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Changing Shorelines: Adaptation Planning for Maine's Coastal State Parks

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Final Report - NOAA Project of Special Merit

Maine Department of Agriculture, Conservation and Forestry

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Cover Photo credits: clockwise from top left: Popham Beach State Park by J. Picher, formerly DACF; Colonial Pemaquid by S. Dickson, DACF; Reid State Park by J. Picher, formerly DACF; Fort Popham by S. Varney, formerly DACF.

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Changing Shorelines: Adaptation Planning for Maine's Coastal State Parks

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Park Managers at the project sites shared their detailed knowledge about, and passion for, the properties they manage, and for Maine's park system. They gave generously of their time for team field visits and other consultations.

- Brian Murray (former) and Meagan Hennessey(current) – Popham Beach State Park, Fort Popham and Popham Colony
- Samantha Wilkinson – Reid State Park
- Kurt Shoener - Crescent Beach State Park, Two Lights State Park and Kettle Cove State Park
- Neill DePaoli - Colonial Pemaquid/Fort William Henry

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1.0 Introduction

Maine's coastal state parks and historic sites are important destinations for citizens and out of state visitors. These jewels, scattered throughout our approximate 5,400 miles of coastline are visually stunning, heavily visited and provide permanent protection for significant natural and cultural features. State parks and historic sites are also drivers of the local, regional and state economy. Statewide in 2004, Maine's state parks accounted for approximately 1.29 million visitor days. Including a multiplier effect, state park visitors supported $95.7M of economic activity in Maine, including 1,449 full and part-time jobs that provide $31.1M of personal income (Morris and others, 2006).

The Maine Department of Agriculture, Conservation and Forestry (DACF) works to protect and manage natural and cultural resources parks, historic sites, reserved and un-reserved public lands under its care "in order to offer a wide range of recreational and educational opportunities and provide environmental and economic benefits for present and future generations". DACF initiated Changing Shorelines: Adaptation Planning for Maine's Coastal State Parks and Historic Sites in the fall of 2014, upon receiving "project of special merit" funding from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration's Office for Coastal Management. Led by the DACF's Maine Coastal Program, in collaboration with the Department's Bureau of Parks and Lands, Maine Geological Survey and Maine Natural Areas Program, and the Maine State Historic Preservation Commission, an interdisciplinary team examined a selected group of coastal state-owned and managed parks and historic sites thought to be especially significant in terms of natural and historical resources and vulnerable to erosion, land loss, flooding from hurricanes, winter storms, sea level rise, and other hazards.

To determine the project focus areas, topic experts each ranked all coastal state parks and historic sites from the perspective of their program's mission and priorities. DACF Bureau of Parks and Lands (BPL) staff ranked sites according to presence and value of infrastructure assets and day use visitation. DACF Maine Natural Areas Program (MNAP) ranked the sites by the presence and rarity of significant natural features, scale of the habitat, and vulnerability to hazards. DACF Maine Geological Survey (MGS) ranked the sites according to their vulnerability under several different hazard scenarios. Maine State Historic Preservation Commission (MSHPC) ranked the sites by known pre-historic and historic features, overall archeological value and vulnerability to hazards. Accordingly, and shown in Figure 1 the sites chosen for this project were Popham "Complex*" (includes Popham Beach State Park and the historic sites of Fort Popham and Popham Colony), Reid State Park, the Historic Sites of Colonial Pemaquid and Fort William Henry and Crescent Beach "Complex" (includes Crescent Beach State Park and Kettle Cove State Park). As used in this study, "complex" notes a geographic area with a number of state facilities in close proximity to each other. Extensive analysis of the most vulnerable project site – Popham Beach State Park and the Popham Complex -- is presented in the following chapter of this report and summary results for the other sites are presented in the report's appendices.

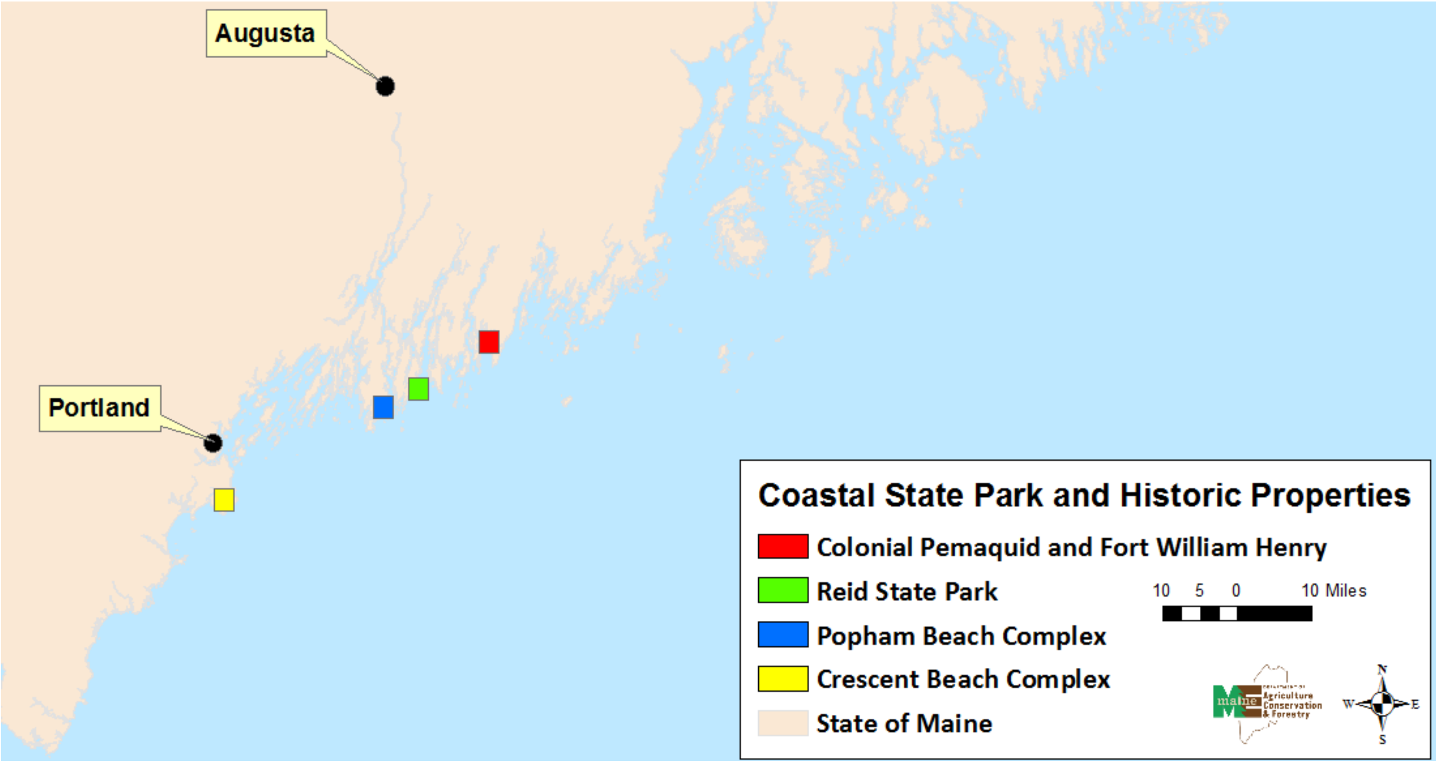

Figure 1. Locations of coastal state park and historic properties selected for detailed analyses.

1.1 Project Goals and Products

The goal of this project was to provide guidance for management of state parks and historic sites in consideration of new stressors, such as more frequent coastal storms and flooding events, short and long term erosion, storm surge and anticipated sea-level rise.

Through this project, we:

- Developed a coastal park vulnerability assessment scoring matrix to derive a priority list of most vulnerable and valuable parks from a multi-disciplinary point of view.
- Developed new vulnerability assessments for four coastal state park and historic site complexes, their habitats, and supporting infrastructure to a variety of hazards;
- Completed Natural Resource Inventories for five state parks.
- Documented detailed adaptation alternatives for Popham Beach State Park and general adaptation alternatives for natural and built features for the remainder of the project study sites. Prepared information for use in management planning, development of best practices, storm preparedness protocols, and future capital planning.
- Investigated visitor preferences for adaptation solutions at Popham Beach State Park and obtained visitor feedback on their preferences for receiving additional information about the park for use in the design of forthcoming park interpretive materials.

1.2 Selected Findings and Recommendations

Site-specific findings and recommendations are discussed in Section 2.0 for the Popham complex and in applicable appendices B, C and D for the remaining properties in the study area. The following bullets are overarching, applicable to all sites and may be applicable to wider DACF parks and historic sites policy and planning discussions.

1.2.1 Policy and Planning

- Maine's Integrated Resource Policy for Public Reserved and Non-reserved Lands, State Parks, and State Historic Sites, ("IRP", 2000 and amended in 2007) provides overall guidance and specific policies for management of state land assets. The IRP did not, however, examine how coastal park management might adapt over time due to variations in shoreline change at coastal properties.
- Managers of coastal state parks and sites that are vulnerable to erosion, storm surge, flooding and sea level rise may experience challenges related to operation and longevity of infrastructure assets and maintenance of important habitats under certain vulnerability scenarios.
- Management objectives for state-owned properties may conflict given future scenarios of shoreline change, e.g. preserving natural features may conflict with a management goal of maximizing visitor use, possibly warranting future discussions about balancing competing objectives.
- Additional policy-level discussions might further examine the need for: detailed management plans at selected coastal state parks and historic sites; formal or informal guidance; and, a closer look at potential capital needs at vulnerable sites. Current and anticipated future conditions at Popham Beach State Park may warrant the development of a formal management plan for the park.
- Planning for maintenance and repairs for parks and historic sites is assessed annually during maintenance inspections of each facility. Needs are prioritized within each respective park and then prioritized against competing needs at other parks and historic sites within each regional office and the park system as a whole. Maine State Parks and Historic Sites operate on a very modest budget based on annual requests. There are literally millions of dollars of deferred maintenance and repairs including repairs resulting from coastal erosion and flooding. Policy makers may want to consider more pro active budgeting with a specific eye towards useful life of assets and resources in vulnerable locations.
- DACF/BPL might consider new designs for parks, including movable assets given lessons learned from rebuilding after severe storms in other areas of the country.
- DACF/BPL/MGS might consider applying "living shoreline" (i.e. soft shoreline protection) pilot projects on state-owned properties.

1.2.2 Education and Outreach

- The project team should continue with planned outreach including a briefing session for policy makers and site managers to review the project results and obtain feedback on next steps and useful formats for project products. The project team should also present the project results to municipal parks and recreation directors at their annual membership meeting in order to share transferable lessons learned.
- Municipalities, residents and the general public may want to be involved in open discussions if management practices change and as adaptation occurs. Property owners adjacent to publicly-owned sites may want to learn about successful practices that they can use on their vulnerable shoreline properties.
- As found in the Popham Beach visitor survey (see Section 2), visitors have a long-standing affinity for the park; are keenly aware of shoreline changes and want to learn more. Given trends in educational and cultural tourism, the visiting public may desire increased interpretive material or events. The Popham visitor survey provides topics that visitors want to learn about and discusses ways that people want to receive information.

1.2.3 Park Management

- Monitoring of shoreline and habitat changes and the review of the efficacy of existing monitoring and management programs should continue and park managers should continue to consult with resource management professionals from other state agencies to provide guidance about site management and adaptation opportunities.

1.2.4 Data Needs

- New data sets (such as more frequent LiDAR and accurate orthorectified imagery) should be acquired to build more sophisticated models of shoreline change.
- Aside from the Popham Complex, this analysis was conducted within the site boundaries of relatively small publicly-owned sites. In future analyses, we recommend looking outside of state-owned property boundaries to look at habitat connectivity adaptation opportunities and to assess off-site infrastructure that may affect access to state-owned properties. (See discussion of Route 209, in Section 2.)

1.2.5 Regulatory Implications

- While outside of the purview of DACF alone, this study also further underscores how dramatic and continual shifts in sand dune systems may warrant an examination of the current regulatory structure for managing development in sand dune systems. MGS and MCP staff should continue discussions with DEP related to this topic.

1.3 Data Limitations and Assumptions

Different datasets used for the asset vulnerability scenarios have different mapping methodologies, assumptions, and limitations. A brief summary follows, and Appendix A provides a detailed explanation of the sources for and methods used for data development.

- MGS sea level rise and storm surge data (MGS, 2015) uses a "bathtub" model for inundating areas on top of the Highest Annual Tide, or HAT, i.e., stillwater elevations that do not account for potential erosion, accretion, shoreline changes, precipitation, or dynamic processes like waves.
- MGS used inundation scenarios associated with Category 1 and 2 hurricanes making landfall at mean high tide (MGS, 2015a) using data developed by the US Army Corps of Engineers from the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model. The SLOSH model outputs storm tide elevations – a combination of predicted tide and storm surge for Category 1 and 2 tropical events making landfall at mean high tide. SLOSH outputs do not account for the potential impacts from waves, extreme tides, freshwater flow, precipitation, or future scenarios of sea level rise. SLOSH data do not have calculated recurrence interval probabilities and removed small low-lying areas that did not have clear tidal connections.
- Special Flood Hazard Area (SFHA) data from effective Federal Emergency Management Agency (FEMA) Digital Flood Insurance Rate Maps (DFIRMs) or preliminary digital maps (if effective maps were paper), were also used to map the extent of the 100-year (1%) floodplain (i.e., a 1% chance of flooding in any given year). These data are derived using historic storms, and combine tides with storm surge and wave action to determine 1% base flood elevations, or BFEs. FEMA DFIRMs do not account for future sea level rise, but may take into account erodibility of primary frontal dunes below a certain size. FEMA DFIRMs include wave action, while the other mapping methods don't. Thus, in many cases, if the 1% event is used to define risk of assets, many more assets would be at "risk" than the other scenarios inspected.
- At Popham Beach State Park (and several others), future shoreline positions were extrapolated using short (10-year) and long-term (50-year) calculated shoreline change rates. These predictions assume that shoreline changes that occurred in the past are predictors of similar changes in the future.

1.4 Other Caveats

We note two important considerations that influenced our study design and recommendations.

- The team struggled with the concept of "forecasting" future conditions given levels of uncertainty. In response, we opted for a scenario-based approach to assessing future possibilities as shown in Table 1a. This method allowed for analysis of existing flooding risk using 1% SFHA data and SLOSH inundation data, and potential future flooding risk due to sea level rise and/or storm surge using scenarios of 1, 2, 3.3, and 6 feet on top of the HAT. A scenario-based approach is consistent with planning for sea level rise using scenarios from the US National Climate Assessment (NOAA, 2012).
- The timing and duration of flooding events and subsequent effects on the design life of affected assets was not explored. Thus, adaptation does not occur all at once and is often comprised of a series of actions, taking advantage of opportunities as they arise. This was inherent in our approach to adaptation alternatives (Table 1b)

1.5 How This Report is Organized

Popham Beach State Park (PBSP) emerged as the most vulnerable property in our analysis and therefore was the site that we focused on in more depth and with more specificity than the others. PBSP and the two other study sites on the Popham peninsula (Fort Popham and Popham Colony historic sites) are featured at length in Section 2 of this report.

Our work related to the remaining four project sites (Colonial Pemaquid, Reid State Park, and Crescent Beach complex) is summarized and presented in an abbreviated fashion in Appendices B to D to this report.

For all project sites, the analysis includes the following maps and tables:

- A location map and general description of the site.
- Maps of short-term, long-term shoreline change and predicted 50-year shoreline change.
- A map of threatened infrastructure assets under three inundation analyses (sea-level rise and storm surge; hurricanes; and flooding).
- A "vulnerability table" which provides the percentage of a given infrastructure asset that is either located within a mapped hazardous area or is inundated by a flooding scenario. Tables are color coded (green, yellow, orange, and red, respectively) based on the percentage of the asset that is "impacted" by the given scenario. See example below in Table 1a and an explanation in Table 1b.
- An "adaptation table" that summarizes these vulnerabilities and lists potential adaptation strategies for each infrastructure asset (protection, accommodation, or retreat strategies). The table also includes recommended park operation strategies (where applicable), and a notes section with additional information. See example below in Table 2a and explanation in Table 2b.
- A discussion of natural resource vulnerabilities and adaptive management considerations.
- For historic sites, a discussion of asset vulnerabilities from a cultural point of view and discussion of adaptive management options.

