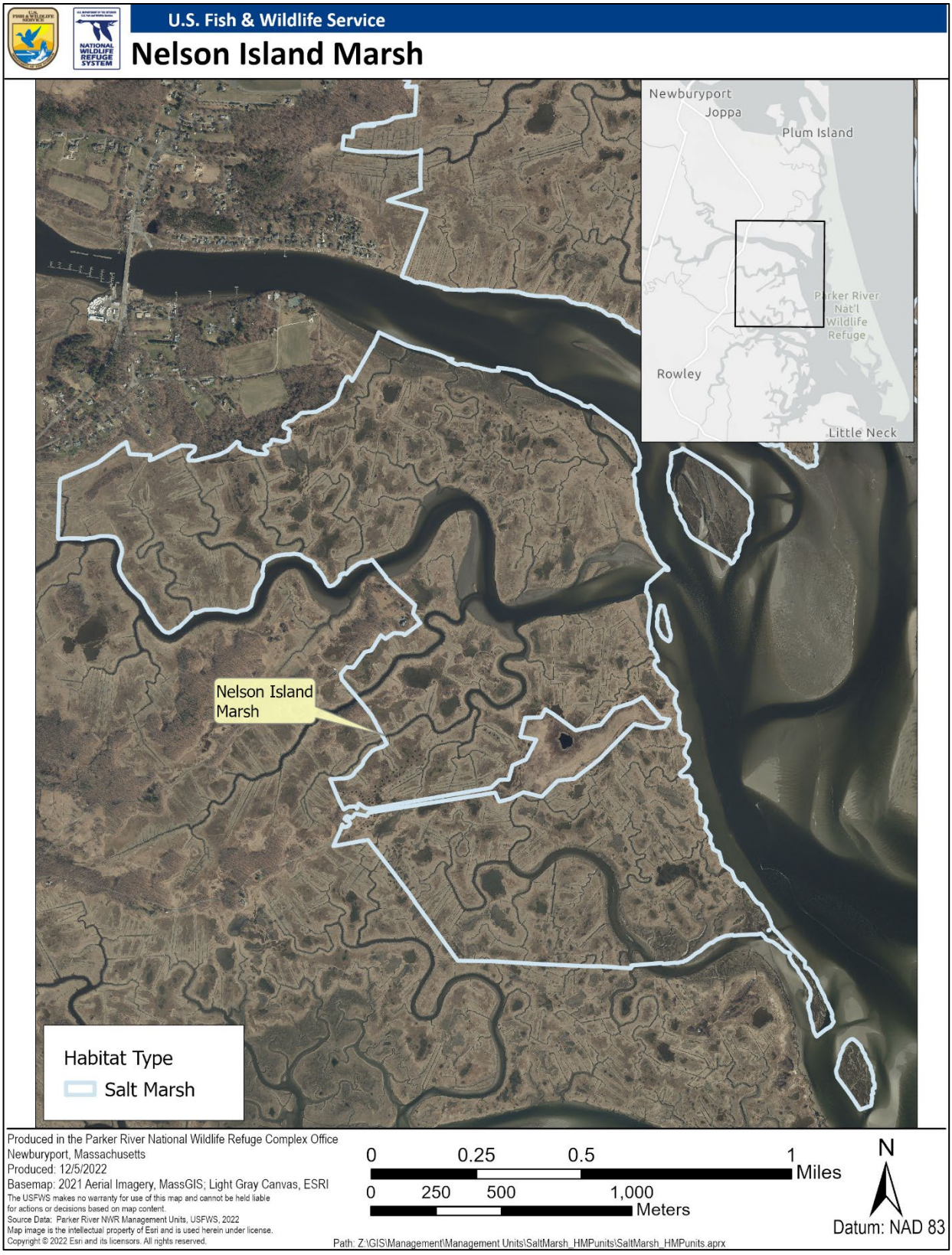

Figure 5-10 Parker River NWR management unit: Nelson Island Marsh

Figure 5-11 Parker River NWR management units: Impoundment Marsh, North Pool, Bill Forward Pool.

Nelson Island Marsh MU (798 acres)

Salt marsh

Nelson Island Marsh is bordered by the Parker River to the north, Plum Island Sound to the east, and the outlet of Nelson Island Creek to the south (Figure 5-10). Much of the abutting land to the west is owned by Essex County Greenbelt or Massachusetts Audubon Society. The Unit includes both Waterfowl Hunt Area B (located in the town of Newbury) and C (Nelson Island, located in the town of Rowley). Access to the northern portion of this unit (Hunt Area B) is via boat or on foot from a small parking area in the Newbury Forest MU located off Marsh Avenue. The marsh surrounding the Nelson Island Shrub Unit can be accessed on foot from the end of Stackyard Road. Mud Creek, a large tidal creek, separates Hunt Areas B and C.

A pilot ditch remediation project was implemented in this unit from 2014 through 2016. This secondary pilot project is testing the spatial distribution of ditches to be kept open for proper draining and flooding. These remediation sites have experienced extensive revegetation and sediment trapping, indicating the successful healing of treated ditches. Continued monitoring will determine marsh-wide impacts of remediation. Success criteria include formation of single channel hydrology that does not clog over time, increase in ground water table and elevation gain in the marsh platform as the ditches heal. Boston University also piloted an eelgrass transplant pilot from 2017 to 2019 as part of an effort to restore eelgrass to Plum Island Sound. Success has been mixed with winter damage and green crab herbivory in some years.

Impoundment Marsh MU (230 acres)

Salt marsh

The Impoundment Marsh lies between the Bill Forward and North Pools to the east and Plum Island Sound to the west (Figure 5-11). From north to south, it stretches from Sub-headquarters to the south end of Bill Forward Pool. This is the narrowest stretch of salt marsh on the refuge, ranging between 625 ft and 1,425 ft wide. The narrowness combined with its proximity to Plum Island Sound makes this marsh highly vulnerable to erosion and marsh degradation. The impoundment dike compounds the problems, preventing flood waters from expanding eastward and causing more impounding within this marsh as compared to other marshes.

To date, little restoration activity has taken place within this unit. It was, however, the pilot site for an early ditch remediation project in 2010. The project demonstrated the proof of concept that we can re-create peat in ditches by placing cut grass in them. The peat in these ditches has not recovered to the same elevation as the adjacent marsh, but *Spartina* is growing in most remediated ditches. A large sediment deposition event caused by a Nor'easter occurred in January 2018, with this site receiving extensive sediment deposits totaling 40 acres. Rough calculations estimated 10-years' worth of elevation gain within this one event. Despite the thickness of the deposit (25.6 $\pm$ 2.9 mm), the entire site was vegetated by August. Subsequent monitoring in 2022 indicated that the vegetation community has transitioned to a diverse mix representative of high marsh and the peat has developed porosity and an extensive root network like other marsh sites.

Photo 5-1 Sediment deposited by Nor'easter Grayson at Parker River NWR, January 2018. Credit: Greg Moore.

Grape Island and Stage Island Marsh MU (543 acres)

Salt marsh

The Grape Island and Stage Island Marsh lie between the southern end of Bill Forward Pool and surrounds Stage Island drumlin (Figure 5-12). Plum Island Sound forms the western boundary, while the Refuge Road and associated upland forms the eastern boundary. Middle Ground, a 37-acre sandbar/marsh island within Plum Island Sound, is also part of this unit. Pine Creek, a large tidal creek, runs through the unit. Access to the marsh west of Pine Creek is challenging and is largely by boat. The north end of this unit abuts the Knobbs sand spit, and the south end of this unit surrounds the Stage Island drumlin. Both these areas are higher in elevation and support nesting Saltmarsh Sparrows.

Figure 5-12 Parker River NWR management units: Grape Island and Stage Island Marshes.