- Natural Resource Inventories were conducted for Popham Beach State Park, Reid State Park and Crescent Beach SP, Kettle Cove SP (and neighboring Two Lights SP) in our study sample. For each of these sites, a summary table of Potential Impacts to Natural Resources (per the vulnerability scenarios described above), along with management considerations for DACF/Bureau of Parks and Public Lands, was completed. Full copies of Natural Resource Inventory reports for the parks are available upon request.
- Historic Sites in the sample (Fort Popham, Popham Colony, Colonial Pemaquid and Crescent Beach were examined for vulnerability using the scenarios referenced above and site investigations of the conditions of built assets. The sections on each of these sites include recommendations for potential adaptation measures (if applicable). Staff drew upon the work of the National Park Service and others that have identified a range of generally accepted practices for historic and cultural resource adaptation.

1.6 Guide to Interpreting Vulnerability and Adaptation Tables

The tables on the following pages provide the key to interpret both the vulnerability tables and adaptation tables. As discussed above, these tables were completed for each study, and included in the subsequent chapter on the Popham Beach complex and in the report appendices, for the remainder of the sites.

Property	Asset	Mean Elev* (ft NAVD)	Length, area or number	Mapped Flood Zone (Effective)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**							Shoreline Change	
					D1	D2	EHA	CBRS	HAT (6.3ft)	HAT+1 (7.3ft)	HAT+2 (8.3 ft)	CAT 1 (9.2 ft)	HAT+3.3 (9.6 ft)	HAT+6 (12.3 ft)	CAT 2 (12.9 ft)	10 year ST trend	50 year LT trend
Park A	Asset 1	7.0	100.0	VE (12) - 100%	24%	49%	100%	100%		20%	43%	75%	100%	100%	100%		

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

Green	Not present or not inundated (0%)
Yellow	Minimally present or inundated (<25%)
Orange	Moderately present or inundated (25-50%)
Red	Extremely present or inundated (>50%)

Table 1a. Example of matrix used to classify vulnerabilities of park assets.

Table Attribute	Description
Property	Name of the coastal state park or property
Asset	type of asset
Mean Elevation	mean elevation of the asset, in feet referenced to NAVD88 vertical datum
Length, area or number	the physical length (in meters), area (in square meters) or number of individual assets
Mapped Flood Zone (Effective or Preliminary)	Percentage of the asset mapped within FEMA 1% ***Special Flood Hazard Areas (AE or VE zones)***: The 1% BFE, in feet NAVD, of the flood zone is provided in parentheses
Coastal Sand Dunes	Percentage of the asset mapped within the Coastal Sand Dune boundaries per MGS maps, including the frontal dune (D1), back dune (D2) or the Erosion Hazard Area (EHA); also, percentage within the Coastal Barrier Resource System (CBRS)
Sea Level Rise/Storm Surge/SLOSH	Percentage of the asset mapped within inundation areas due to sea level rise and/or storm surge (Highest Annual Tide, or HAT, plus scenarios of 1, 2, 3.3, and 6 feet of sea level rise and/or storm surge), or a Category 1 or 2 hurricane at high tide according to Sea, Lake and Overland Surges from Hurricanes modeling
Shoreline Change	Percentage of the asset that may be eroded in either 10-or-50-years based on short and long-term shoreline changes

Table 1b. Definitions of attributes used to classify vulnerabilities of park assets.

Table 2a. Example of adaptation strategies for park assets

Property	Asset	Flood Zone	Dune System	CBRS Unit	Hazard or Scenario	Potential Impact	Protection Strategy	Accomodation Strategy	Retreat Strategy	Park Operations Strategy	Notes
Park A	Asset 1	AE(10)	D2	ME-16	1 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, structural protection	allow flooding; elevate	N/A	limit access; temporary protection	outside park; need MEDOT coordination
	Asset 1	N/A	D2	ME-16P	Erosion 10 year short-term; 50-year long-term	erosive loss	green infrastructure, dune and beach restoration	allow loss	relocate	limit access; temporary protection	need MEDOT coordination

Table Attribute	Description
Property	name of the coastal state park or property
Asset	type of asset
Flood Zone	Designation on DFIRM -- 1% Special Flood Hazard Areas (AE or VE zones)
Dune System	Designation within the Coastal Sand Dune boundaries per MGS maps, (used in implementation of the Natural Resources Protection Act, i.e. frontal dune (D1), back dune (D2) and the Erosion Hazard Area (EHA).
CBRS Unit	Coastal Barrier Resource System identification unit. The federal Coastal Barrier Resources Act (CBRA) of 1982 designated relatively undeveloped coastal barriers along the Atlantic and Gulf coasts and made these areas ineligible for most new federal expenditures and financial assistance. Areas within the CBRS can be developed provided that private developers or other non-federal parties bear the full cost. Maine also has a state CBRA.
Hazard or Scenario	Refers to the scenario of concern for each asset, such as “1 foot or more of sea level rise or storm surge”
Potential Impact	Anticipated impacts such as flooding or erosion
Protection Strategies	Protection strategies involve "hard" and "soft" structural measures used to decrease vulnerability for structures and infrastructure. Examples of hard engineered structures include sea walls, rock rip-rap, bulkheads, retaining walls, sheet-pile or other hard materials, wave attenuators, etc.
Accommodation Strategies	Accommodation strategies refer to modifications in designs or practices that allow natural processes to occur, but reduce the vulnerability to infrastructure and other assets. Examples include elevating roads and walkways, elevating/floodproofing structures, more effective stormwater management; altering the use of properties, allowing marshes to migrate inland.
Retreat Strategies	As used in this study, retreat strategies involve the abandonment of damaged or threatened assets or removal and relocation to less vulnerable areas.

Table 2b. Definitions of attributes used to describe adaptation of park assets.

2.0 Findings and Recommendations for the Popham Beach Complex

2.1 Introduction

The complex is located at the southern end of the Phippsburg peninsula and is comprised of Popham Beach State Park and the Fort Popham and Popham Colony State Historic Sites (Figure 2). Access to the complex and the properties is via State Route 209. Analyses found that many sections of this road are at-risk to inundation, limiting access to the entire peninsula (see Vehicular and Building Access on the Popham Complex).

In summary, we found that Popham Beach State Park is the most vulnerable property to flooding and erosion. Access to the State Park via Route 209 – along with the rest of the peninsula – is especially at-risk due to flooding. Fort Popham is extremely vulnerable to flooding, as is its access via a section of Popham Road (Route 209). Finally, Popham Colony is least vulnerable to erosion and flooding, but access via Fort Baldwin Road can be compromised even under low inundation scenarios. See individual sections below for further discussions of each property.

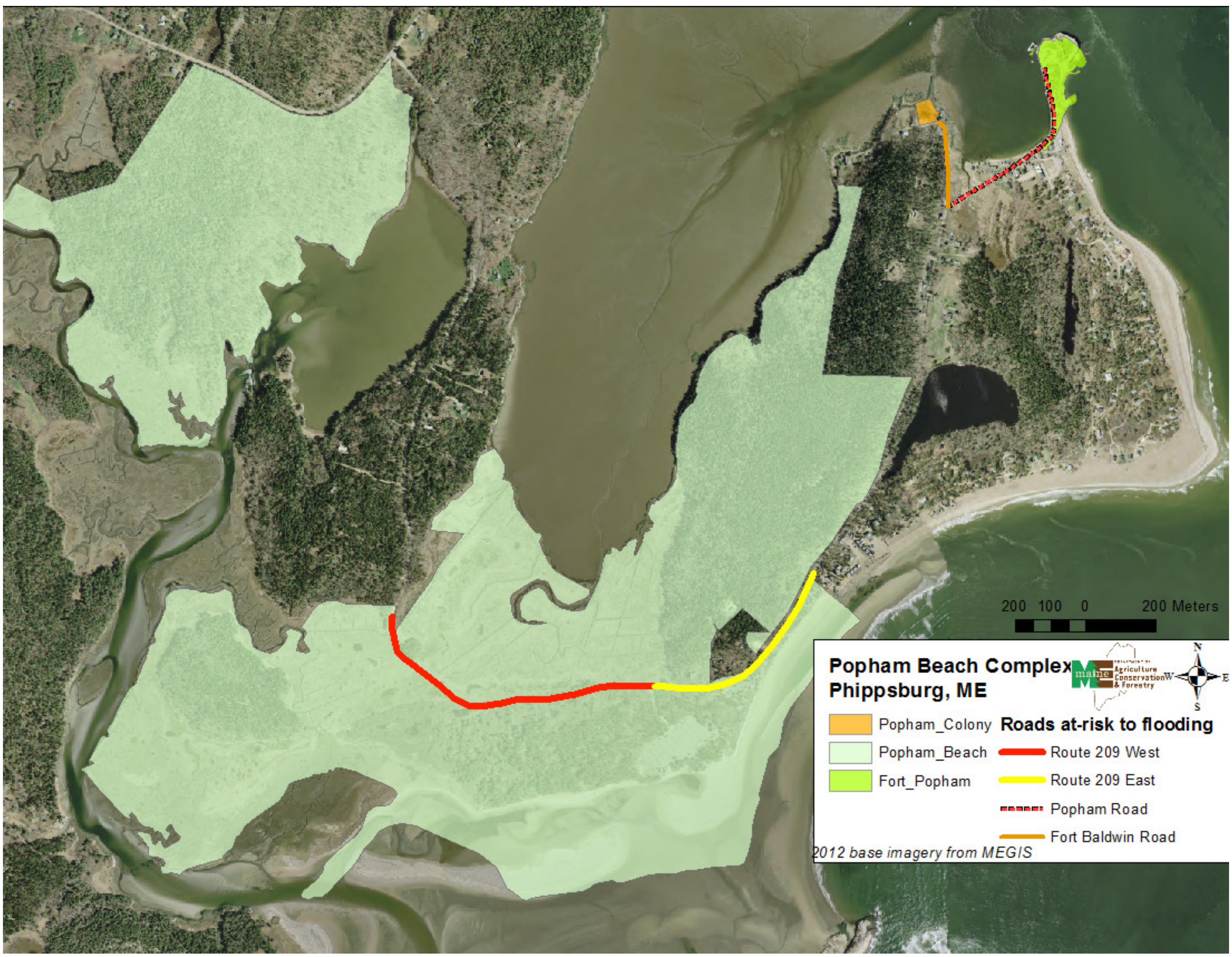

Figure 2. Properties comprising the Popham Beach Complex, located on the Popham Peninsula in Phippsburg, ME.

2.2 Regional Vulnerability – Roads and Development on the Popham Peninsula

One major finding of our analysis showed that vehicular access, whether within a park property or outside of park boundaries is consistently one of the first types of assets that may be compromised by inundation. Road assets within park boundaries that may be inundated by minimal (i.e., 1 foot) of sea level rise or storm surge include Popham Road at Fort Popham. Roads outside of park boundaries that are most at-risk include Route 209 near Popham Beach, Fort Baldwin Road near Popham Colony, and Popham Road near Fort Popham. BPL should ensure that any needed adaptation for vehicular access inside park boundaries is appropriately coordinated with responsible entities for adjacent road networks.

Total	Buildings		Roads	
	#	% Impacted	# miles	% Impacted
Scenario	**161**	**0.0%**	**9.0**	**0.0%**
HAT	1	0.6%	0.0	0.0%
HAT+1ft	4	2.5%	0.5	5.6%
HAT+2ft	19	11.8%	0.8	8.9%
CAT1	27	16.8%	1.3	14.4%
HAT+3.3ft	36	22.4%	1.7	18.9%
CAT2	42	26.1%	2.0	22.2%
EHA	67	41.6%	2.1	23.3%
HAT+6ft	70	43.5%	2.5	27.8%
1% Floodplain	78	48.4%	2.7	30.0%

Table 3. (from left to right) Number and percentage of buildings and miles and percentage impacted under different inundation scenarios.

2.2 Continued

The project team investigated potential inundation and erosion of public and private roads and buildings on the greater Popham peninsula area, per the previously described inundation scenarios. Nineteen buildings are at risk of inundation under a 2-foot rise in sea level. There are 36 buildings affected by a 3.3-foot rise in sea level. Seventy-eight buildings – almost 50% of the buildings on the peninsula – are in the 100-year floodplain. Similarly, about 42% of buildings are in the Erosion Hazard Area, or EHA, while 23% of peninsular roads are in the EHA. About 30% of the 9 miles of roads on the peninsula are located within the 100-year floodplain.

As an example, Figure 3 shows the 1% floodplain in reference to public and private roads on the peninsula. Additional figures supporting this analysis are included in Appendix E.

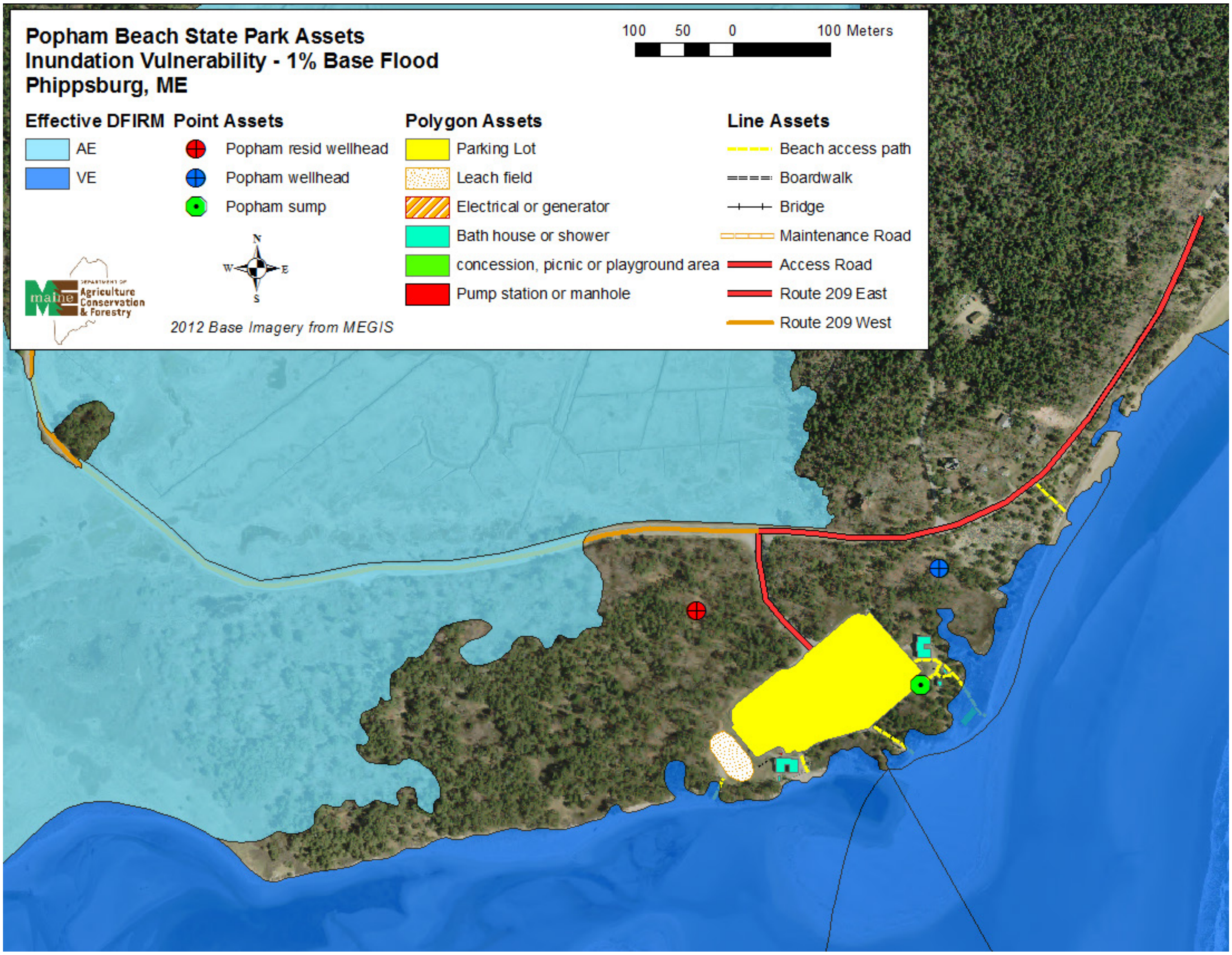

Figure 3. About 30% of roads on the Popham peninsula are mapped within the 1% floodplain.

2.3 Popham Beach State Park – Site Vulnerability Analysis and Adaptation

2.3.1 General Characteristics

Popham Beach State Park is one of Maine's most visited state parks, and is located at the southern tip of the Town of Phippsburg. Eight parcels total approximately 609 acres; bounded by the ocean to the south, state-owned and private properties to the east, the Morse River to the west, and estuary, marsh, and uplands to the north. Habitats in the park include pitch-pine woodland forest, tidal wetlands, dune grasslands, and beaches. The area of the park where the majority of infrastructure assets are located is comprised of almost entirely of regulated coastal sand dunes, which extend from the shoreline over 1,500 feet inland to Route 209.

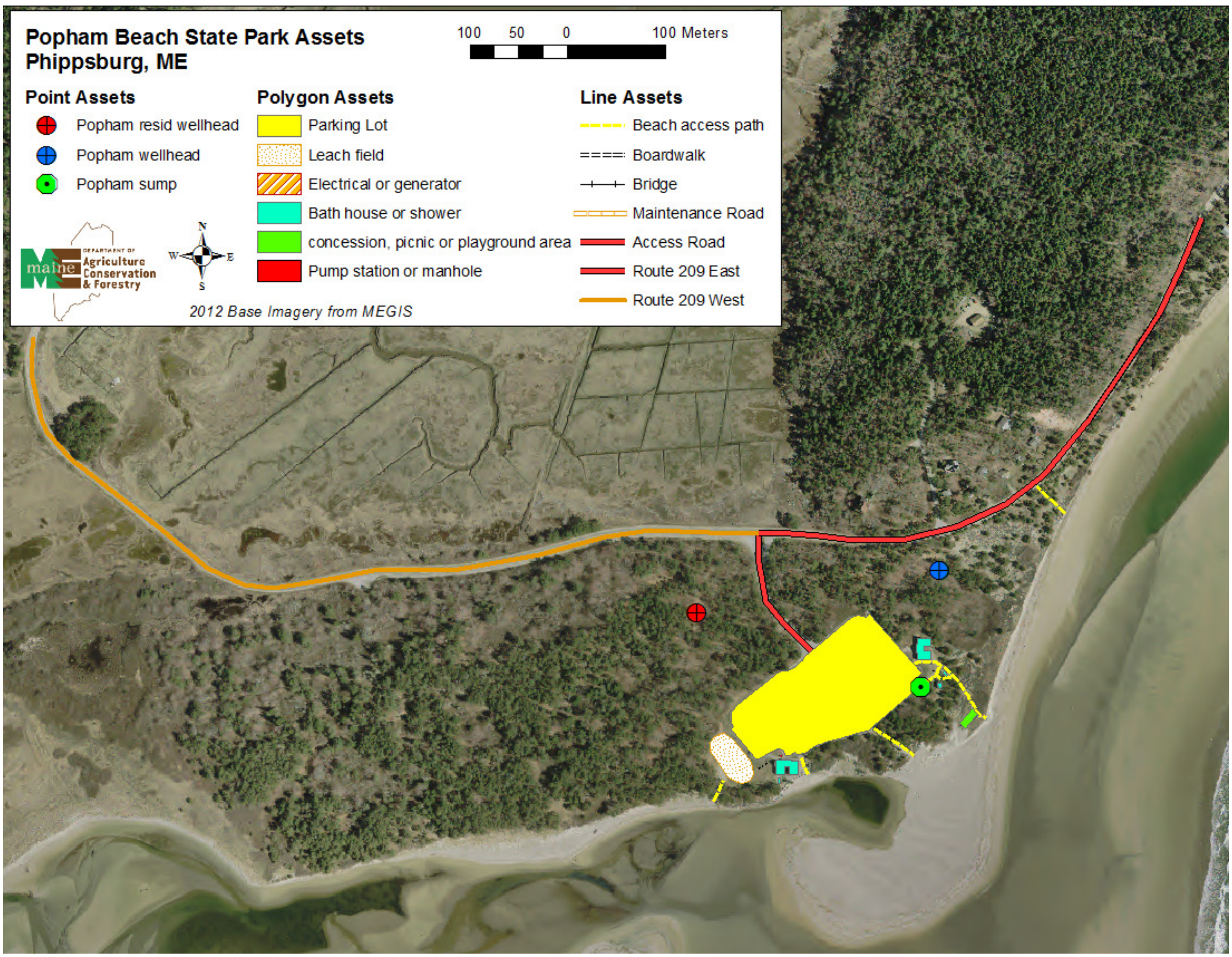

Figure 4. Major built assets at Popham Beach State Park.

2.3.1 (Continued)

Based on the position of the 2016 shoreline, the park has approximately 1.3 miles of sandy beach frontage at high tide. Major built assets within park boundaries include a 435-foot paved access road, 4 acre paved parking lot, two bath houses with running water and toilets, and a pump station and leach field (Figure 4). Access to the park is provided from State Route 209.

Popham Beach State Park is exceptionally vulnerable to coastal erosion (Figure 5). Shoreline erosion is driven by meandering of the Morse River channel; when the channel is relatively out to sea and located at the western edge of the property, the beach and dune system at Popham Beach State Park accretes or is relatively stable. When the channel meanders to the east – towards the center of the park – the beach and dune tend to erode. Shoreline changes along Popham Beach are some of the most dynamic of any sandy beach system in Maine.

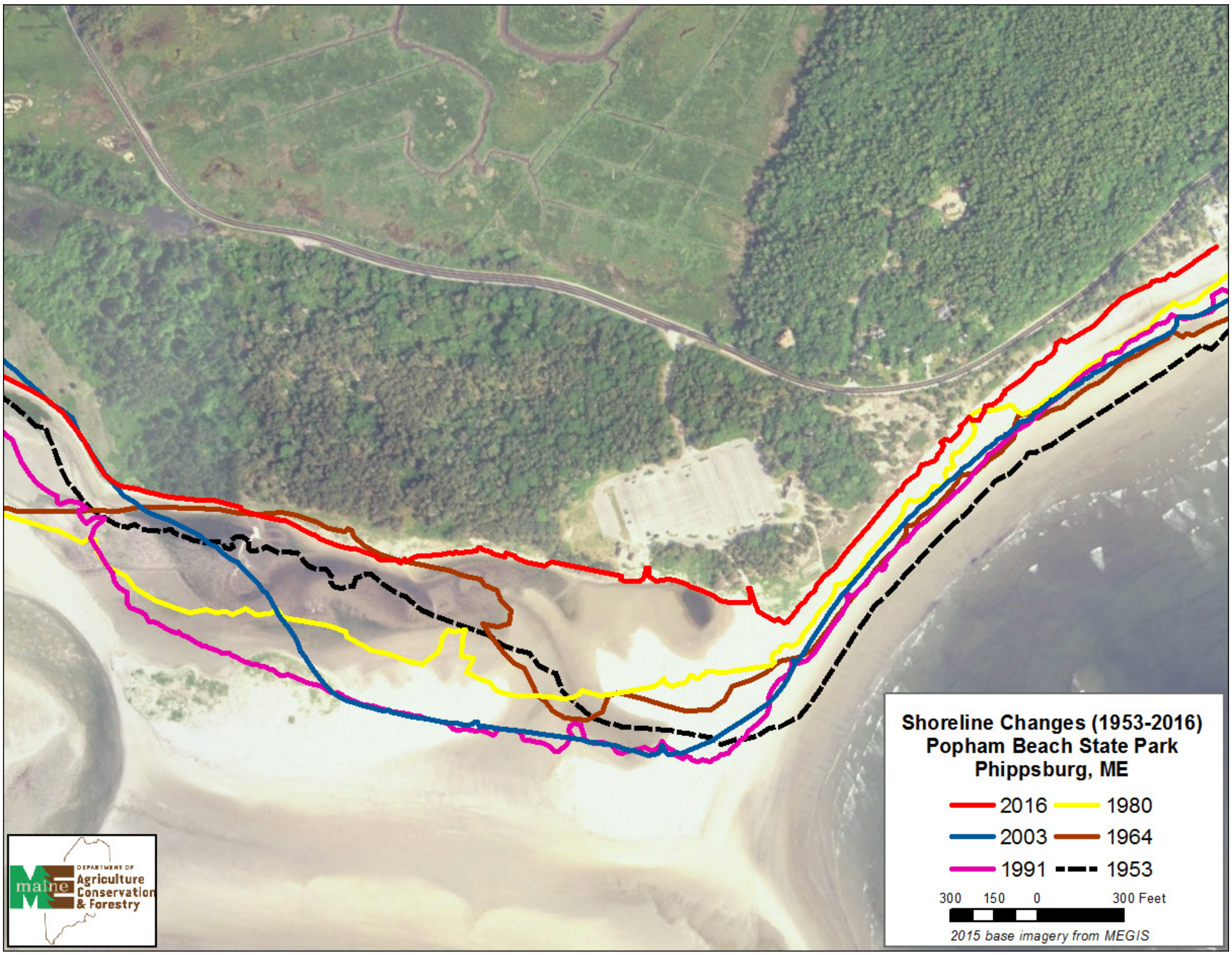

Figure 5. Shoreline positions from 1953 to 2016 at Popham Beach State Park. Note dramatic changes from 1991-2016. The Morse River channel is seen at the lower left side of the figure.

2.3.2 Long-term Shoreline Change Analyses

Figure 5 shows historic shoreline positions from 1953 to 2016 along the main beach section of Popham Beach State Park. The 2016 shoreline is the most landward-most of them all. Additional analysis by MNAP of aerial imagery from 1998 to 2015 shows that shoreline changes led to the loss of approximately 29.5 acres of dune grassland, and 2.5 acres of pitch pine woodlands. From 1991 to 2016, the shoreline in front of the parking area eroded and receded approximately 625 feet. From 1953 to 2016, the shoreline receded at a net rate of -2 feet per year. The worst erosion was concentrated near the Morse River channel (over -4 feet per year), near the public bath house (about -4 feet per year), and along East Beach (about -2 to -4 feet per year). Shoreline changes were greatest over the period of 1991-2016, especially in front of the existing bath house, where the shoreline eroded up to 625 feet.

Figure 6 shows calculated long-term shoreline change rates based on shoreline positions from 1953 through 2016. Greens to dark greens show areas of shoreline growth, while yellows to reds to dark reds show areas of shoreline erosion, in increasing magnitude. The area of highest erosion occurred near where the Morse River swung northwards, into the dunes and pitch-pine woodlands (between transects 50-60 on Figure 6). The shoreline just west of the parking lot and bath house (between transects 80-110) showed dune growth at up to 4 feet per year, while the shoreline directly fronting the bath house and parking lot eroded at up to about -4 feet per year (between transects 120-130).

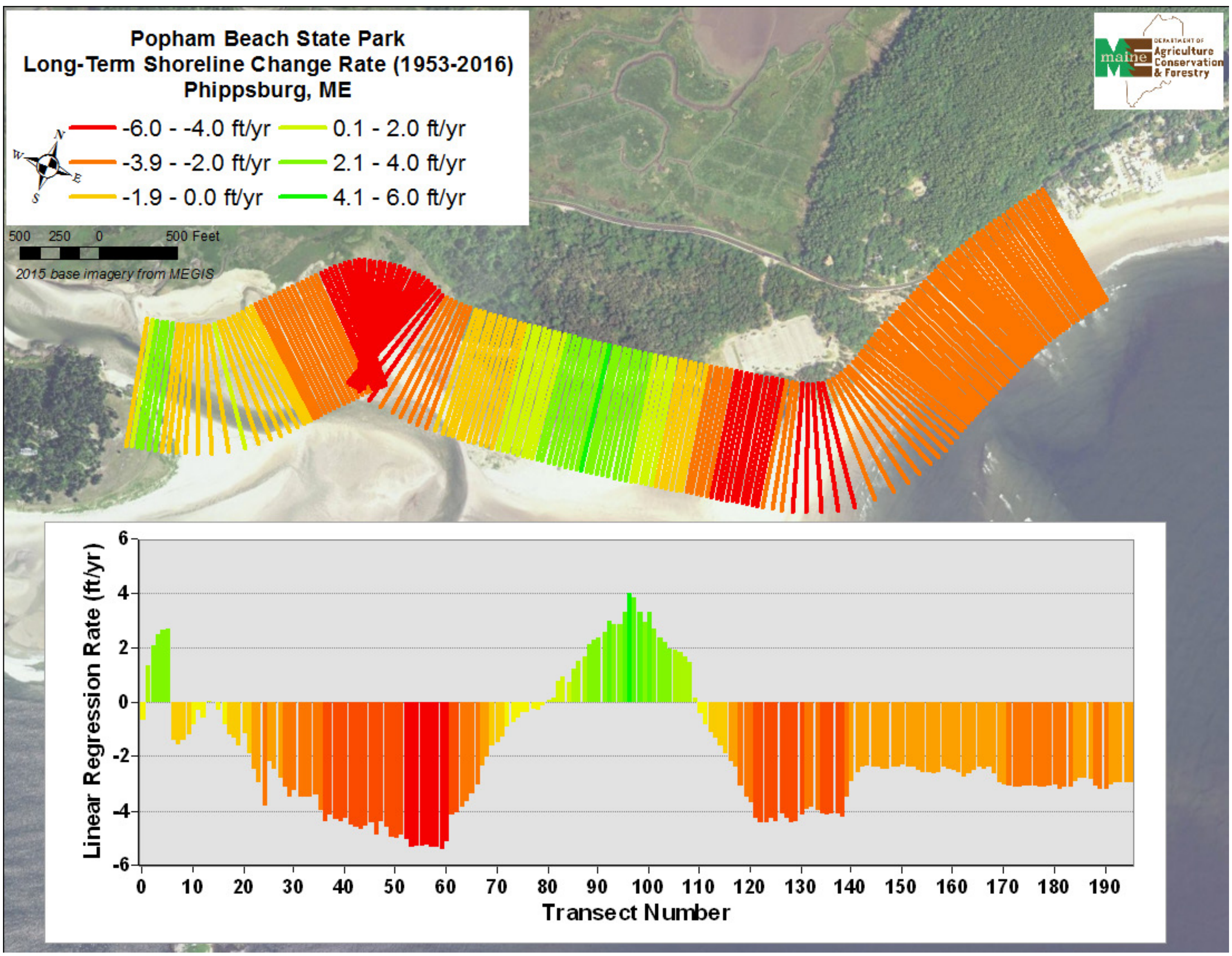

Figure 6. Long-term shoreline change rates along Popham Beach State Park.

2.3.2 (Continued)

Using long-term calculated rates from Figure 6, shoreline change trends were extrapolated over 50 years, as shown in Figure 7. Based on these data, significant future erosion (over 200 feet) could impact the existing western bathhouse, parking lot, leach field, and ancillary pump station facilities. Other significant potential impacts include erosion of the pitch-pine woodland habitat, and erosion of the shoreline adjacent to Route 209 east of the park, which provides access to the remainder of the Popham peninsula. The Route 209 potential erosion issue is currently being investigated by a Federal Highway Administration (FHA) grant to the Maine Department of Transportation for green infrastructure approaches to shoreline stabilization.

Based on the length of this dataset (1953 to 2016), we would recommend that these shoreline change predictions be used for future planning as opposed to much shorter shoreline change measurements and projections, detailed in Section 2.3.3, below.