McCue Marsh MU (56 acres)

Salt marsh

Also known as Waterfowl Hunt Area D, this marsh is located just south of the Rowley River in the Town of Ipswich (Figure 5-13). Large areas of this unit are low marsh that are flooded daily and dominated by tall form *Spartina alterniflora*. Access to this parcel is via boat only.

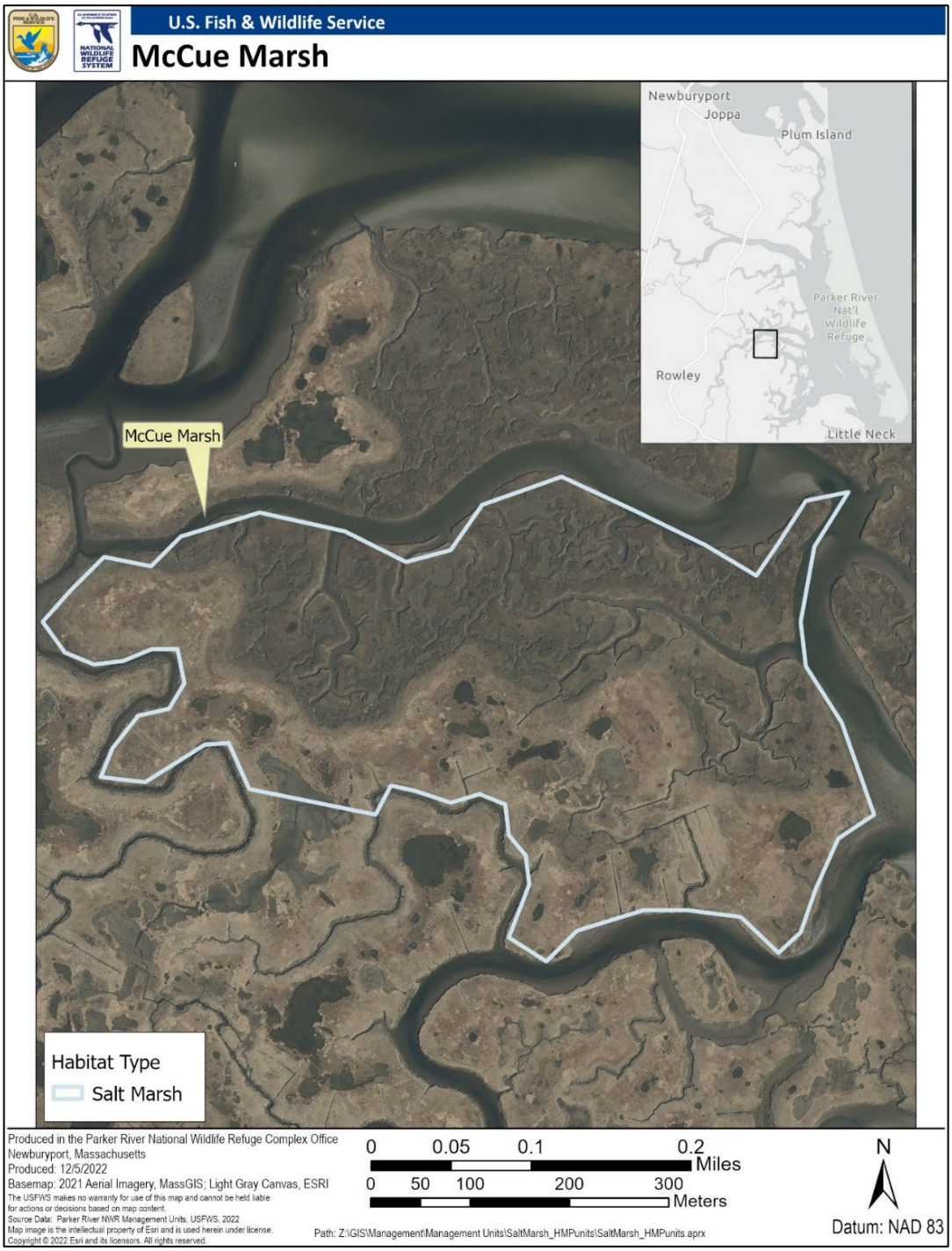

Figure 5-13 Parker River NWR management unit: McCue Marsh.

Strategies for Salt Marsh

Sustain natural processes

- Restore 8,000 acres of salt marsh in the Great Marsh, including 2,500 acres on the refuge, using hydrological restoration techniques piloted by refuge staff and Salt Marsh Restoration Team (SMARTeam).
- Monitor the restoration site, natural pool breaches, natural ditch remediation, and sediment deposition sites to understand how the marsh is responding to climate change with and without restoration intervention.
- Continue to fine tune restoration techniques, including determining the appropriate width and depth of runneling, identifying the best restoration techniques for different sites, and selecting the sites that need intervention.
- Restore impoundments to salt marsh (See Objective 2.2 Impoundments above).
- Work with engineers and transportation experts to allow for movement of water and sediment across the refuge road to accommodate eastward marsh migration.
- Assess potential for marsh migration on west side of the refuge, including establishing marsh migration transect per Tiner et al. (2014).
- Assess the potential for thin layer deposition as a strategy to increase accretion rates by continuing to monitor and evaluate natural deposition events.
- By 2030, work with US Army Corp of Engineers, regulators, and partners to pilot a thin layer deposition project to benefit salt marsh habitat and nesting species such as Saltmarsh Sparrows and Common Terns.
- Work with Regional Fire staff to understand role of fire in salt marsh, including benefits of fire and impacts to accretion rates and ability to capture sediment.
- Work with Parker-Ipswich-Essex Rivers Partnership, local towns, and conservation groups to protect and restore the Parker River Watershed and Plum Island Sound.
- Continue to read sediment elevation tables (SET) and feldspar horizon markers on a rotating basis. Analyze SET data to assess marsh accretion rates relative to sea level rise and impacts of plant species on accretion.
- Monitor extent, sediment elevation, sediment thickness, and revegetation of the natural 2018 sediment deposition event at the Impoundment Marsh MU by partnering with the University of New Hampshire. Monitor impacts of any similar events in the future.
- Use aerial imagery and LIDAR to document the timing, frequency, and pattern of pool breaches and sedimentation events.
- Support (e.g., access permission, funding, labor, etc.) partners implementing eelgrass restoration in Plum Island Sound and areas adjacent to the refuge.

Support migratory birds, ROC, and T&E species

Sustain bird populations

- Annually conduct point count surveys with an emphasis on Saltmarsh Sparrows; support similar surveys conducted by the Saltmarsh Habitat and Avian Research Program (SHARP 2023).
- Conduct Saltmarsh Sparrow rapid demographic surveys in accordance with SHARP protocols, contributing to regional monitoring and modeling efforts.

- Coordinate with SHARP and other regional partners regarding development of new Saltmarsh Sparrow restoration techniques.
- Continue to annually monitor Common Tern nesting colonies in Plum Island Sound as part of the State's annual colonial nesting bird survey.
- Redesign and implement a volunteer bird survey protocol to quantitatively assess waterbird and shorebird use, specifically at the salt pannes.

Minimize human disturbance

- Continue to review requests for public access to and use of the salt marsh and associated mudflats (e.g., clamming, research, aquaculture) to minimize potential human impact.
- Continue to collaborate with the Northeast Mosquito Control District to implement the minimum, least environmentally damaging strategies for nuisance mosquito control.

Restore and maintain BIDEH

- Partner with Mass Audubon and other partners to treat using hand-pulling and herbicides perennial pepperweed within the 28,000-acre Great Marsh, aiming for increased eradication from more marsh areas.
- Control *Phragmites* using herbicides to reduce expansion, while working to pilot innovative treatment that focuses on hydrology restoration as a long-term control method.
- Monitor erosion near the road immediately south of Lot 1 (Plum Island River Marsh MU).
- Continue to monitor and treat Japanese knotweed using chemical and mechanical means near Headquarters.