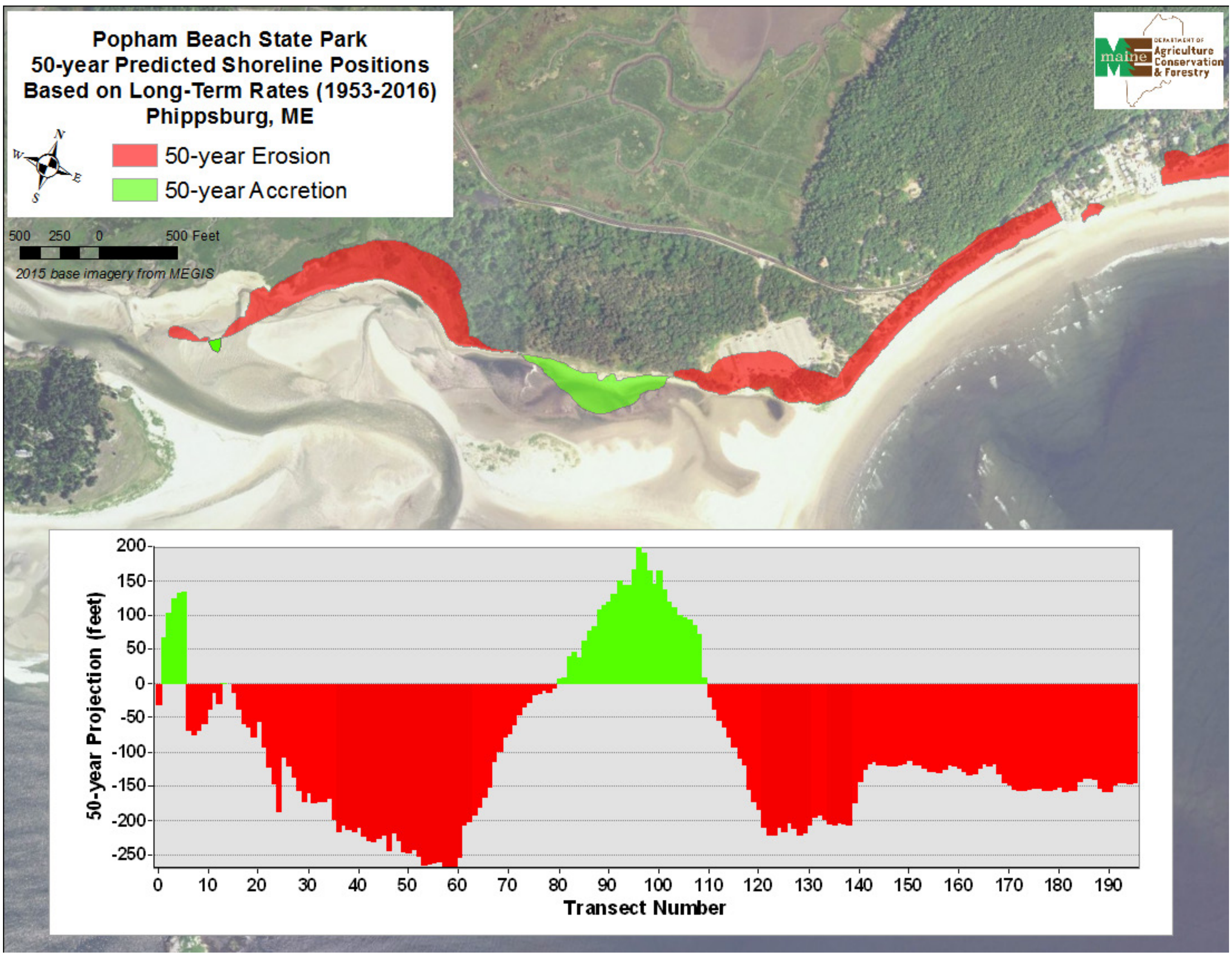

Figure 7. 50-year predicted shoreline position along Popham Beach State Park.

2.3.3 Short-term Shoreline Change Analyses

Short-term shoreline change data from shorelines mapped between 2010 and 2015 showed extremely high rates of erosion in front of the parking lot and western bathhouse – upwards of 50-60 feet per year (transects 120-130 on Figure 8a). Shoreline change to the west of the bathhouse was generally much less, and positive in some small segments, while erosion to the east of the bathhouse was on the order of 10-20 feet per year. Extrapolation of these extreme short-term shoreline change rates over 10 years indicates that the bathhouse, majority of the parking lot and associated facilities, and Route 209 to the east could potentially be subject to extensive erosion (Figure 8b). *However, we do not recommend using such extremely short-term datasets to make such predictions.* Recent changes along East Beach – located east of the parking lot – including the development of a wide berm due to landward migration of an offshore sand bar system, indicate that the shoreline has stabilized somewhat.

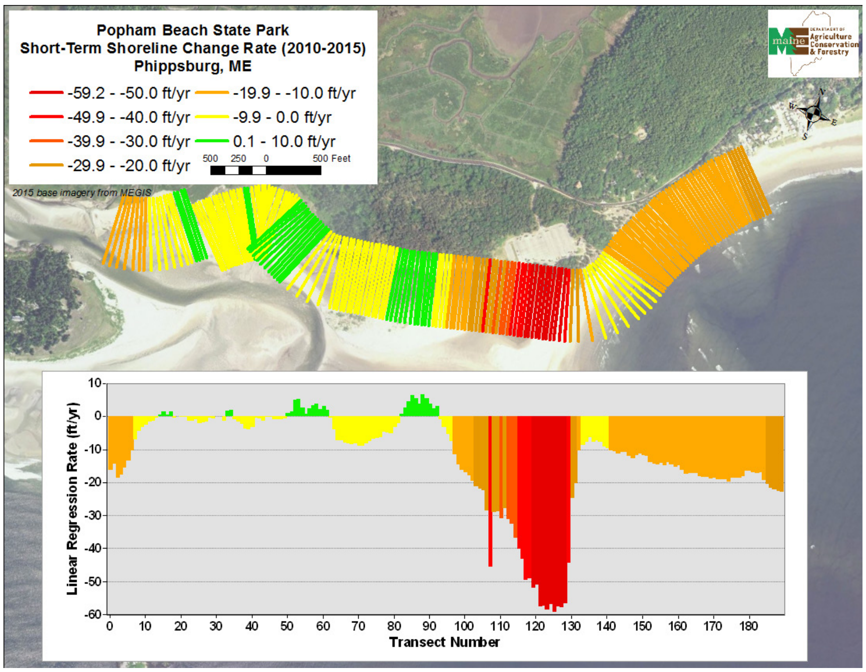

Figure 8a. Short-term shoreline change rates along Popham Beach State Park. Note the extremely high rates of erosion, especially along the Popham Beach parking lot.

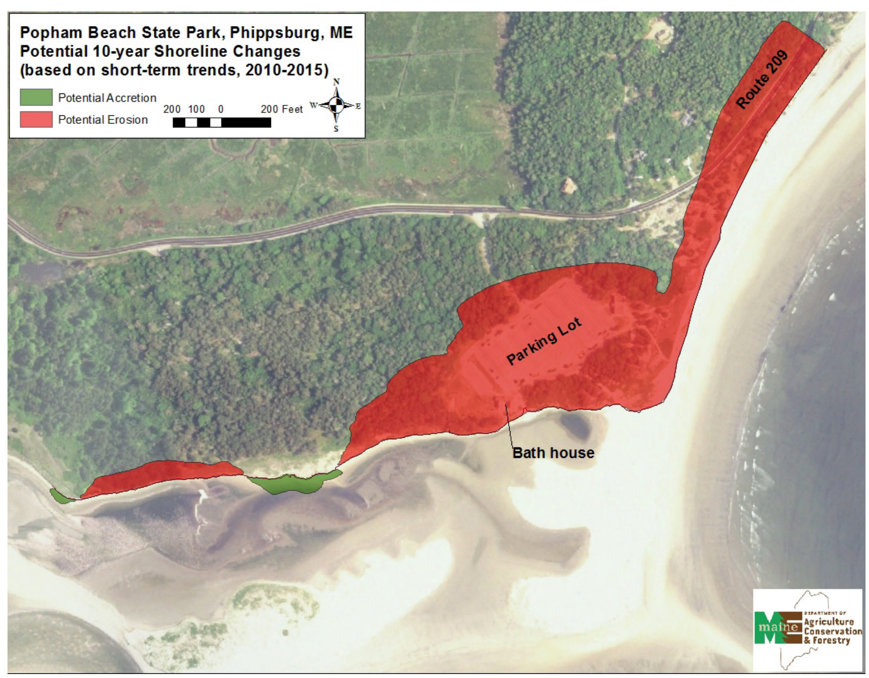

Figure 8b. Potential 10-year predicted areas of erosion and accretion based on short-term (2010-2015) shoreline changes.

2.3.4 Inundation Analyses

A major component of this study was to evaluate the potential for water damage to park infrastructure using several different methods, including: the 1% Special Flood Hazard Area (SFHA), sea level rise or storm surge (on top of the highest annual tide, or HAT), and hurricanes (see Table 4).

Property	Asset	Mean Elev* (ft NAVD)	Length, area or Number	Mapped Flood Zone (Effective)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**							Shoreline Change	
					D1	D2	EHA	CBRS	HAT (6.3ft)	HAT+1 (7.3ft)	HAT+2 (8.3 ft)	CAT 1 (9.3 ft)	HAT+3.3 (9.6 ft)	HAT+6 (12.3 ft)	CAT 2 (12.9 ft)	10 year ST trend	50 year LT trend
Popham Beach	Route 209 (west of entrance)	8.6	890 m	AE (9,10) - 67%		63%		ME-16		3%	51%	87%	88%	100%	100%		
	Access road	10.8	138 m			100%		ME-16				6%	6%	56%	94%	32%	
	Route 209 (east of entrance)	17.3	630 m			100%		ME-16P				5%	5%	10%	10%	36%	31%
	Recreational - beach paths	varies	288 m	VE (15, 17,18) - 23%	9%	91%	74%	ME-16, 16P				2%	2%	40%	6%	100%	57%
	Recreational - shower facilities	13.7	6			100%	67%	ME-16					17%	67%		100%	33%
	Manhole 4	9.5	N/A			100%	100%	ME-16P						100%	100%	100%	
	Recreational - entry shack	12.5	1			100%		ME-16						100%	100%	100%	
	Leach field	12.7	0.34 ac			100%		ME-16						15%	41%	100%	50%
	Parking lot	13.1	3.99 ac			100%	<1%	ME-16, 16P						28%	16%	100%	37%
	Pump station/sewage sump	10.7	N/A			100%	100%	ME-16P						100%		100%	
	Manhole 5	10.7	N/A			100%	100%	ME-16P						100%		100%	
	Manhole 6	11.0	N/A			100%	100%	ME-16P						100%		100%	
	East Bath House	10.8	0.07 ac			100%	36%	ME-16P						100%		100%	
	Manhole 1	12.8	N/A			100%		ME-16								100%	100%
	Manhole 2	13.4	N/A			100%		ME-16								100%	100%
	Manhole 3	13.6	N/A			100%		ME-16								100%	100%
	Generator	13.9	N/A			100%		ME-16								100%	100%
	West Bath House	14.1	0.07 ac			100%		ME-16								100%	100%
	Recreational - picnic area/tables	20.0	0.04 ac	VE (15) - 100%	100%		100%	ME-16P								100%	100%
	Residence well head	17.1	N/A			100%		ME-16									
	Park well head	13.1	N/A			100%		ME-16									

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

Green	Not present or not inundated (0%)
Yellow	Minimally present or inundated (<25%)
Orange	Moderately present or inundated (25-50%)
Red	Extremely present or inundated (>50%)

Table 4. Vulnerability of assets at Popham Beach State Park. Included is percent of the asset that is present within: the effective FEMA flood zone; Maine regulated coastal sand dunes (front dune, back dune, or Erosion Hazard Area), sea level rise, storm surge, and SLOSH inundation scenarios; and ten-year short-term and fifty-year long-term projected shoreline changes. For explanations of the columns in Table 4, see Table 1b.

2.3.4 (Continued)

Popham Beach State Park is mostly vulnerable to tidal flooding from the north – across Route 209. This vulnerability from the north is partly due to the higher topographic relief of the ocean-facing dunes. Dunes appear to be of sufficient height to withstand static flooding except for the highest surge or sea level rise scenarios. As mentioned earlier, splashover from wave action is not included in these scenarios. Even then, most of the impacts to facilities within the park are generally limited to ponded areas with no clear tidal connection. These impacts appear to be limited to the access road, areas of the parking lot, leach field, and east bath house (Figure 9).

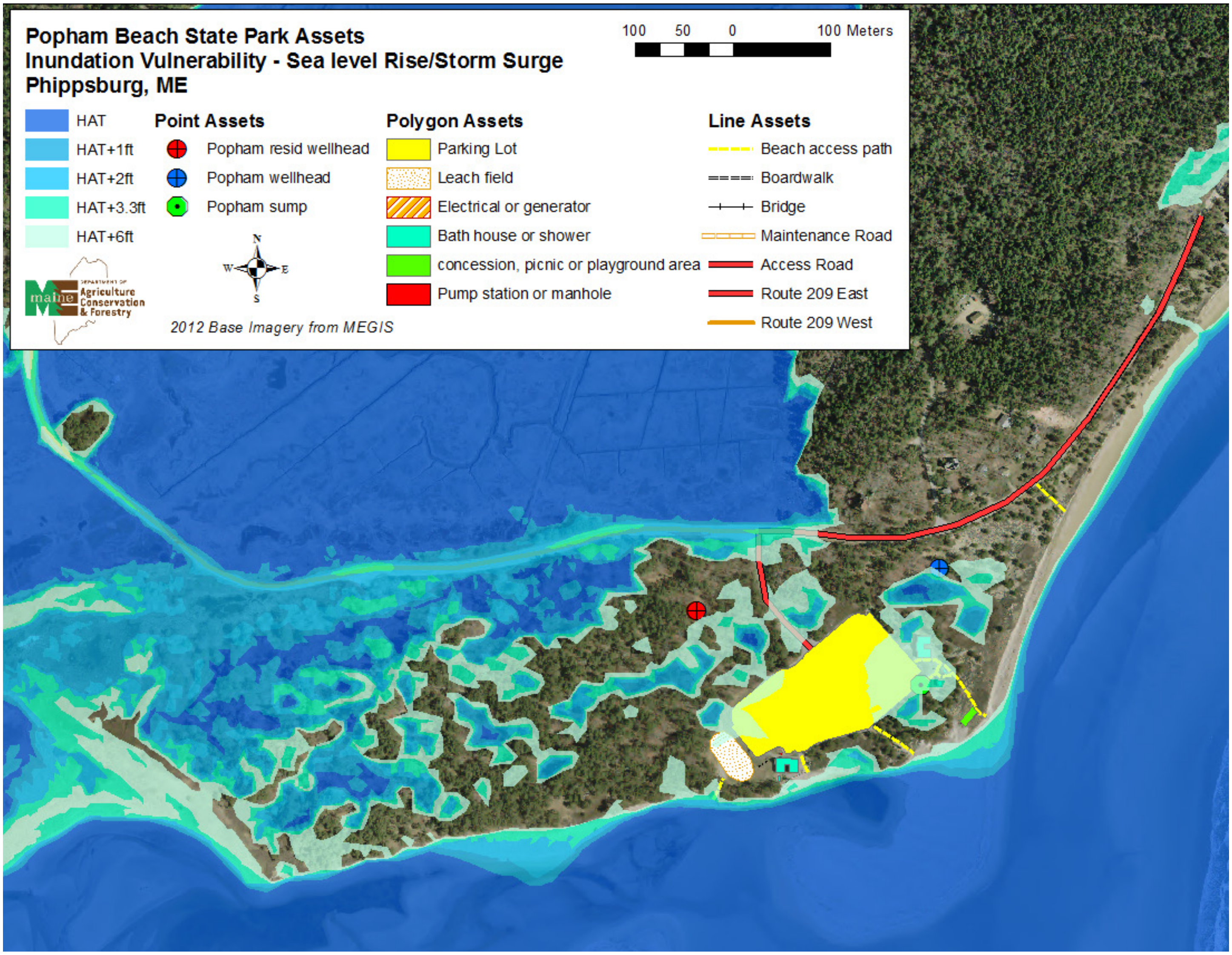

Figure 9. Potential Inundation to sea level rise and/or storm surge on top of highest annual tide at Popham Beach State Park.

2.3.4 (Continued)

Similar to scenarios of storm surge and sea level rise, hurricanes can cause inundation of the park from the north. The dune area impacted by a Category 1 hurricane is approximately the same as the HAT +1 scenario. The Category 2 conditions have a more significant impact to park infrastructure. A Category 2 hurricane could potentially breach the dune system near the western bathhouse, resulting in extensive flooding through the parking lot and leach field (Figure 10). It is important to realize that all hurricane simulations occur on an initial water level of Mean High Water that is about 2.5 feet lower than HAT in the southern Maine region. If a hurricane were to coincide with a high astronomical tide an additional inundation of 2 feet should be expected.

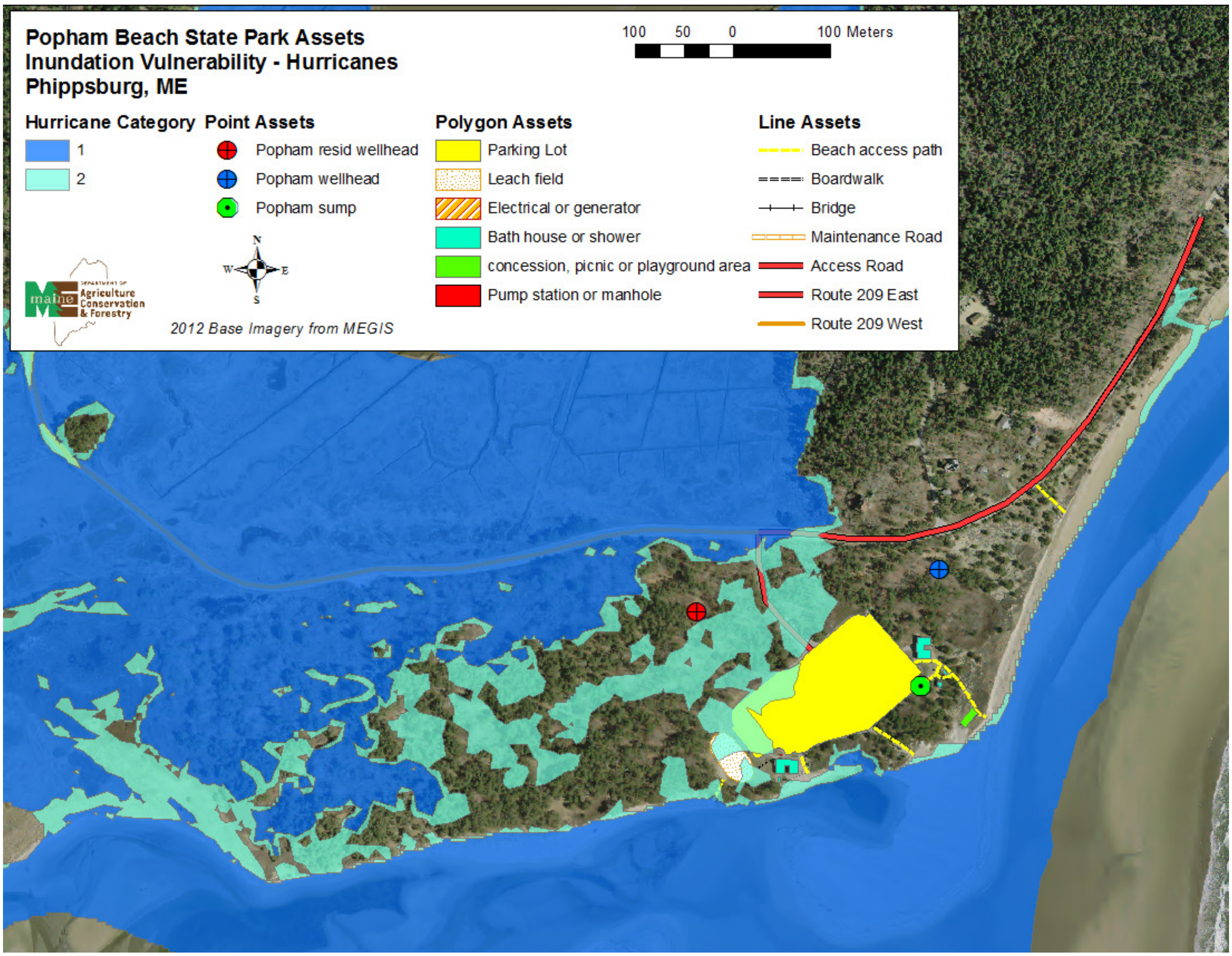

Figure 10. Potential inundation to Category 1 and 2 hurricanes at Popham Beach State Park.

2.3.4 (Continued)

Simulations showed that access via Route 209 to the entire Popham Beach peninsula is at substantial risk to inundation, even under lower scenarios. Under a scenario of just 1 foot of SLR or storm surge on top of the HAT, about 40 meters, or about 4% of Route 209 could be inundated at the times of highest tides (Figure 9). This would be occurring on an almost monthly basis, and would have significant impacts to accessing the park and peninsula. With 2 feet of sea level rise, this number increased to 56% of Route 209 being inundated during the highest tides. The effective FEMA SFHA shows a large section of Route 209 in the 100-year floodplain (Figure 11). Aside from this, no assets are mapped in the 100-year floodplain aside from beach paths and a picnic area.

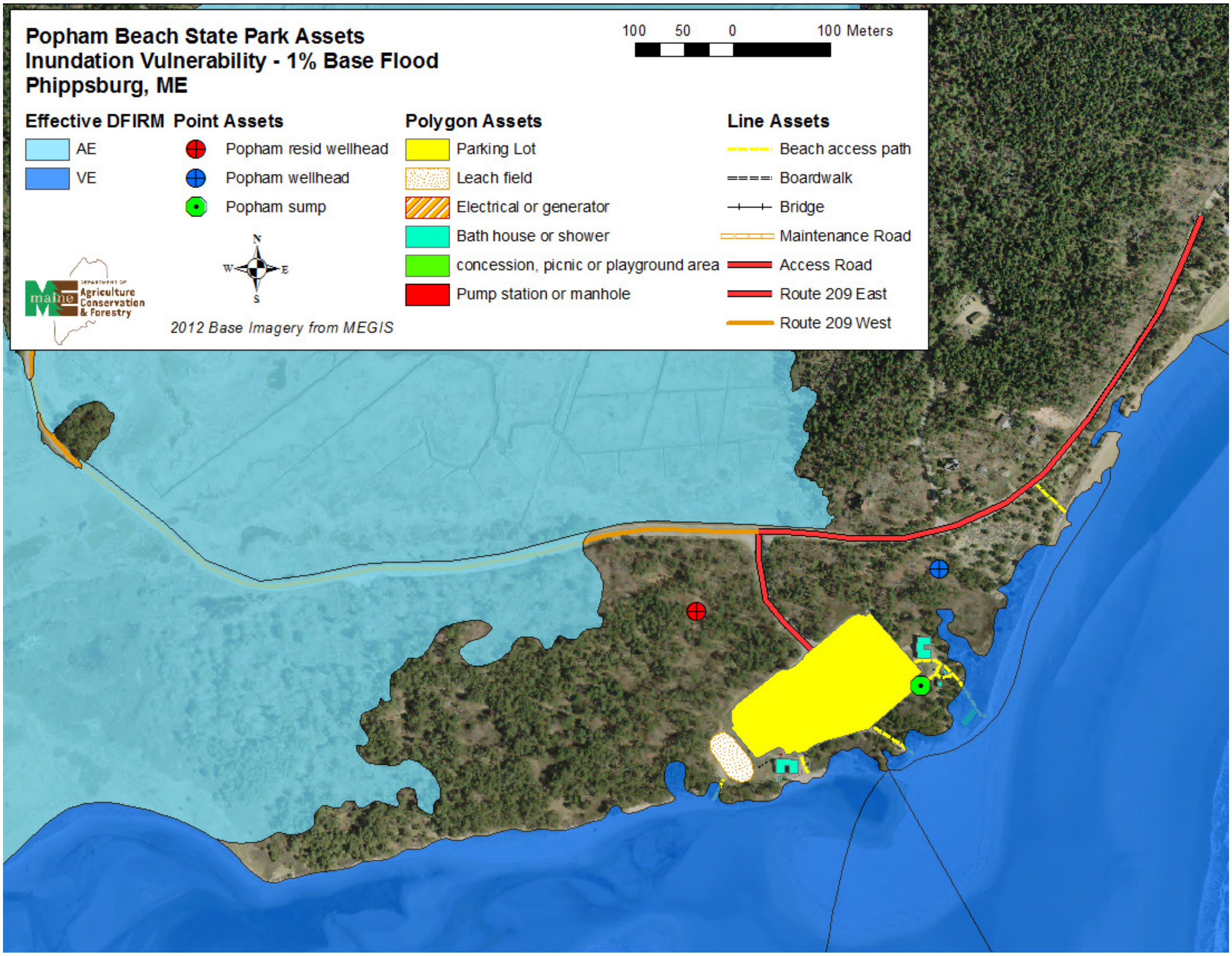

Figure 11. Effective 1% SFHA per FEMA DFIRM at Popham Beach State Park.

2.3.4 (Continued)

A more detailed inundation frequency analysis was completed for the low-lying stretch of Route 209 (west of Popham Beach State Park). Hourly tidal elevation data from 1912 to 2014 from the NOAA Portland tidal station was offset to Fort Popham, Hunniwell Point, using a known tide correction factor (e.g., 0.92 of high in Portland, NOAA, 2015). Using these hourly measurements and the minimum elevation of Route 209 (12.8 feet MLLW), the historical flood frequency for existing conditions was calculated.

Using this method, an hourly measurement that exceeded the minimal flood stage of 12.8 feet MLLW was considered a “flood” event. This methodology is similar to that used by the NOAA CO-OPs Inundation Analysis Tool.

From 1912 to 2014, the low-lying stretch of Route 209 averaged approximately 0.2 flood events per year (Figure 12). The number of existing flood events (from 1912-2014) appeared to slightly increase over the past 20 years, to 0.3 events per year.

If the historical flood frequency data (1912-2014) were used as an indicator of future conditions, when 1 foot of sea level rise is added, the average flood frequency would increase to about 6 flood events per year. With 2 feet, the average number of flood events would increase to 76.

If only the last 20 years were used as a proxy for the future, with 1 foot of sea level rise, the number of flood events per year would increase to 13. With 2 feet, this would increase to approximately 130 events per year.

This kind of information could be very useful for road and park access management or improvement planning by the Town of Phippsburg, BPL, and Maine DOT.13 flood events per year, or almost once monthly.

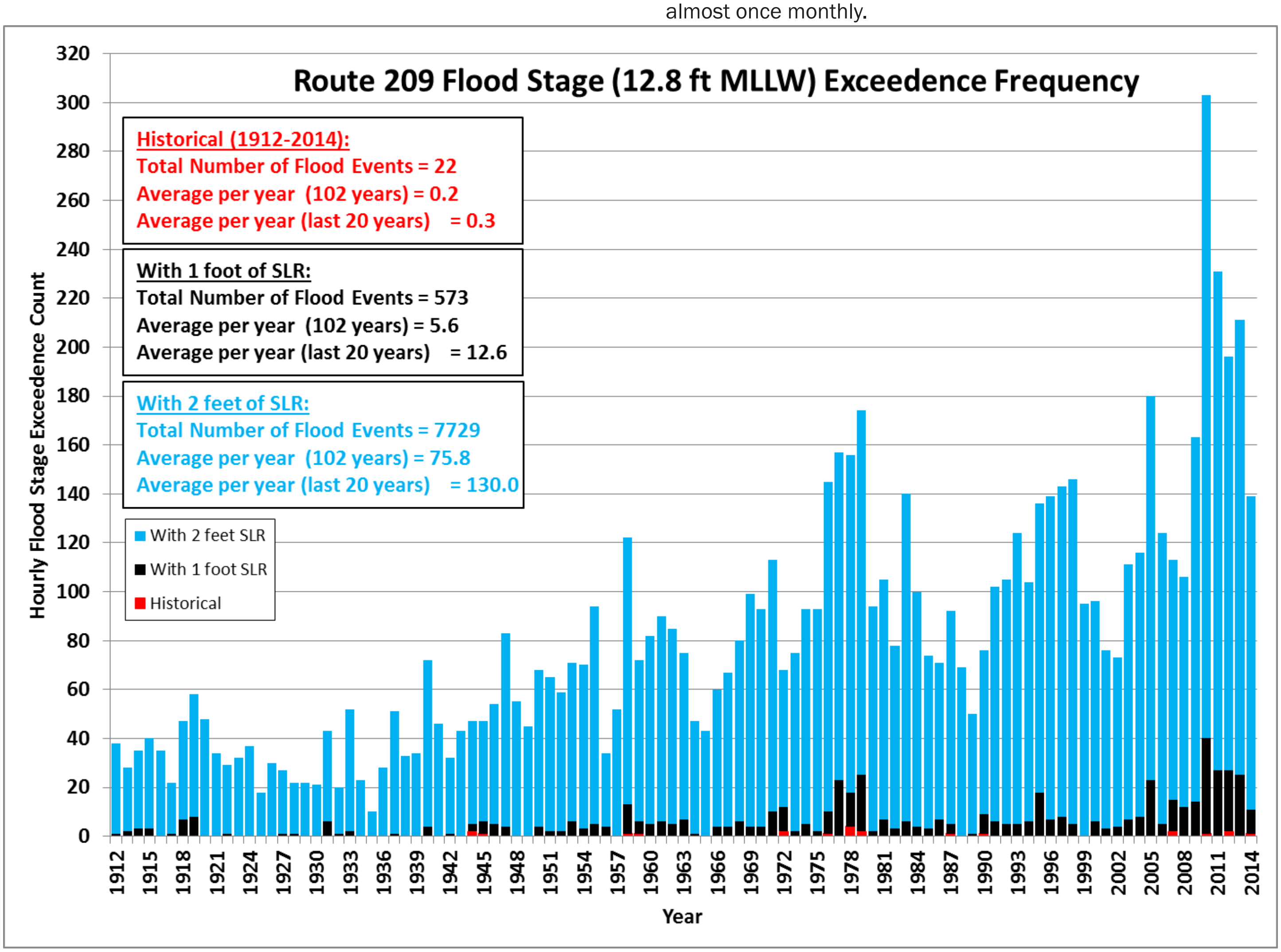

Figure 12. Existing and potential future flood stages (after 1 and 2 feet of sea level rise) exceedance frequency at Route 209. Data from NOAA CO-OPs.

2.3.5 Water Supply and Wastewater Treatment Asset Analysis and Potential Adaptation

Coastal state parks need sufficient supplies of potable water, and the ability to safely remove and dispose of wastewater. Water resources at coastal sites may be threatened by sea-level rise or storm surge due to direct inundation of the land surface by the sea, the movement of saltwater into groundwater aquifers, or the flooding of infrastructure from below by rising fresh water tables associated with long-term sea-level rise. Of all the study sites in this project, only the water resources at Popham Beach were determined to be potentially at risk from sea level rise or storm surge. This determination was based on elevation and distance from the shore, as well as the vulnerability of individual aquifers and types of infrastructure. Beginning in the summer of 2015, MGS performed an investigation and modeling study of groundwater at Popham Beach State Park. The purposes of the study were to understand the recharge and flow of groundwater through the unconsolidated aquifer system, quantify the potential effects of sea-level rise and related environmental changes on groundwater, and to assess the vulnerability of park water resources to changing hydrogeologic conditions, including saltwater intrusion.

The investigation involved installing and monitoring a network of observation wells, making water and terrain conductivity measurements, and constructing models of the saltwater interface and groundwater flow at the site. A numerical computer model of groundwater flow was then used to estimate the risk of saltwater intrusion as seal level rises, precipitation increases, and shorelines change. See Appendix F for further details about the context of the investigation, the methods employed, and more detailed results.

Approximately 2 million gallons of fresh water per year are drawn from a shallow well in the sandy back-dune aquifer. The parking lot, bath houses, and water supply infrastructure for the Park are located on top of a thick (>80 ft) unconfined aquifer of unconsolidated fine-to-medium sand that overlies regional bedrock. The water supply for the park is a gravel-pack well of about 28 ft in depth, installed in 2008 in an area of forested back dune. The well supplies water for drinking, public showers, and flush toilets (Figure 13).