MANAGEMENT STRATEGIES – THATCHER ISLAND NWR

3.1 Rocky Intertidal Shore

- Habitat priority 2
- ROCs: Roseate Tern, American Oystercatcher
- Other benefitting species: Common and Arctic Terns; Common Eider
- No planned change in acreage
- One management unit: Rocky Shore MU (12 acres, Priority Tier 2, Figure 4-2)

Support migratory birds, ROC, and T&E species

- If deemed a regional priority, reestablish Common Tern colony on Thacher Island and adjacent Milk Island (owned by MassWildlife), in collaboration with MassWildlife and Mass Audubon.
- Continue to monitor nesting American Oystercatchers and Common Eiders.

3.2 Maritime Shrubland

- Habitat priority 2
- ROCs: New England Cottontail
- Other benefitting species: Willow Flycatcher; Eastern Kingbird; migrating songbirds
- No planned change in acreage
- One management unit: Maritime Shrubland MU (10 acres, Priority Tier 2, Figure 4-2)

Support migratory birds, ROC, and T&E species

- Work with New England Cottontail Working Group to assess Thacher Island as an island breeding colony.
- If deemed a priority, develop a reintroduction plan, including veterinarian care, disease protocols, and genetic diversity management plan. Reintroduce New England Cottontail from wild populations or from zoo-born rabbits.
- Work with Thacher Island Association to minimize trails that fragment Maritime shrub habitat. For needed trails, aim to have canopy cover over trails to reduce aerial predation of cottontails.

Restore and maintain BIDEH

- Conduct a biotic inventory of plants, insects, and birds.
- Map and assess need to treat invasive plants such as bush honeysuckle, rusty willow, glossy buckthorn, common barberry, purple loosestrife, and *Phragmites*.

Chapter 6. REFERENCES

*All references accessed in 2022 or 2023, unless otherwise noted.

ACJV. 2019. Salt Marsh Bird Conservation Plan: Partners Working to Conserve Salt Marshes and the Birds That Depend on Them. Atlantic Coast Joint Venture. *https://www.acjv.org/documents/salt_marsh_bird_plan_final_web.pdf*.

ACJV. 2020a. Eastern Black Rail Conservation Plan for the Atlantic Coast. Atlantic Coast Joint Venture. *https://www.acjv.org/documents/BLRA_Plan.pdf*.

ACJV. 2020b. Saltmarsh Sparrow. Atlantic Coast Joint Venture. *https://acjv.org/saltmarsh-sparrow-2/* (accessed 9 September 2020).

ACJV. 2022. Saltmarsh Restoration Priorities for the Saltmarsh Sparrow: Massachusetts Atlantic Coast Joint Venture. *https://acjv.org/documents/MA_SALS_comp_guidance_doc.pdf*.

Adamcik RS, Ballantoni ES, DeLong DC, Jr., Schomaker JH, Hamilton DB, Laubhan MK, Schroeder RL. 2004. Writing Refuge Management Goals and Objectives: A Handbook. U.S. Fish and Wildlife Service. Arlington, VA. *https://pubs.er.usgs.gov/publication/93894*.

Adamowicz S, Wilson G, Burdick D, Ferguson W, Hopping R. 2020. Farmers in the marsh: Lessons from history and case studies for the future. Wetland Science and Practice 37:182-195:*https://members.sws.org/wetland-science-and-practice/Details/july-2020-wetland-science-practice-46660*.

AMBCC. 2014. Marine Bird Species Priority List - July 2014. Atlantic Marine Bird Conservation Cooperative. *https://atlanticmarinebirds.org/downloads/AMBC_MarineBirds_SWAP_Ranks_July2014_final.pdf* (accessed 10/27/2022).

Anderson MG, Ferree CE. 2010. Conserving the stage: Climate change and the geophysical underpinnings of species diversity. PLOS One 5:e11554. DOI: 10.1371/journal.pone.0011554.

Andres M. 2016. On the recent destabilization of the Gulf Stream path downstream of Cape Hatteras. Geophysical Research Letters 43:9836-9842. DOI: *https://doi.org/10.1002/2016GL069966*.

Baker A, P. Gonzalez, Morrison RIG, Harrington BA. 2020. Red Knot (*Calidris canutus*), version 1.0 in Billerman SM, editor. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY, USA:*https://doi.org/10.2173/bow.redkno.01*.

Barton A, D., Irwin A, J., Finkel Z, V., Stock C, A. 2016. Anthropogenic climate change drives shift and shuffle in North Atlantic phytoplankton communities. Proceedings of the National Academy of Sciences 113:2964-2969. DOI: 10.1073/pnas.1519080113.

Bat Cons. Int. 2020. Species Profiles. Bat Conservation International. *http://www.batcon.org/resources/media-education/species-profiles* (accessed 16 July 2020).

Buchsbaum R, Pederson J, Robinson WE, editors. 2005. The Decline of Fisheries Resources in New England: Evaluating the Impact of Overfishing, Contamination, and Habitat Degradation. MIT Sea Grant College Program Publication No. 05-5. Massachusetts Institute of Technology, Cambridge, MA:*https://repository.library.noaa.gov/view/noaa/9670*.

Buchsbaum R, Purinton T, Magnuson B. 1998. The Marine Resources of the Parker River-Plum Island Sound Estuary: An Update After 30 Years. Massachusetts Office of Coastal Zone Management. *https://www.mass.gov/files/documents/2016/08/ug/marine-resources-preb.pdf*.

Burdick BD. 2017. Innovative Salt Marsh Restoration Techniques for the Great Marsh. University of New Hampshire. Durham, NH. *https://ecos.fws.gov/ServCat/Reference/Profile/143348*.

Burdick DM, Moore GE, Adamowicz SC, Wilson GM, Peter CR. 2020. Mitigating the legacy effects of ditching in a New England salt marsh. Estuaries and Coasts 43:1672-1679. DOI: 10.1007/s12237-019-00656-5.

Burge CA, et al. 2014. Climate change influences on marine infectious diseases: Implications for management and society. Annual Review of Marine Science 6:249-277. DOI: 10.1146/annurev-marine-010213-135029.

Carroll C, Noss RF. 2021. Rewilding in the face of climate change. Conservation Biology 35:155-167. DOI: *https://doi.org/10.1111/cobi.13531*.

Center for Biological Diversity. 2020. Invertebrates. *https://www.biologicaldiversity.org/species/invertebrates/* (accessed 16 July 2020).

Chen K, He R. 2015. Mean circulation in the coastal ocean off northeastern North America from a regional-scale ocean model. Ocean Science 11:503-517. DOI: 10.5194/os-11-503-2015

Chen K, He R, Powell BS, Gawarkiewicz GG, Moore AM, Arango HG. 2014. Data assimilative modeling investigation of Gulf Stream Warm Core Ring interaction with continental shelf and slope circulation. Journal of Geophysical Research: Oceans 119:5968-5991. DOI: *https://doi.org/10.1002/2014JC009898*.

Chivers WJ, Walne AW, Hays GC. 2017. Mismatch between marine plankton range movements and the velocity of climate change. Nature Communications 8:14434. DOI: 10.1038/ncomms14434.

Christensen NL, et al. 2021. Ecosystem-based management for military training, biodiversity, carbon storage and climate resiliency on a complex coastal land/water-scape. Journal of Environmental Management 280:111755. DOI: *https://doi.org/10.1016/j.jenvman.2020.111755*.

Clark JA, Harvey E. 2002. Assessing multi-species recovery plans under the Endangered Species Act. Ecological Applications 12:655-662.

Commonwealth of MA. 2022. Resilient MA: Climate Change Clearinghouse for the Commonwealth. Commonwealth of Massachusetts (accessed 6/1/2022).