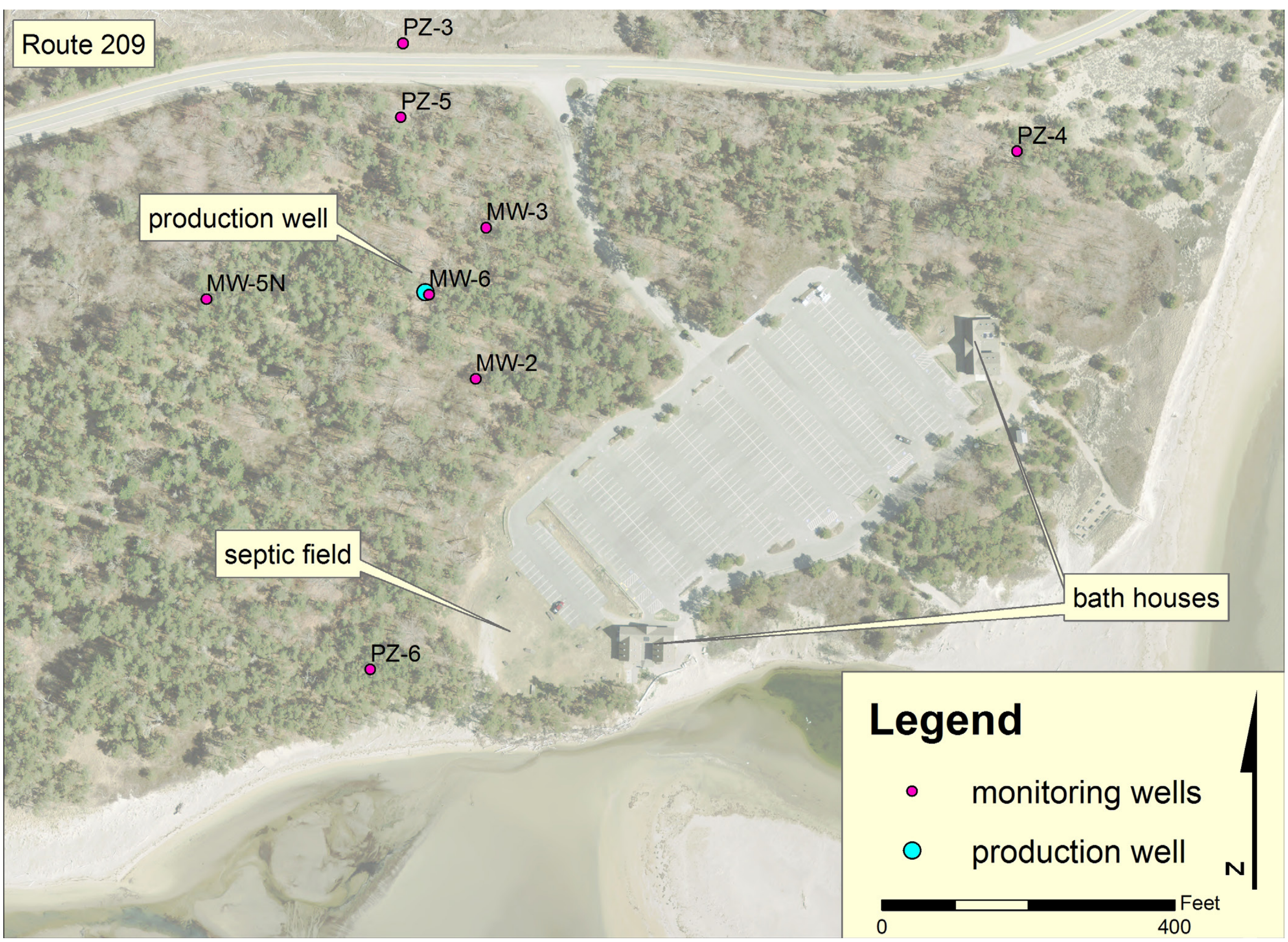

Figure 13. Map of the well field and park infrastructure at Popham Beach State Park, showing the production pumping well and monitoring well locations.

2.3.5 (Continued)

According to study results, saltwater is not currently contaminating fresh water resources in the shallow back-dune aquifer, and the water supply well is not under direct threat of permanent saltwater intrusion under moderate levels of sea-level rise or anticipated shoreline erosion. An increase in the pumping rate, for example to accommodate increased park visitation, is unlikely to have a detrimental effect on the freshwater aquifer or water resources at the park. Furthermore, the risk to the water supply from storm surge and overtopping of the freshwater aquifer was not directly addressed during this modeling exercise. A hurricane storm surge has the potential to push saltwater on top of the land surface significantly inland towards the pumping well, and the likelihood for quick infiltration of this saltwater into the top of the freshwater aquifer is high, especially given the high recharge ratio and permeability of the sandy dune sediments. Further modeling work that incorporates storm surge and unsaturated zone processes would help clarify this risk. From an adaptation standpoint, saltwater infiltration can be managed by ceasing pumping of well water during storm surges until a lack of salt contamination is verified. The timing and degree of contamination depends on the length of inundation time. In terms of adaptation to permanent contamination (at 6 feet SLR), an alternative water supply should be considered – potentially bedrock wells on nearby Sabino Hill.

Wastewater is disposed of in a septic system and grey-water leach fields adjacent to the parking lot and bath house. The lowest chamber of the septic system is about 4 ft above the estimated seasonal high water table, which is also close enough to cause concern that rising sea levels and increasing precipitation rates will cause the water table to rise and flood the septic system. According to study results, the septic system is at risk of failing to maintain necessary unsaturated conditions at 2.45 ft of sea-level rise (i.e., there will be less than 2 ft of unsaturated material beneath the lowest septic chamber), and is predicted to be flooded at least half of the year at less than 5 ft of sea-level rise. The lower chambers of the septic system are at risk of flooding at 3.3 ft of sea level rise. Adaptation for this would include decommissioning of the lower-elevation septic chamber and reducing water consumption.

Adaptation strategies for the leach field appear to be limited. Any replacement septic field would have to be built higher than the current one to be above any potential rise in the water table—likely built on top of imported sandy fill. However, the location of a new field would be difficult given required regulatory setbacks and specific conditions at the park. Several test pits were excavated to the northwest of the existing septic field, and a "reserve area" - identified just to the north of the existing field – was reserved for a future replacement septic system. However, with recent shoreline changes, the reserve area (and the current location of the field) is no longer the required 300 feet from the high-tide line. A new field would also have to be 300 feet from the supply well, and two other drinking water wells on the east side of the property. Leach field relocation is also limited by existing special habitats – pitch pine woodland, which should not be disturbed based on the importance of this habitat type. A potential location for a relocated field could be over a part of the existing parking lot, likely near the northern corner of the lot in order to maintain a distance of greater than 300 feet from the current shoreline. A raised septic system could potentially be located here – but in order to preserve parking spaces, the parking lot would have to be reconstructed over the septic. Further engineering analysis relating to the feasibility of this is warranted.

2.3.6 Natural Resource Analysis and Potential Adaptation

The biological systems at Popham Beach State Park are diverse and contain both common and exemplary natural community types and rare and threatened species (Figures 14 and 15). The undisturbed Beach Strand and Dune Grassland communities provide nesting habitat for the state endangered Least Tern (*Sternula antillarum*) and the state endangered and federally threatened Piping Plover (*Charadrius melodus*). Roughly 1/3 of the park is Spartina Saltmarsh, which provides important habitat for many plant and animal species, including the state endangered purple foxglove (Agalinis purpurea), rare saltmarsh tuber bulrush (*Bolboschoenus robustus*), rare saltmarsh false-foxglove (*Agalinis martiima*), Saltmarsh Sparrow (*Ammodramus caudacutus, special concern*), and the salt marsh tiger beetle (*Cicindela marginata special concern*). The park also supports the state's largest occurrence of Pitch Pine Dune Woodland (45 acres), a rare forest type occurring on stable back dunes. Because of its limited range and past history of development, Pitch Pine Dune Woodland is very rare in Maine as well as globally rare.

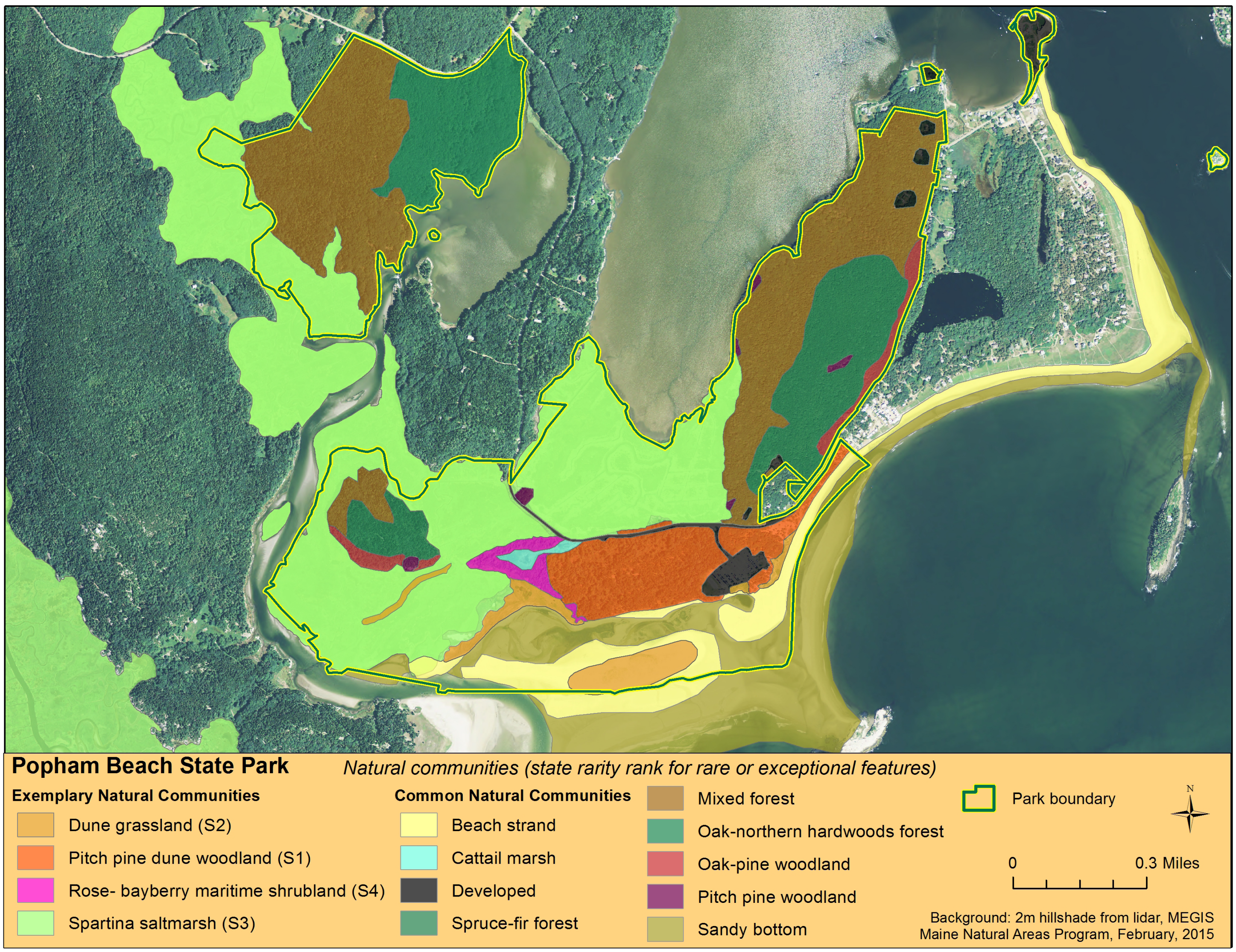

Figure 14. Natural Community Types at Popham Beach State Park.

2.3.6 (Continued)

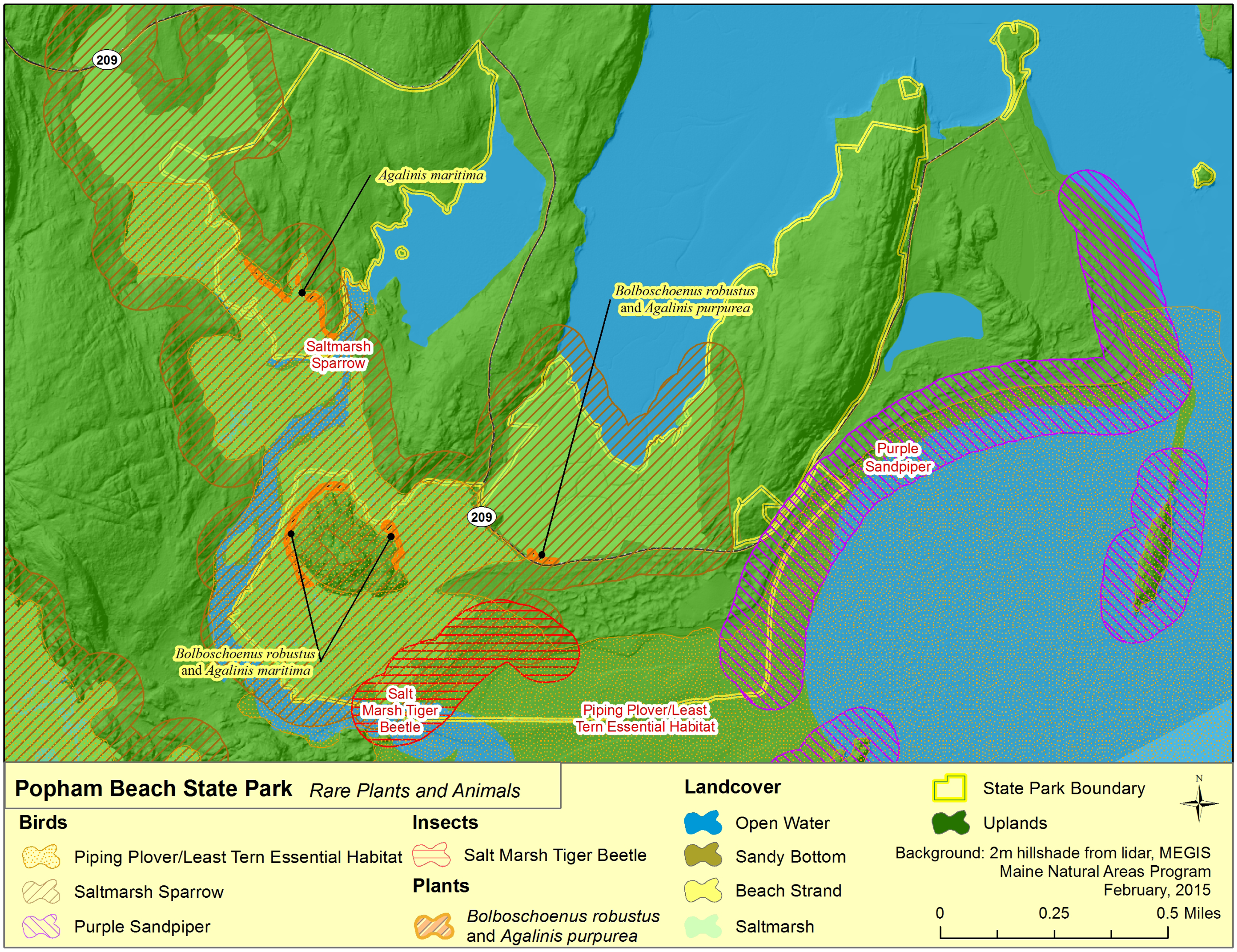

Figure 15. Rare Plants and Animals at Popham Beach State Park.

2.3.6 (Continued)

Most of the significant natural features within the park are vulnerable to impacts from sea level rise as well as increased storm intensity and frequency. The Bureau of Parks and Lands has a high responsibility for several features within the park because of their extreme rarity within the state, and their disproportionate occurrence on state park lands. Those features include Dune Grasslands, Pitch Pine Dune Woodlands, Piping Plover (E) - Least Tern (E) Essential Habitat, Saltmarsh Sparrow, Saltmarsh Tiger Beetle, and large purple false foxglove.

While the habitats unable to adapt to sea level rise such as Pitch Pine Dune Woodland may decrease in size, other habitats such as Beach Strands, Dune Grasslands, and Spartina Saltmarsh may be able to adapt to sea level rise by migrating inland. The mechanics allowing each coastal habitat to move inland are different. The Spartina Saltmarsh on the west side of the park will provide room for the landward movement of the dune formation and the associated Dune Grassland. There is relatively less room for the Spartina Saltmarshes themselves to migrate landward as sea level rises, and if some or all of the existing marsh cannot keep up with the continued tidal elevation increases, areas of marsh will be lost. As sea level rises and tidal marshes migrate onto adjacent low elevation areas, they will colonize the area currently supporting the Maritime Shrubland, as well as a portion of the Pitch Pine Dune Woodland. Looking at the whole Morse River estuary (~262 acres), the only area with any significant potential to accommodate marsh migration are these areas within the park, though even they are relatively small in comparison to the whole marsh (~10%).