CZM. 2000. Parker River/Essex Bay Area of Critical Environmental Concern (ACEC) Resource Inventory. (Parker River/Essex Bay ACEC was renamed to The Great Marsh ACEC). Massachusetts Office of Coastal Zone Management.

CZM. 2023. Sea Level Affecting Marshes Model (SLAMM): Massachusetts. Massachusetts Office of Coastal Zone Management. *https://www.mass.gov/service-details/sea-level-affecting-marshes-model-slamm* (accessed 1/17/2023).

Donehower CE, Bird DM, Hall CS, Kress SW. 2007. Effects of gull predation and predator control on tern nesting success at Eastern Egg Rock, Maine. Waterbirds: The International Journal of Waterbird Biology 30:29-39:*http://www.jstor.org/stable/4501791*.

Drilling N, Harrington B. 1996. Energetic consequences of chronic human disturbance of shorebirds at migration stopover areas. Bulletin of the Ecological Society of America 77:120-132.

Drury WH. 1973. Population changes in New England seabirds. Bird-Banding 44:267-313. DOI: 10.2307/4511982.

Duff EB, Buchsbaum RN, Burdick DM. 2013. Results of Vegetation, Nekton and Salinity Sampling at the North Pool of the Parker River NWR, 2001-2012: Effects of Water Management. Massachusetts Audubon Society. Wenham, MA.

Dukes JS, et al. 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? Canadian Journal of Forest Research 39:231-248. DOI: 10.1139/X08-171.

Dupigny-Giroux LA, et al. 2018. Northeast. Pages 669–742 in Reidmiller DR, Avery CW, Easterling DR, Kunkel KE, Lewis KLM, Maycock TK, and Stewart BC, editors. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program, Washington, DC, USA. DOI: 10.7930/NCA4.2018.CH18.

eBird. 2022. eBird Data Access. Basic Dataset (EBD). Version: EBD_relNov-2022. Cornell Lab of Ornithology. Ithaca, NY. *https://ebird.org/data/download* (accessed 11/14/2022).

EMHW. 2022. Eastern Massachusetts Hawk Watch. Eastern Massachusetts Hawk Watch,. *https://massbird.org/emhw/* (accessed 6/14/2022).

Erickson TB, Brooks J, Nilles EJ, Pham PN, Vinck P. 2019. Environmental health effects attributed to toxic and infectious agents following hurricanes, cyclones, flash floods and major hydrometeorological events. Journal of Toxicology and Environmental Health, Part B 22:157-171. DOI: 10.1080/10937404.2019.1654422.

Erwin RM, Cahoon DR, Prosser DJ, Sanders GM, Hensel P. 2006. Surface elevation dynamics in vegetated *Spartina* marshes versus unvegetated tidal ponds along the Mid-Atlantic coast, USA, with implications to waterbirds. Estuaries and Coasts 29:96-106. DOI: 10.1007/BF02784702.

Ferretti A, Maggini I, Fusani L. 2021. How to recover after sea crossing: The importance of small islands for passerines during spring migration. Ethology, Ecology & Evolution 33:307-320. DOI: 10.1080/03949370.2021.1886181.

Fitzgerald D, Hughes Z, Farron S, Malgieri TJ, Hein C, Georgiou IY. 2017. Field Survey Report on Three Impoundments at Parker River National Wildlife Refuge. Boston University - Virginia Institute of Marine Sciences - University of New Orleans. *https://ecos.fws.gov/ServCat/Reference/Profile/131743*.

Fitzgerald DM, Hughes ZJ, Georgiou IY, Black S, Novak A. 2020. Enhanced, climate-driven sedimentation on salt marshes. Geophysical Research Letters 47:e2019GL086737. DOI: *https://doi.org/10.1029/2019GL086737*.

Flemer B, Moon D. 2019. Joppa Flats Bird Banding Station at the Parker River National Wildlife Refuge: Activity Report for 2019. Massachusetts Audubon Society. Joppa Flats Education Center. Newburyport, MA.

Frumhoff PC, McCarthy JJ, Melillo JM, Moser SC, Wuebbles DJ. 2007. Confronting Climate Change in the US Northeast: Science, Impacts, and Solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Union of Concerned Scientists (UCS), Cambridge, MA:*https://www.ucsusa.org/resources/confronting-climate-change-us-northeast*.

Galbraith H, Jones R, Park R, Clough J, Herrod-Julius S, Harrington B, Page G. 2002. Global climate change and sea level rise: Potential losses of intertidal habitat for shorebirds. Waterbirds 25:173-183, 111:*https://doi.org/10.1675/1524-4695(2002)025[0173:GCCASL]2.0.CO;2*.

Ganju NK, Defne Z, Fagherazzi S. 2020. Are elevation and open-water conversion of salt marshes connected? Geophysical Research Letters 47:e2019GL086703. DOI: *https://doi.org/10.1029/2019GL086703*.

Gawarkiewicz GG, Todd RE, Plueddemann AJ, Andres M, Manning JP. 2012. Direct interaction between the Gulf Stream and the shelfbreak south of New England. Scientific Reports 2:553. DOI: 10.1038/srep00553.

GMRI. 2021. Gulf of Maine Warming Update: Summer 2021. Gulf of Maine Research Institute. *https://www.gmri.org/stories/gulf-of-maine-warming-update-summer-2021/*.

Greenberg R, Maldonado JE, Droege S, McDonald MV. 2006. Tidal marshes: A global perspective on the evolution and conservation of their terrestrial vertebrates. BioScience 56:675-685. DOI: 10.1641/0006-3568(2006)56.

Greenlaw JS, Elphick CS, Post W, Rising JD. 2020. Saltmarsh Sparrow (*Ammospiza caudacuta*), version 1.0 in Rodewald PG, editor. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY:*https://doi.org/10.2173/bow.roster.01*.

Groves T. 2021. Invasive Plant Control Report 2021: Parker River NWR. U.S. Fish and Wildlife Service, Parker River NWR. *https://ecos.fws.gov/ServCat/Reference/Profile/149976*.

Gutierrez BT, Plant NG, Pendleton EA, Thieler ER. 2014. Using a Bayesian Network to Predict Shore-line Change Vulnerability to Sea-level Rise for the Coasts of the United States. USGS Open-File Report 2014–1083. U.S. Geological Survey. Reston, VA. *https://doi.org/10.3133/ofr20141083*.

Hall CS, Kress SW. 2004. Comparison of Common Tern reproductive performance at four restored colonies along the Maine coast, 1991-2002. Waterbirds 27:424-433:*https://doi.org/10.1675/1524-4695(2004)027[0424:COCTRP]2.0.CO;2*.

Harrington BA, Koch S, Niles LK, Kalasz K. 2010. Red Knots with different winter destinations: Differential use of an autumn stopover area. Waterbirds 33:357-363:*https://doi.org/10.1675/063.033.0312*.

Harrington BA, Leddy LE. 1982. Sightings of knots banded and color-marked in Massachusetts in August 1980. Journal of Field Ornithology 53:55-57.

Harrington BA, Winn B, Brown SC. 2007. Molt and body mass of Red Knots in the eastern United States. The Wilson Journal of Ornithology 119:35-42:*https://doi.org/10.1676/04-086.1*.

Hartley MJ, Weldon AJ. 2020. Saltmarsh Sparrow Conservation Plan. Atlantic Coast Joint Venture. *https://www.acjv.org/documents/SALS_plan_final.pdf*.

Hein CJ, Fallon AR, Rosen P, Hoagland P, Georgiou IY, FitzGerald DM, Morris M, Baker S, Marino GB, Fitzsimons G. 2019. Shoreline dynamics along a developed river mouth barrier island: Multi-decadal cycles of erosion and event-driven mitigation. Frontiers in Earth Science 7. DOI: 10.3389/feart.2019.00103.