The Spartina Saltmarsh on the north side of Rt. 209, adjoining Atkins Bay, is bordered by sloping land and road, and has negligible potential for marsh migration. The future of the Pitch Pine Dune Woodland at Popham Beach State Park is somewhat uncertain as it cannot gradually migrate like a beach or dune as it becomes inundated by rising sea levels. However, only about a third (37%) of the community will become tidal at 3.3’ of sea level rise, and the remainder will likely persist unless other erosional forces destabilize it. If a significant portion is retained, it will provide a seed source for the eventual colonization of any adjacent, newly developed, persistent dunes. Coastal dune and wetland systems provide important buffers against storm surges for coastal development. When coastal dune and wetland systems are compromised or lost, the adjacent upland areas and associated development become increasing vulnerable to damage from storms. To reduce the potential for damage and the related costs of repairs, and to allow landward transgression of sensitive dune and marsh environments, new park infrastructure should be designed to be adaptable or moveable, or placed in areas where it won’t be affected by sea level rise and other climate change impacts. During the next major erosion cycle, there may be pressure to protect park infrastructure with new seawalls. This type of adaptation could have negative consequences for Popham’s iconic dunes, saltmarshes, and beach, while only providing marginal protection for structures. See Appendix G for the complete natural resources inventory of Popham Beach State Park.

2.4 Previous Adaptation through Shoreline Management and Erosion Control Practices

Shoreline change and the subsequent width of the dry beach and sand dunes at Popham Beach State Park relate to the migration of the channel of the Morse River. Historical migration of the Morse River channel has been detailed in numerous studies (Fitzgerald et al., 2000; Fenster and Fitzgerald, 1996; Goldschmidt, et al., 1991), and has also been documented in several MGS Geologic Sites of the Month (Dickson, 2008, 2010, 2011). MGS analysis of shoreline changes found that the vegetated shoreline from 1991 to 2016 receded almost 625 feet, resulting in a significant loss of acres of recreational beaches, dunes, and pitch pine woodland habitats. The last time the shoreline along Popham Beach was near the current location of the park's parking lot was in 1953, more than a decade before the park was developed in 1968.

A series of more recent images documenting migration of the Morse River inlet and subsequent erosion at Popham Beach State Park from 1997 to 2016 is shown in Appendix H. The green arrow next to the bath house showing growth to the SW is really a remnant of scraping and not a sand migration direction. Green arrows show areas that underwent growth, or accretion, while red lines show areas of erosion. This series shows that as the Morse River migrated eastward, it eroded the beach and dune that front the park to the point where the bath house was threatened. By 2010 – a year which had anomalously high sea levels and a series of northeaster storms – even though the main channel had naturally reopened nearer to Morse Mountain, the abandoned secondary channel continued to be active enough during higher tides to erode the beach, dunes, and pitch pine woodlands, and breach the tombolo to the east. This resulted in erosion along East Beach as well.

In order to combat the erosion immediately threatening the bath house, in 2010 and 2011 MGS worked with BPL to institute a temporary shoreline protection plan. This included using mechanical equipment to raft fallen pine trees together (Figure 16a) and placement of jersey barriers adjacent to the bath house for protection during winter storms (Figure 16b).

Figure 16a. Rafting of fallen trees to help stabilize the eroding bank along the bathhouse.

Figure 16b. Placement of jersey barriers for additional splashover protection and to temporarily help anchor rafted trees. Images by S. Dickson, MGS.

2.4 (Continued)

Also during this time, BPL explored the potential strategy of mechanically opening the Morse River inlet back near Morse Mountain, and closing the existing inlet using excavated beach sand. Complicating this strategy were ownership issues of the sand spit at the Morse River inlet, and feedback from neighboring property owners which showed a preference for simply allowing natural processes to occur. Due to the immediate need for doing something, BPL chose not to pursue this effort at the time and instead chose to pursue a beach scraping project to help close the secondary inlet channel nearest the bath house (Dickson, 2012). During this week-long effort in 2011, mechanical equipment was used during low tides to scrape approximately 10,000 cubic yards of sand to close off the inlet, and add an area of sloped sand in front of the bath house (Figure17a and 17b). This effort was successful in protecting the bath house from damage, and eventually helped mitigate some of the erosion caused by the Morse River channel, though it took several years to alleviate erosion hazards (Kelley, 2013). As the Morse River channel re-established at a more western location, the sand bar in front of the park continued to grow and vegetated dunes became more established, as is visible in the image from 2013. As this barrier island became more pronounced, significant wading bird habitat was created, which required additional management by BPL, IF&W, and Maine Audubon using fencing and signage. Since this time, the Morse River has started to migrate eastward again, and is now eroding this island at an estimated rate of 215 feet per year (Gordon and Dickson, 2016), as evidenced by more recent imagery from 2014 to 2016.

Figure 17a. Closing of the secondary channel in front of the bathhouse using beach scraping and mechanical equipment. Images by S. Dickson, MGS.

Figure 17b

2.5 Threshold-Driven Management and Adaptation at Popham Beach State Park

In the section that follows, we describe a "threshold-driven management approach" of adapting to erosion caused by migration of the Morse River. Through such an approach, strategies would be employed depending on certain specific defined thresholds being reached. Figure 18 spatially illustrates some *general* recommended thresholds for these different management activities. These would be further refined for a fully developed adaptive management plan. A 1998 base image was used in Figure 18 to show maximum dune extent, and the maximum inland shoreline position from 2010 is also shown. Each of the strategies mapped in Figure 18 are discussed below in more detail.

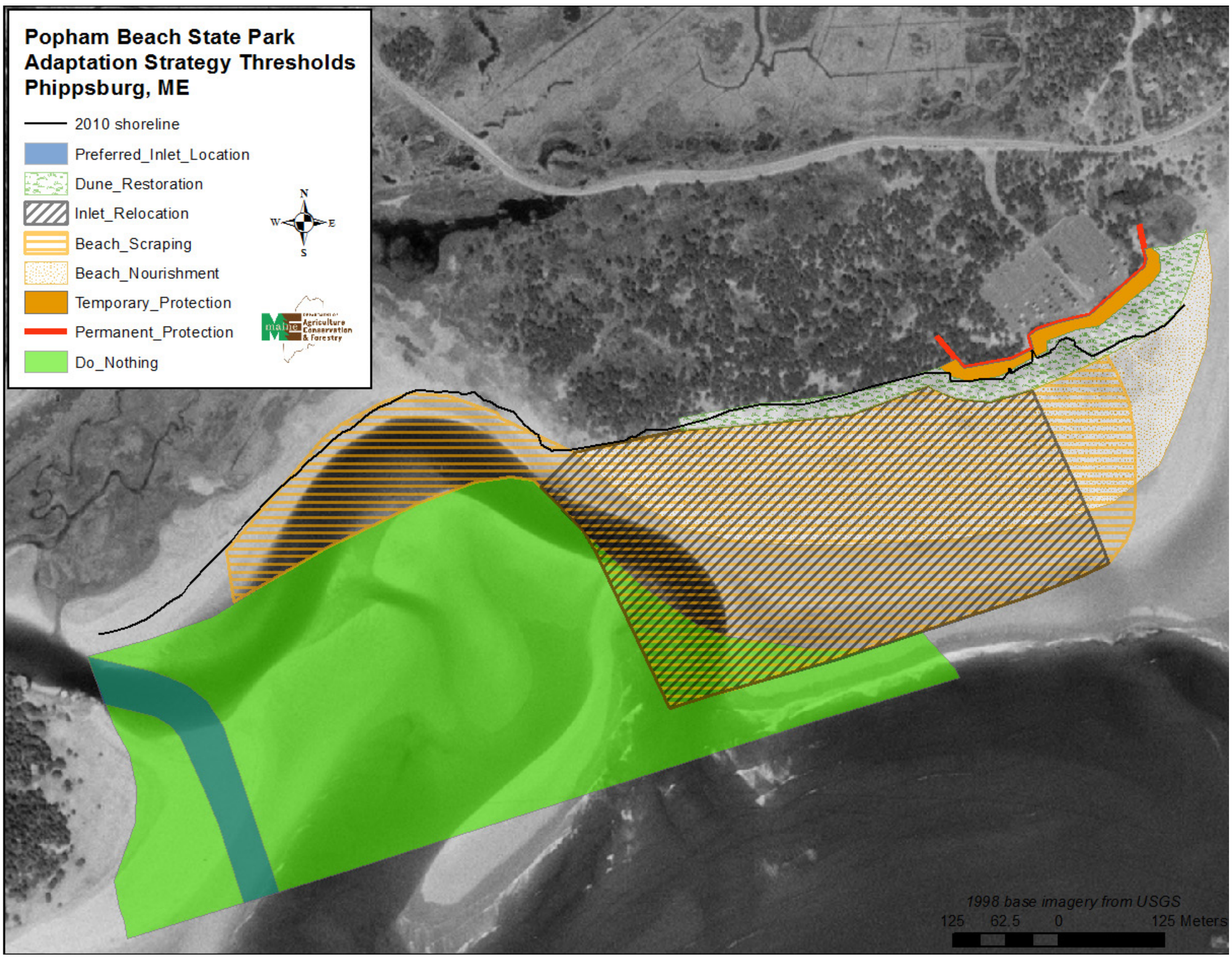

Figure 18. Potential adaptation strategies and spatial thresholds at Popham Beach State Park. 1997 base imagery from MEGIS. Different colors represent different strategies, as shown in the legend.

2.5 (Continued)

Do Nothing. In areas where erosion threatens no valuable assets or habitats, doing nothing should be the preferred approach. When the Morse River is nearest to Morse Mountain, little to no action is needed. As the Morse River migrates eastwards (or even westwards), the do-nothing strategy could continue to be employed in the general area denoted as green in Figure 18. Letting nature takes its course allows for the formation of a large spit that extends eastward from the Morse Mountain area as the inlet migrates eastward. This spit will later provide sand for the beach at the state park.

Episodic Beach Scraping. This strategy, when employed in the past, was employed as an emergency action when the channel had already migrated dramatically to the east and north, and was threatening the western bath house. It was permitted relatively easily, completed relatively quickly in the winter using simple mechanical equipment working at low tide (using access from the Park), and was limited to the scraping of approximately 10,000 cubic yards of material. A recommendation of this report is that scraping could be employed as a more proactive approach, for areas as shown in Figure 18 with orange cross-hatch. Proactive use of scraping could divert the migrating channel southwards if it is swinging northwards, away from vital pitch-pine woodland habitat. Scraping could be employed to help divert a main or a secondary channel well before the migrating channel threatens any infrastructure. Scraping to divert the channel would likely be more effective if it is a secondary channel and a main channel has formed elsewhere (closer to Morse Mountain). Scraping could also help divert a main channel, but likely would be inadequate for closing it unless another, larger channel were excavated at the same time. Beach scraping of amounts larger than 10,000 cubic yards may lead to a more complex permitting process, but would likely avoid special permissions that may be needed with neighboring property owners since all activities would be completed on State-owned lands.

Dune Planting and Restoration. BPL should consider dune planting and restoration as management activities that could help protect built assets and vital habitats, such as pitch-pine woodlands. Dune planting and restoration should be considered at times when the shoreline in front of the bath-house has been confirmed *to be stable to accreting* based on monitoring. This would allow for better establishment of dune vegetation. Dune restoration should work to create a sacrificial frontal dune that is at a minimum 1 foot above the 100-year Base Flood Elevation, which is 17 feet NAVD88 at this location. The width of the dunes could vary based on where dune restoration is proposed, but would typically be 50 to 150 feet. Dune restoration could be employed in seaward areas when the shoreline has accreted, but it is recommended that BPL focus most dune restoration activities in areas closer to the bath house. Some areas recommended for minimal dune restoration are shown in Figure18 with green thatched grass.

Beach Nourishment. Beach nourishment could be considered at Popham Beach State Park in order to maintain a protective dry beach width that would also allow for substantial recreational purposes. Given the possible extreme erosion rates in the area at times (due to migration of the Morse River channel), beach nourishment *would likely be most successful after the channel has either naturally or artificially been relocated* back to a location nearest to Morse Mountain. Nourishment would be most beneficial if used to “fill” the area between the nearest exposed sandbars and dunes in order to recreate a large dry beach and potentially couple this with dune restoration efforts, as shown as speckled brown in Figure 18. MGS estimates the needed beach nourishment volume would be approximately 75,000 to 100,000 cubic yards at the main beach at Popham Beach State Park, which could cost anywhere from $1.5M to $2M depending on sand source.

Placement of Temporary Barriers. As was noted in the previous section, MGS and BPL used rafted fallen pitch-pine trees (from on-site) in order to temporarily stabilize the bank adjacent to the bath house when erosion directly threatened the bath house. This was deemed to have been a successful method for slowing the bank erosion (Kelley, 2013). BPL could consider this method again in the future should river-induced erosion reach closer to the bath house. At the same time, BPL placed jersey barriers behind the rafted trees in order to minimize wave overwash during large storm events. Again, the use of these temporary measures should only be considered if erosion threatens infrastructure.

2.5 (Continued)

Placement of Permanent Barriers. As a last resort, BPL could consider constructing a sheetpile (or similar) seawall to protect vital assets at Popham Beach State Park. The wall should be placed wholly within the back dune (D2), and be placed landward to the maximum extent practicable. The wall would likely need to be constructed to also protect the leach field and eastern bath house from outflanking, as shown in Figure 18. Consultation with an engineer would be needed for exact structure placement, and to determine potential impacts on the existing water table. However, this strategy would be precedent setting in Maine for using engineering structures to protect infrastructure in the back dune, and therefore, is not recommended as any immediate alternative.

Mechanical Inlet Relocation. The concept of a tidal inlet management plan is not new, especially at altered tidal inlets. Numerous large developed tidal inlets are formally managed through regional, state, and federal management plans and efforts, e.g. North Carolina and Florida. Small tidal inlets with little-to-no development have typically not been the subject of large, expensive management plan efforts. In general, substantial at-risk development is needed to justify the time, effort, and expense to develop a formal plan. That said, many smaller inlets are managed in some form. Via a threshold-driven tidal inlet management plan, mechanical relocation of the Morse River inlet could be considered once the Do-Nothing erosion threshold was exceeded. This alternative is attractive because it would likely obviate the need for the other listed adaptation strategies, such as episodic beach scraping, beach nourishment, dune restoration, and placement of temporary or permanent barriers. However, this alternative could also be used in conjunction with the threshold-based adaptation plan – that is, other methods would be employed before inlet relocation is considered.

Mechanical relocation could employ methods similar to those described by Kana and Mason (1988) for the much larger Captain Sam's Inlet in South Carolina. Mechanical relocation is meant to mimic the natural process of inlet migration and bypassing. Once the main channel of the Morse River swings far enough to the east (and subsequently builds a large enough spit that extends east from Morse Mountain mechanical relocation could be undertaken. This would involve excavation of a larger and deeper channel back to the west, and east of Morse Mountain, while the excavated material is stockpiled adjacent to the existing channel on State Park property and used to help close the migrating channel. This is shown as the "preferred inlet location" on Figure 18. The recommended width and depth of the excavated main channel would need to be determined using the estimated tidal prism of the Morse River and Spirit Pond. The tidal prism is the volume of water exchanged with every rise and fall of the tides. The tidal prism is unusually large because, since at least the 1950s, salt water has entered Spirit Pond and this larger geographic extent has allowed greater tidal exchange than is often the case with typical Maine back-barrier salt marshes.

Once the new main channel was excavated, the secondary channel could then be closed using the stockpiled material. We expect that the newly opened inlet would begin to migrate, as it has done in the past, to continue cyclic meandering. Inlet relocation work may need to be completed approximately every 10-20 years.

2.6 Inlet Management Plan

The dynamic nature of the Morse River inlet indicates that it will likely migrate east again, potentially threatening park assets such as the bath house. Thus, we recommend developing a comprehensive beach and inlet management plan in concert with neighboring property owners in order to prepare for such an occurrence.

Such a plan is economically warranted: over the last ten years (2006-2016), BPL spent slightly over $1.35 million to construct the new bathhouses, septic system and leach field and to make parking lot improvements at Popham Beach State Park. In 2009, BPL spent $41,300 on tree log erosion control devices to protect the bathhouse and the adjacent forest. Beach scraping in 2011 cost $48,610 and repairs after a winter storm in December 2011 cost $12,005. Material costs between 2008 and 2016 were approximately $5,000.

The concept of tidal inlet management planning is not new, especially at altered tidal inlets. Numerous large developed tidal inlets throughout the country are formally managed through regional, state, and federal management plans and efforts. Examples from Florida and North Carolina were researched for this project. Most of these management plans are for large, developed inlets, and include sediment bypassing, dredging, beach nourishment, and engineering stabilization methods and cost potentially millions of dollars each year.