Hein CJ, FitzGerald DM, Carruthers EA, Stone BD, Barnhardt WA, Gontz AM. 2012. Refining the model of barrier island formation along a paraglacial coast in the Gulf of Maine. Marine Geology 307-310:40-57. DOI: *https://doi.org/10.1016/j.margeo.2012.03.001*.

Helmers DL. 1992. Shorebird Management Manual. Western Hemisphere Shorebird Reserve Network, Manomet, MA.

Holman H. 2022. New England Cottontail Rabbit Captive Rearing and Reintroduction. 2011-2022 (Draft). New England Cottontail Initiative Population Working Group.

Hoy J. 2006. Grassland Inventory and Assessment at Parker River National Wildlife Refuge - July- August 2006. Newburyport, MA. *https://ecos.fws.gov/ServCat/DownloadFile/2555*.

Hunt K, Gibson D, Catlin D. 2019. Atlantic Flyway Disturbance Project: Biological Data Collection Report (final). Virginia Tech Shorebird Program. Blacksburg, VA. *https://www.vtshorebirds.org/s/Atlantic-Flyway-Disturbance-Project-Final-Report.pdf*.

James-Pirri M-J, Erwin RM, Prosser DJ, Taylor JD. 2012. Responses of salt marsh ecosystems to mosquito control management practices along the Atlantic Coast (U.S.A.). Restoration Ecology 20:395-404. DOI: 10.1111/j.1526-100X.2010.00767.x.

James-Pirri MJ, Erwin RM, Prosser DJ. 2008. U.S. Fish And Wildlife Service (Region 5) Salt Marsh Study, 2001 To 2006: An Assessment of Hydrologic Alterations on Salt Marsh Ecosystems Along the Atlantic Coast. USGS Patuxent Wildlife Research Center and University of Rhode Island:*http://pubs.er.usgs.gov/publication/5200343*.

Johnson KA. 2014. Climate Change Vulnerability Assessment for Natural Resources Management: Toolbox of Methods with Case Studies. Version 2.0. Science Applications. U.S. Fish and Wildlife Service. Arlington, VA. *http://climate.calcommons.org/sites/default/files/Johnson%20KA%202013%20Guide%20to%20Vulnerability%20Assessment%20Methods_Version%202.0.pdf*.

Karmalkar AV, Bradley RS. 2017. Consequences of global warming of 1.5 °C and 2 °C for regional temperature and precipitation changes in the contiguous United States. PLOS ONE 12:e0168697. DOI: 10.1371/journal.pone.0168697.

Kieffer M. 2021. Plum Island Sound Atlantic Sturgeon Pilot Investigation: Preliminary Report on Pilot Investigations during 2021. U.S. Geological Survey.

Kirkey A, Pau N. 2022. Piping Plover and Least Tern Monitoring and Management Program at Parker River NWR. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/149855*.

Kirwan ML, Guntenspergen GR, D'Alpaos A, Morris JT, Mudd SM, Temmerman S. 2010. Limits on the adaptability of coastal marshes to rising sea level. Geophysical Research Letters 37. DOI: 10.1029/2010gl045489.

Knutson MG. 2021. General Land Management Strategies for National Wildlife Refuges. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Department of the Interior Region 1. Hadley, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/132859*.

Koch S, N. Pau, O'Brien K, McGourty E, Ernest N, King E. 2008. Proposed Management Prescriptions and Site Condition Summary for Shrub Adaptive Management Consultancy. U.S. Fish & Wildlife Service. Eastern Massachusetts National Wildlife Refuge Complex. Sudbury, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/114949*.

Konisky RA. 2004. Analysis of Expected Habitat Response to Current and Potential Tidal Restoration Conditions at the North Pool (Parker River National Wildlife Refuge). Newfield, NH. *https://ecos.fws.gov/ServCat/DownloadFile/197946*.

Kress S, Hall C. 2004. Tern Management Handbook: Coastal Northeastern United States and Atlantic Canada. U.S. Fish and Wildlife Service. Hadley, MA. *http://web4.audubon.org/bird/puffin/pdfs/2004_Kress_and_Hall_Tern_Management_Handbook.pdf*.

Lane O, Adams EM, Pau N, O'Brien KM, Regan K, Farina M, Schneider-Moran T, Zarudsky J. 2020. Long-term monitoring of mercury in adult Saltmarsh Sparrows breeding in Maine, Massachusetts and New York, USA 2000–2017. Ecotoxicology 29:1148-1160. DOI: 10.1007/s10646-020-02180-w.

Lane OP, O'Brien KM, Evers DC, Hodgman TP, Major A, Pau N, Ducey MJ, Taylor R, Perry D. 2011. Mercury in breeding Saltmarsh Sparrows (*Ammodramus caudacutus caudacutus*). Ecotoxicology 20:1984-1991.

Langston AK, Durán Vinent O, Herbert ER, Kirwan ML. 2020. Modeling long-term salt marsh response to sea level rise in the sediment-deficient Plum Island Estuary, MA. Limnology and Oceanography 65:2142-2157. DOI: *https://doi.org/10.1002/lno.11444*.

Longcore JR, McAuley DG, Hepp GR, Rhymer JM. 2020. American Black Duck (*Anas rubripes*), version 1.0 in Poole AF, and Gill FB, editors. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY:*https://doi.org/10.2173/bow.ambduc.01*.

Louis Berger Group. 2004. North Pool Restoration Study Feasibility Report. Massachusetts Coastal Zone Management, Wetlands Restoration Program. *https://ecos.fws.gov/ServCat/Reference/Profile/131742*.

Mass Audubon. 2020. Salt Marsh Science Project & Seaside Stewardship. *https://www.massaudubon.org/get-outdoors/wildlife-sanctuaries/endicott/salt-marsh-project* (accessed 16 July 2020).

MassWildlife. 2022a. List of Endangered, Threatened, and Special Concern Species. Commonwealth of Massachusetts. *https://www.mass.gov/info-details/list-of-endangered-threatened-and-special-concern-species* (accessed 10/27/2022).

MassWildlife. 2022b. Massachusetts State Wildlife Action Plan. Commonwealth of Massachusetts. *https://www.mass.gov/service-details/state-wildlife-action-plan-swap* (accessed 10/27/2022).

Mawdsley JR, O'Malley R, Ojima DS. 2009. A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology 23:1080-1089:*http://ejournals.ebsco.com/direct.asp?ArticleID=441DA7BE53F7ED70DBE6*.

Maynard J, et al. 2016. Improving marine disease surveillance through sea temperature monitoring, outlooks and projections. Philosophical Transactions of the Royal Society B: Biological Sciences 371:20150208. DOI: 10.1098/rstb.2015.0208.

Mayor SJ, Guralnick RP, Tingley MW, Otegui J, Withey JC, Elmendorf SC, Andrew ME, Leyk S, Pearse IS, Schneider DC. 2017. Increasing phenological asynchrony between spring green-up and arrival of migratory birds. Scientific Reports 7:1902. DOI: 10.1038/s41598-017-02045-z.

Mengak L, Dayer A, Longenecker R, Spiegel C. 2019. Guidance and Best Practices for Evaluating and Managing Human Disturbances to Migrating Shorebirds on Coastal Lands In The Northeastern United States. U.S. Fish & Wildlife Service. *https://atlanticflywayshorebirds.org/human-disturbance-guidance-and-best-practices-document/*.

Mengak L, Dayer AA. 2020. Defining human disturbance to shorebirds using manager and scientist input. Environmental Management 65:62-73. DOI: 10.1007/s00267-019-01230-2.

Mikula T, Adamowicz SC, Pau N, Stearns R, Hojnacki K. 2019. Salt Marsh Integrity at Parker River National Wildlife Refuge: A report to the U.S. Fish & Wildlife Service, Northeast Region. U.S. Fish & Wildlife Service. Hadley, MA.

Minchinton TE. 2002. Precipitation during El Niño correlates with increasing spread of *Phragmites australis* in New England, USA, coastal marshes. Marine Ecology Progress Series 242:305-309:*https://www.int-res.com/abstracts/meps/v242/p305-309/*.

Moore G, Burdick D, Payne AJ, Routhier M. 2019. Effects of a Natural Sediment Event on Salt Marsh Resiliency: Assessing Potential Marsh Management Implications in Massachusetts. Essex, MA.

Moore GE, Burdick DM, Routhier MR, Novak AB, Payne AR. 2021. Effects of a large-scale, natural sediment deposition event on plant cover in a Massachusetts salt marsh. PLOS ONE 16:e0245564. DOI: 10.1371/journal.pone.0245564.

Morris JT, Sundareshwar PV, Nietch CT, Kjerfve B, Cahoon DR. 2002. Responses of coastal wetlands to rising sea level. Ecology 83:2869-2877. DOI: 10.1890/0012-9658(2002)083[2869:Rocwtr]2.0.Co;2.

Mostello C, Kiah Walker, Veinotte A, Longsdorf J. 2019. Inventory of Terns, Laughing Gulls, and Black Skimmers Nesting in Massachusetts in 2017. Massachusetts Division of Fisheries & Wildlife. *https://www.mass.gov/doc/inventory-of-terns-laughing-gulls-and-black-skimmers-nesting-in-ma-in-2017/download*.

Murdukhayeva A, August P, Bradley M, LaBash C, Shaw N. 2013. Assessment of inundation risk from sea level rise and storm surge in northeastern coastal national parks. Journal of Coastal Research 29:1-16. DOI: 10.2112/JCOASTRES-D-12-00196.1.

NABCI. 2016. State of North America's Birds 2016. North American Bird Conservation Initiative. *https://www.stateofthebirds.org/2016/* (accessed 10/27/2022).

NatureServe. 2020. NatureServe Explorer [web application]. NatureServe. Arlington, VA. *https://explorer.natureserve.org/* (accessed 6/22/2022).

NAWMP. 2012. North American Waterfowl Management Plan 2012. Plan Committee of the North American Waterfowl Management Plan. *https://nawmp.org/document/2012-nawmp-action-plan*.

NAWMP. 2018. North American Waterfowl Management Plan (NAWMP) Update: Connecting People, Waterfowl, and Wetlands. North American Waterfowl Management Plan Committee. *https://www.fws.gov/partner/north-american-waterfowl-management-plan*.

Neckles HA, Guntenspergen GR, Shriver WG, Danz NP, Wiest WA, Nagel JL, Olker JH. 2013. Identification of Metrics to Monitor Salt Marsh Integrity on National Wildlife Refuges in Relation to Conservation and Management Objectives. U. S. Geological Survey. *http://pubs.er.usgs.gov/publication/70046960*.

Neckles HA, Lyons JE, Nagel JL, Adamowicz SC, Mikula T, Guiteras ST, Mitchell LR. 2019. Optimization Of Salt Marsh Management At The Bombay Hook National Wildlife Refuge, Delaware, Through Use Of Structured Decision Making. Open-File Report. Survey USG. Reston, VA. *http://pubs.er.usgs.gov/publication/ofr20181160*.

NHGF. 2023. Tern Restoration Project. New Hampshire Game and Fish. *https://www.wildlife.state.nh.us/nongame/project-tern.html* (accessed 1/26/2023).

Nisbet ICT. 1973. Terns in Massachusetts: Present numbers and historical changes. Bird-Banding 44:27-55. DOI: 10.2307/4511926.

Nisbet ICT, M. Gochfeld, Burger J. 2020. Roseate Tern (*Sterna dougallii*), version 1.0 in Billerman SM, editor. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY, USA:*https://doi.org/10.2173/bow.roster.01*.

NOAA. 2020. Essential Fish Habitat. National Oceanic and Atmospheric Administration,. *https://www.fisheries.noaa.gov/national/habitat-conservation/essential-fish-habitat* (accessed 16 July 2020).

NOAA. 2022a. Climate at a Glance: County Time Series. NOAA National Centers for Environmental Information. *https://www.ncdc.noaa.gov/cag/* (accessed 6/1/2022).

NOAA. 2022b. Species Directory: Marine Mammals. National Oceanic and Atmospheric Administration - Fisheries. *https://www.fisheries.noaa.gov/species-directory/marine-mammals* (accessed 10/27/2022).

Novak AB, Short FT. 2012. Creating the Basis for Successful Restoration: An Eelgrass Habitat Suitability Model in GIS for Plum Island Sound, Massachusetts. University of New Hampshire, Jackson Estuarine Laboratory *https://www.mass.gov/doc/creating-the-basis-for-successful-restoration-an-eelgrass-habitat-suitability-model-in-gis-for/download*.

Oosterlee L, Cox TJS, Temmerman S, Meire P. 2020. Effects of tidal re-introduction design on sedimentation rates in previously embanked tidal marshes. Estuarine, Coastal and Shelf Science 244:106428. DOI: *https://doi.org/10.1016/j.ecss.2019.106428*.

Oosterlee L, Cox TJS, Vandenbruwaene W, Maris T, Temmerman S, Meire P. 2018. Tidal marsh restoration design affects feedbacks between inundation and elevation change. Estuaries and Coasts 41:613-625. DOI: 10.1007/s12237-017-0314-2.

Parrish JD. 2000. Behavioral, energetic, and conservation implications of foraging plasticity during migration. Pages 53-70 in Moore FR, editor. Stopover Ecology of Nearctic Neotropical Landbird Migrants: Habitat Relations and Conservation Implications. Cooper Ornitholigical Society, Western Fdn Vertebrate Zoology 439 Calle San Pablo/Camarillo/CA 93010/USA.

Pau N. 2021a. 100-acre Marsh Restoration at Parker River NWR, Narrative for NOI for Ecological Restoration. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Northeast Region. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/136067*.

Pau N. 2021b. Parker River, Great Bay, and Thacher Island National Wildlife Refuges Inventory and Monitoring Plan. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Department of the Interior Region 1. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/131340*.

Pau N, Hojnacki K, Moody K, Moore S. 2021. Summary of Saltmarsh Sharp-tailed Sparrow Productivity and Mercury Investigations, Parker River National Wildlife Refuge. U.S. Fish and Wildlife Service. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/150075*.

Pau N, O'Brien K, Koch S, McGourty E, King E, Ernst N. 2012. Assessing the Status and Change Over Time in Populations of Fall-migrating Landbirds Using Shrub Habitats on USFWS Field stations. Adaptive Management Project Record. Parker River National Wildlife Refuge. U.S. Fish and Wildlife Service, Northeast Region. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/114955*.

Pau N, Walker K, Healey L. 2022. Salt Marsh Restoration Techniques and Research at Parker River National Wildlife Refuge. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Northeast Region. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/144249*.

Pershing A, J., et al. 2015. Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. Science 350:809-812. DOI: 10.1126/science.aac9819.

Powell M, Casey J. 2019. Crafting SMART Biological Management Objectives: A Practical Guide. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Department of the Interior Region 1. Hadley, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/112228*

Psuty NP, Ames K, Butler K, Habeck A. 2017. National Wildlife Refuge Shoreline Position (1D) and Coastal Topographic (2D) Change Monitoring 2011-2017 Trend Report. Publication Series on Coastal Change. United States Fish and Wildlife Service. Hadley, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/98178*.

Rai R, Joshi S, Roy S, Singh O, Samir M, Chandra A. 2015. Implications of changing climate on productivity of temperate fruit crops with special reference to apple. Journal of Horticulture 2:135-141.

Rochlin I, James-Pirri M-J, Adamowicz SC, Wolfe RJ, Capotosto P, Dempsey ME, Iwanejko T, Ninivaggi DV. 2012. Integrated Marsh Management (IMM): A new perspective on mosquito control and best management practices for salt marsh restoration. Wetlands Ecology and Management 20:219-232. DOI: 10.1007/s11273-012-9251-9.

Roman CT, Raposa KB, Adamowicz SC, James-Pirri M-J, Catena JG. 2002. Quantifying vegetation and nekton response to tidal restoration of a New England salt marsh. Restoration Ecology 10:450-460. DOI: *https://doi.org/10.1046/j.1526-100X.2002.01036.x*.

RSPB. 2021. International (East Atlantic) Species Action Plan for the Conservation of the Roseate Tern *Sterna dougallii* (2021-2030). Roseate Tern LIFE Project. The Royal Society for the Protection of Birds. *http://roseatetern.org/uploads/3/5/8/0/35804201/east_atlantic_roseate_tern_sap_final.pdf*.

Runkle J, Kunkel KE, Frankson R, Easterling DR, DeGaetano AT, Stewart BC, Sweet W, Spaccio J. 2022. Massachusetts State Climate Summary. NOAA Technical Report NESDIS 150-MA in Kunkel KE, Frankson R, Runkle J, Champion SM, Stevens LE, Easterling DR, Stewart BC, McCarrick A, and Lemery CR, editors. NOAA/NESDIS, Silver Spring, MD:*https://statesummaries.ncics.org/chapter/ma/*.

Saunders MA, Lea AS. 2008. Large contribution of sea surface warming to recent increase in Atlantic hurricane activity. Nature 451:557-560. DOI: 10.1038/nature06422.

Scopel L, Diamond A, Kress S, Shannon P. 2019. Varied breeding responses of seabirds to a regime shift in prey base in the Gulf of Maine. Marine Ecology Progress Series 626:177-196:*https://www.int-res.com/abstracts/meps/v626/p177-196/*.

Seavey JR, Gilmer B, McGarigal KM. 2011. Effect of sea-level rise on Piping Plover (*Charadrius melodus*) breeding habitat. Biological Conservation 144:393-401. DOI: *https://doi.org/10.1016/j.biocon.2010.09.017*.

SHARP. 2023. Demographic Protocols. University of Connecticut. *https://www.tidalmarshbirds.org/?page_id=1596https://www.tidalmarshbirds.org/?page_id=1596* (accessed 1/4/2023).

Smith DC, Konrad V, Koulouris H, Hawes E, Borns HW. 1989. Salt marshes as a factor in the agriculture of northeastern North America. Agricultural History 63:270-294:*http://www.jstor.org/stable/3743517*.

Steele Associates Marine Consultants L. 2021. Shortnose Sturgeon Survey Report Merrimack River, MA. Prepared for: Stantec.

Steinkamp M. 2008. New England/Mid-Atlantic Coast Bird Conservation Region (BCR 30) Implementation Plan. Atlantic Coast Joint Venture. Laurel, MD. *https://acjv.org/documents/BCR30_June18_07_final_draft.pdf*.

Stevens R, Nichols B, Gagne D, Cygan D, Snyder E. 2015. Picking Our Battles: A Guide to Planning Successful Invasive Plant Management Projects. New Hampshire Fish and Game Department and NH Natural Heritage Bureau Invasive Plant Working Group. *https://wildlife.state.nh.us/invasives/documents/picking-battles.pdf*.

Swain PC. 2020. Classification of the Natural Communities of Massachusetts. Natural Heritage & Endangered Species Program, Massachusetts Division of Fisheries and Wildlife, Westborough, MA:*https://www.mass.gov/service-details/classification-of-natural-communities*.

Taylor JA, Paveglio FL. 2017. Identifying Refuge Resources of Concern and Management Priorities: A Handbook. National Wildlife Refuge System. U.S. Fish and Wildlife Service. Arlington, VA. *https://ecos.fws.gov/ServCat/Reference/Profile/85243*.

Taylor PD, et al. 2017. The Motus Wildlife Tracking System: A collaborative research network to enhance the understanding of wildlife movement. Avian Conservation and Ecology 12. DOI: 10.5751/ACE-00953-120108.

Thomas AC, Pershing AJ, Friedland KD, Nye JA, Mills KE, Alexander MA, Record NR, Weatherbee R, Henderson ME. 2017. Seasonal trends and phenology shifts in sea surface temperature on the North American northeastern continental shelf. Elementa: Science of the Anthropocene 5:48. DOI: 10.1525/elementa.240.

Thompson BC, Jackson JA, Burger J, Hill LA, Kirsch EM, Atwood JL. 2020. Least Tern (*Sternula antillarum*), version 1.0 in Poole AF, and Gill FB, editors. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY:*https://doi.org/10.2173/bow.leater1.01*.

Tiner RW, Veneman PLM. 2014. An approach to monitoring coastal marsh migration in the Northeast. Wetland Science and Practice 31:10-13:*https://members.sws.org/wetland-science-and-practice/Details/september-2014-wetland-science-practice-46869*.

Tomczyk R. 2002. Parker River Watershed: Year 3 Watershed Assessment Report. Executive Office of Environmental Affairs. Massachusetts Watershed Initiative.

TTOR. 2020. State of the Coast 2020. The Trustees of Reservations. *https://www.onthecoast.thetrustees.org/about* (accessed 11/22/2022).

USDA FS. 2020. Pitch Pine. U.S. Department of Agriculture - Forest Service. *https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_1/pinus/rigida.htm* (accessed 28 August 2020).

USDA NRCS. 2022. Web Soil Survey. USDA Natural Resources Conservation Service. *https://www.nrcs.usda.gov/resources/data-and-reports/web-soil-survey* (accessed 11/22/2022).

USFWS. 1996. Piping Plover (*Charadrius melodus*) Atlantic Coast Population Revised Recovery Plan. U.S. Fish and Wildlife Service. Hadley, MA. *https://ecos.fws.gov/docs/recovery_plan/030916a.pdf*.

USFWS. 2002. Habitat Management Plans: Service Manual (620 FW 1). U.S. Fish and Wildlife Service. Washington, DC. *http://www.fws.gov/policy/620fw1.html*.

USFWS. 2007. Parker River and Thacher Island National Wildlife Refuges Habitat Management Plan. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Northeast Region. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/2459*.

USFWS. 2009. Piping Plover (*Charadrius melodus*). 5-Year Review: Summary and Evaluation. U.S. Fish and Wildlife Service. Hadley, MA.

USFWS. 2012. 2011-2012 Annual Habitat Work Plan: Parker River National Wildlife Refuge. Newburyport, MA. *https://ecos.fws.gov/ServCat/DownloadFile/225376*.

USFWS. 2014. Terrestrial and Wetland Representative Species of the North Atlantic: Species Selected, Considered, and Associated Habitats (Ecological Systems). U.S. Fish & Wildlife Service - Northeast Region. North Atlantic Landscape Conservation Cooperative. Hadley, MA.

USFWS. 2016a. Endangered and Threatened Wildlife and Plants; 4(d) Rule for the Northern Long-Eared Bat, Final Rule (50 CFR Part 17). U.S. Fish and Wildlife Service. Washington, DC. *https://www.govinfo.gov/content/pkg/FR-2016-01-14/pdf/2016-00617.pdf#page=1*.

USFWS. 2016b. Great Thicket National Wildlife Refuge Final Land Protection Plan/ Environmental Assessment. U.S. Fish and Wildlife Service - Northeast Region. Hadley, MA. *https://www.fws.gov/northeast/refuges/planning/lpp/final_lppea.html*.

USFWS. 2019. Recovery outline for the Rufa Red Knot (*Calidris canutus rufa*). U.S. Fish and Wildlife Service. Hadley, MA. *https://ecos.fws.gov/docs/recovery_plan/20190409%20Red%20Knot%20Recovery%20Outline%20final%20signed.pdf*.

USFWS. 2020. Roseate Tern, Northeastern North American Population (*Sterna dougallii dougallii*) 5-Year Review: Summary and Evaluation Northeast Roseate Tern Recovery Team. U.S. Fish & Wildlife Service. Hadley, MA. *https://ecos.fws.gov/docs/tess/species_nonpublish/3063.pdf*.

USFWS. 2021a. Birds of Conservation Concern 2021. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Migratory Birds, Falls Church, VA:*https://www.fws.gov/media/birds-conservation-concern-2021pdf*. *https://www.fws.gov/media/birds-conservation-concern-2021pdf*.

USFWS. 2021b. North Atlantic-Appalachian Region, National Wildlife Refuge System, SMART Objectives. Version 1. National Wildlife Refuge System - Division of Natural Resources and Conservation Planning. U.S. Fish and Wildlife Service, Department of the Interior Region 1. Hadley, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/137670*.

USFWS. 2021c. Priority At-Risk Species List - North Atlantic-Appalachian Region. U.S. Fish and Wildlife Service. Hadley, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/148765*.

USFWS. 2022a. Effects of Off-Road Vehicles On Beaches: A Literature Review. Supplemental Report to the Compatibility Determination for Fishing at Parker River National Wildlife Refuge. U.S. Fish and Wildlife Service. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/146898*.

USFWS. 2022b. Environmental Conservation Online System (ECOS). U.S. Fish and Wildlife Service. *https://ecos.fws.gov/ecp/* (accessed 10/27/2022).

USFWS. 2022c. Saltmarsh Sparrow Peer Review Plan for Species Status Assessment. U.S. Fish and Wildlife Service. *https://www.fws.gov/media/saltmarsh-sparrow-peer-review-plan-ssa* (accessed 11/22/2022).

USFWS. 2023. New England Cottontail. U.S. Fish and Wildlife Service. *https://fws.gov/species/new-england-cottontail-sylvilagus-transitionalis* (accessed 1/25/2023).

USGS. 2022. State Wildlife Action Plans (SWAP): A National Look at Species of Greatest Conservation Need as Reported in State Wildlife Action Plans. U.S. Geological Survey. *https://www1.usgs.gov/csas/swap/* (accessed 19/27/2022).

Virgin SDS, Beck AD, Boone LK, Dykstra AK, Ollerhead J, Barbeau MA, McLellan NR. 2020. A managed realignment in the upper Bay of Fundy: Community dynamics during salt marsh restoration over 8 years in a megatidal, ice-influenced environment. Ecological Engineering 149:105713. DOI: *https://doi.org/10.1016/j.ecoleng.2020.105713*.

Vitz A, Veinotte A, Mostello C. 2021. Summary of the 2020 Massachusetts Piping Plover Census. Massachusetts Division of Fisheries & Wildlife. Natural Heritage & Endangered Species Program. *https://www.mass.gov/doc/summary-of-the-2020-massachusetts-piping-plover-census/download#:~:text=Observers%20reported%20breeding%20Piping%20Plovers,763%20in%202019*).

Wagner DL, Nelson MW, Schweitzer DF. 2003. Shrubland *Lepidoptera* of southern New England and southeastern New York: Ecology, conservation, and management. Forest Ecology and Management 185:95-112. DOI: *https://doi.org/10.1016/S0378-1127(03)00249-4*.

Walker K, Pau N. 2021. Piping Plover and Least Tern Monitoring and Management Program at Parker River National Wildlife Refuge. National Wildlife Refuge System. U.S. Fish and Wildlife Service, Department of the Interior Region 1. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/142949*.

Walsh J, Kovach AI, Babbitt KJ, O'Brien KM. 2012. Fine-scale population structure and asymmetrical dispersal in an obligate salt-marsh passerine, the Saltmarsh Sparrow (*Ammodramus caudacutus*). The Auk 129:247-258. DOI: 10.1525/auk.2012.11153.

Warnecke L, Turner JM, Bollinger TK, Lorch JM, Misra V, Cryan PM, Wibbelt G, Blehert DS, Willis CKR. 2012. Inoculation of bats with European *Geomyces destructans* supports the novel pathogen hypothesis for the origin of White-Nose Syndrome. Proceedings of the National Academy of Sciences 109:6999-7003. DOI: 10.1073/pnas.1200374109.

Wasson K, Ganju NK, Defne Z, Endris C, Elsey-Quirk T, Thorne KM, Freeman CM, Guntenspergen G, Nowacki DJ, Raposa KB. 2019. Understanding tidal marsh trajectories: Evaluation of multiple indicators of marsh persistence. Environmental Research Letters 14:124073. DOI: 10.1088/1748-9326/ab5a94.

Weare N. 1996. Plum Island: The Way It Was, 2nd edition. Newburyport Press, Newburyport, MA.

Welch L. 2015. Tern colony diets and productivity (personal comm.), Maine Coastal Islands National Wildlife Refuge Complex.

Wells CD, et al. 2014. Report on the 2013 Rapid Assessment Survey of Marine Species at New England Bays and Harbors. Massachusetts Office of Coastal Zone Management. *https://www.mass.gov/files/documents/2016/08/vd/ras-2013-final.pdf*.

Whale Sense. 2022. Endangered and Threatened Species Under NMFS' Jurisdiction. Whale Sense. *https://whalesense.org/wp-content/uploads/2013/03/marine-endangered-species.pdf* (accessed 10/27/2022).

Wheelwright NT, Rising JD. 2020. Savannah Sparrow (*Passerculus sandwichensis*), version 1.0. in Poole AF, editor. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY:*https://doi.org/10.2173/bow.savspa.01*.

Woods Hole Group. 2018. Stage Island Pool Hydrodynamic Model Technical Report. Bourne, Massachusetts. *https://ecos.fws.gov/ServCat/Reference/Profile/142858*.

Woods Hole Group. 2019a. Impoundment Modeling and Restoration Report. Bourne, Massachusetts. *https://ecos.fws.gov/ServCat/Reference/Profile/142859*.

Woods Hole Group. 2019b. USFWS Impoundment Modeling and Restoration Report. Bourne, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/142859*.

Wurster F, Hunt KJ. 2015. Water Resource Inventory and Assessment - Parker River National Wildlife Refuge. U.S. Fish & Wildlife Service. Newburyport, MA. *https://ecos.fws.gov/ServCat/Reference/Profile/49019*.

Xerces Society. 2020. Pollinator Conservation Program. *https://xerces.org/pollinator-conservation* (accessed 16 July 2020).

Yates D, Meattey D. 2010. Bat Survey for Parker River and Great Bay National Wildlife Refuges. BRI Report 2008-09. Biodiversity Research Institute,. Portland, ME. *https://briwildlife.org/mammal-program/*.

Zeigler SL, Gutierrez BT, Sturdivant EJ, Catlin DH, Fraser JD, Hecht A, Karpanty SM, Plant NG, Thieler ER. 2019a. Using a Bayesian network to understand the importance of coastal storms and undeveloped landscapes for the creation and maintenance of early successional habitat. PloS one 14:e0209986-e0209986. DOI: 10.1371/journal.pone.0209986.

Zeigler SL, Sturdivant EJ, Gutierrez BT. 2019b. Evaluating barrier island characteristics and Piping Plover (*Charadrius melodus*) habitat availability along the U.S. Atlantic Coast: Geospatial approaches and methodology. Open-File Report. Survey USG. Reston, VA. *http://pubs.er.usgs.gov/publication/ofr20191071*.

APPENDIX A. ENVIRONMENTAL ASSESSMENT