Small tidal inlets with little-to-no development have typically not been the subject of large, expensive inlet management plans. In general, substantial at-risk development is needed to justify the time, effort, and expense to develop a formal plan. That said, many smaller inlets are managed in some form. In Southampton along New York's Long Island, a plan was developed for managing Mecox Bay and Cut for water quality purposes, flood mitigation, recreational and aesthetic purposes (Frano, 2004). A small tidal inlet, known as The Cut, has been artificially opened on almost an annual basis for nearly 400 years (by Shinnecock Native Americans, then the town) in order to maintain the brackish water quality in Mecox Bay needed for shellfish habitat. The opening is typically allowed to close naturally due to longshore transport of sand. The work has been completed in a few hours by the town mostly using an excavator from the upland under long term (10-15 year) permits.

2.6.1 Inlet Relocation

Inlet management through mechanically realigning or relocating inlets has also occurred in other locations in the country, e.g. North and South Carolina. This approach is considered to work *with* natural processes, as opposed to stabilizing a shoreline, which works *against* them. Inlet relocation or realignment reproduces the natural evolution of a migrating tidal inlet.

One of the best examples of inlet relocation that may be pertinent to the Morse River scenario near Popham Beach is at Captain Sam's Inlet, located between Kiawah Island and Seabrook Island in South Carolina. Although much larger than the Morse River, this inlet had a regular history of migrating to the west and threatening the developed shoreline along Seabrook Island (the shoreline along the prograding Kiawah Island spit is undeveloped). In the late 1970s and early 1980s, this migration was severely threatening development at the eastern end of Seabrook Island. In a period of a few winter months in 1983, a new channel basin was excavated using land-based equipment. High-tide sills were kept in-place at either end of the channel in order to keep the ocean out until the old channel was filled. Excavated material was stockpiled adjacent to the old channel, and used for mechanically closing the old inlet. Once the new inlet was ready, the seaward sill was excavated (at low tide), and the channel allowed to fill and breach during the following rising tide. A few days later, after the new inlet was becoming better established the old channel was mechanically closed by constructing a sand dike using bulldozers (Kana and Mason, 1988). The overall cost of the project was $300,000 (Figure 19).

Kana (1989) estimated that this effort in 1983 allowed the natural bypassing of approximately 1,000,000 cubic meters of sand which caused the adjacent eroding beach to grow by over 300 meters. Although the process needed to be repeated in 1996 (Kana and McKee, 2003), the second project was again completed using only land-based methods, and cost $500,000. This example of mechanical inlet relocation – though on a much larger scale – could be a transferable approach for managing the Morse River.

2.6.1 (Continued)

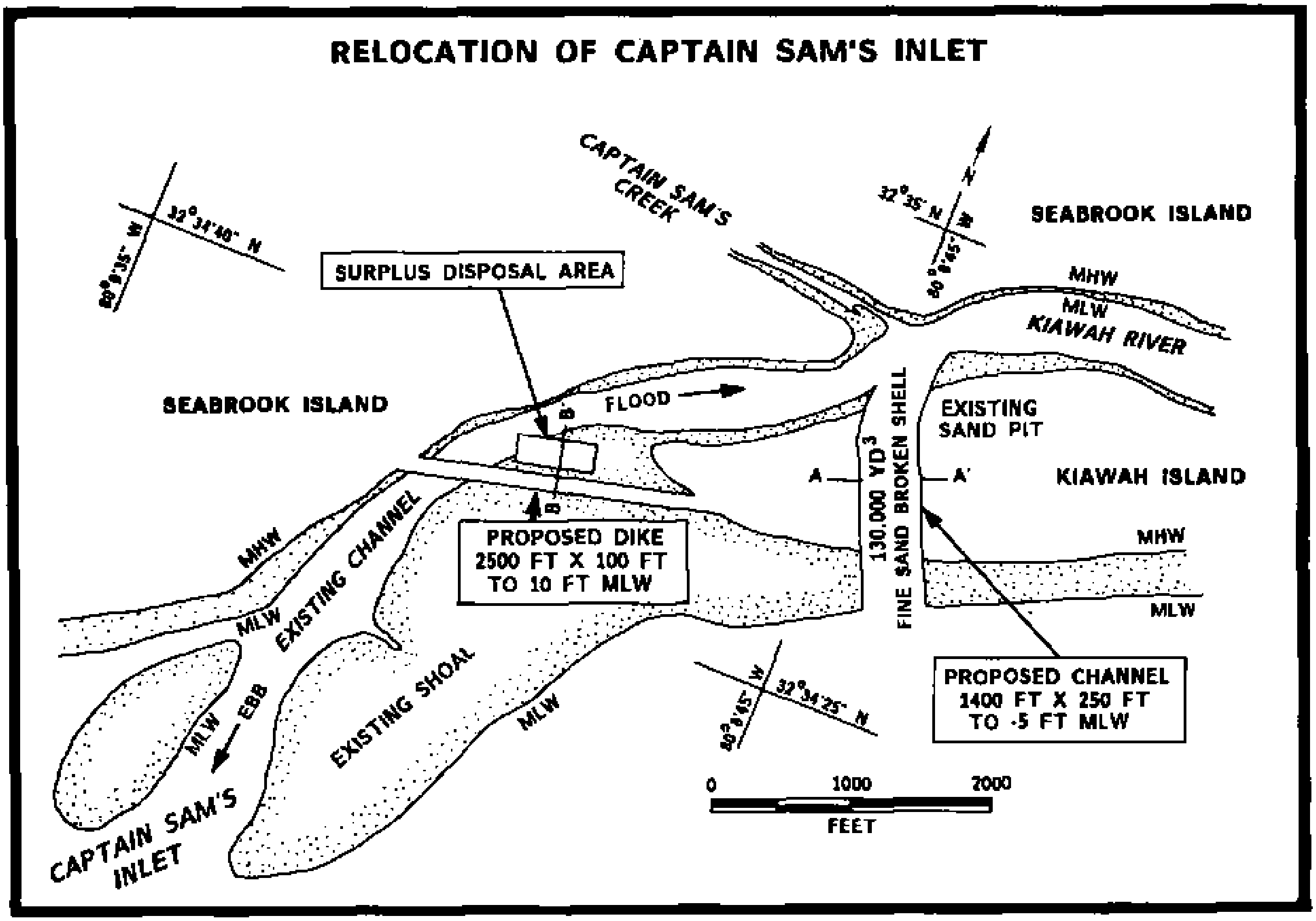

Figure 19. Plans for relocation of Captain Sam's Inlet. From Kana (1989).

BPL manages the Park for public recreation as well as related conservation purposes and is interested in protecting both state investment in the erosion-threatened bath house, and the sand dune and pitch pine woodland habitats. The area on the west side of the Morse River channel is private conservation land. It includes roughly 600 acres of permanently protected salt marshes and coastal uplands that extend from the Sprague River to the Morse River and to the upland edge of Seawall Beach. These lands are owned and managed in their natural state for conservation objectives by a private, not-for-profit conservation organization. This basic difference in land management objectives between BPL and the private conservation organization presents a challenge to development of mutually acceptable solutions to coastal erosion concerns related to the mobility of the Morse River channel. In addition, since the Morse River is the boundary between these ownerships, and it is dynamic and constantly shifting from west to east, it is likely that property boundary subsequently shifts as well. Thus, inlet relocation would require a detailed agreement and plan with the neighboring property owners.

Permitting from the Maine DEP and US Army Corps of Engineers would need to be sought in order to pursue this strategy; it's possible that relocation could be allowed under longer-term (10 year) permits with routine monitoring of impacts to the entire beach, dune, forest, and salt marsh ecosystem. Clarification would need to be sought regarding whether the federal Coastal Barrier Resources Act (CBRA; CITE) and Maine Coastal Barrier Resources System (Maine CBRS; CITE) allow mechanical channel relocation activity.

Any inlet management strategy would have to be designed with an extensive public involvement strategy with adjacent property owners, the municipality, and neighboring residences and businesses and might involve formal agreements or MOUs.

2.7 Recommended Best Management Practices

Several best management beach and dune practices should be employed at Popham Beach State Park regardless of the position of the Morse River inlet or the proximity of erosion to park assets.

Monitoring Erosion – MGS currently monitors the seaward edge of established dune vegetation with RTK-GPS on an annual basis as part of the Maine Beach Mapping Program (MBMAP). A hand-held GPS is also used by MGS on a much more frequent basis to monitor shorter-term changes. At a minimum, this existing monitoring should continue. However, it is recommended that a more frequent shoreline monitoring program (e.g., monthly or every other month RTK surveys) occur in support of any beach or inlet management. This will help to more accurately determine when certain thresholds have been met.

Seaweed Management – Seaweed that washes up on the beach that is typically removed or scraped to different locations in order to ensure a "clean" recreational beach should be placed at the toe of existing sand dunes in layers not to exceed 6 inches in depth. This will provide nutrients to beach grass root systems and help beach grass growth.

Dune Fencing and Signage – Dunes with established elevations and vegetation should be fenced with simple stakes and twine and signed in order to keep the public out and prevent damage from foot traffic. In areas where dune growth is desirable, straight or zig-zag dune fencing or matrix staking, as shown in the Figure 20 a-c, could be utilized (Schaller, 2015). These methods should be employed within 10-15 feet of the edge of existing dunes, and placed at elevations that exceed the highest annual tide by about a foot, if possible.

Dune Path Management – Dune paths should be altered to create a zig-zag approach to the shoreline in order to minimize any wave run-up and end-effect erosion caused by straight paths. This path design can be created as dunes grow back. In addition, elevated wooden dune walkovers should be used, where possible, in order to minimize impacts to dune vegetation and to maintain adequate protective dune elevations (Slovinsky, 2011). These can be seasonally removed, if needed. These measures may not be possible at all beach access locations in order to ensure ADA (and horse) access.

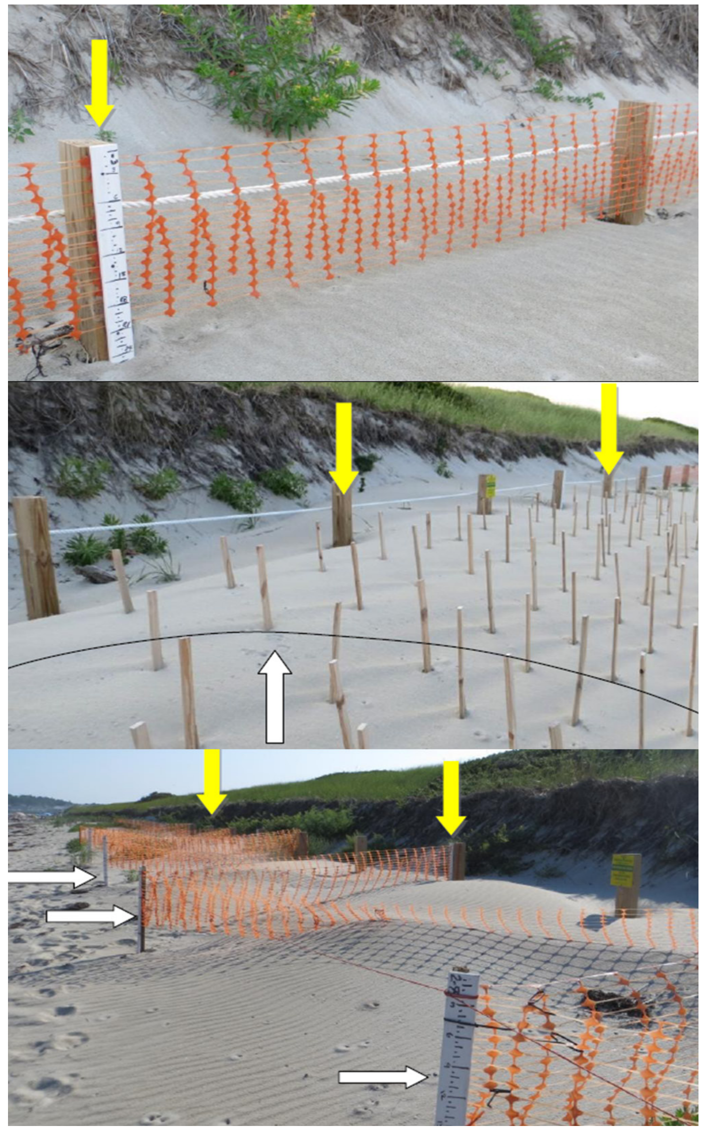

Figure 20. Sand dune fencing options including a) straight line fencing; b) wood-stake matrix; and c) zig-zag fencing. Yellow arrows point to measuring stakes, white arrows at berm. Images from Schaller (2015).

2.8 Range of Adaptation Measures for Popham Beach Assets

Following the format of Table 4 presented in Section I of this report, we analyzed adaptation measures for each asset within the park boundaries. Table 5 summarizes identified adaptation strategies.

Property	Asset	Flood Zone	Dune System	CBRS Unit	Hazard or Scenario	Potential Impact	Protection Strategy	Accomodation Strategy	Retreat Strategy	Park Operations Strategy	Notes
Popham Beach	Route 209 (west)	AE(10)	D2	ME-16	1 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, wall	allow flooding; elevate	N/A	limit access; temporary protection	need MEDOT
	Route 209 (east)	N/A	D2	ME-16P	Erosion 10 year ST; 50-year LT	erosive loss	green infrastructurel, dune and beach restoration	N/A	relocate	limit access; temporary protection	need MEDOT
	Route 209 (east)	N/A	D2	ME-16P	3 ft or more SLR/SS; Cat 1 or 2	flooding	dune and beach restoration	N/A	relocate	limit access; temporary protection	need MEDOT
	Park access road	N/A	D2	ME-16	3 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure	allow flooding; elevate	N/A	limit access; temporary protection	
	Park access booth	N/A	D2	ME-16	6 ft or more SLR/SS; Cat 2	flooding	floodproofing	elevate	relocate	limit access; temporary protection	
	Pump Station East	N/A	D2	ME-16P	Cat 1 or 2 ; 6 ft SLR/SS	flooding	wall, floodproofing	elevate/floodproof	relocate	temporary protection	
	Pump Station East	N/A	D2	ME-16P	Erosion 10-year	erosive loss	green infrastructure, wall	N/A	relocate	temporary protection	
	East Bath House	N/A	D2	ME-16P	Cat 1 or 2 ; 6 ft SLR/SS	flooding	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	East Bath House	N/A	D2	ME-16P	Erosion 10-year	erosive loss	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	Manhole 4, 5, 6	N/A	D2	ME-16P	Cat 1 or 2 ; 6 ft SLR/SS	flooding	wall, floodproofing	N/A	relocate	temporary protection	
	Parking lot	N/A	D2	ME-16, 16P	Cat 1 or 2 ; 6 ft SLR/SS	flooding	green infrastructure, dune and beach restoration	allow flooding; elevate	relocate	temporary protection	
	Parking lot	N/A	D2	ME-16, 16P	Erosion 10 year and 50-year	erosive loss	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	Leach field	N/A	D2	ME-16	Erosion 10 year and 50-year	erosive loss	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	Manhole 1, 2, 3	N/A	D2	ME-16	Cat 2	flooding	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	Manhole 1, 2	N/A	D2	ME-16	Erosion 10 year and 50-year	erosive loss	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	Manhole 3	N/A	D2	ME-16	Erosion 10 yearand 50-year	erosive loss	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	West Bath House	N/A	D2	ME-16	Cat 2	flooding	green infrastructure, dune and beach restoration; wall	floodproof	relocate	temporary protection	
	West Bath House	N/A	D2	ME-16	Erosion 10 year and 50-year	erosive loss	green infrastructure, dune and beach restoration; wall	floodproof	relocate	temporary protection	
	Generator	N/A	D2	ME-16	Cat 2	flooding	green infrastructure, dune and beach restoration	floodproof	relocate	temporary protection	
	Generator	N/A	D2	ME-16	Erosion 10 year and 50-year	erosive loss	green infrastructure, dune and beach restoration	floodproof	relocate	temporary protection	
	Park well head	N/A	D2	ME-16	Cat 2	flooding	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	Beach access	VE(15, 17,18)	D1, D2	ME-16, 16P	3 ft or more SLR/SS; Cat 1 or 2	flooding	dune and beach restoration	allow flooding	relocate	allow erosion; limit access; remove walks	
	Beach access	VE(17,18)	D1, D2	ME-16, 16P	Erosion 10 year and 50-year	erosive loss	dune and beach restoration	allow limited erosion	relocate	allow erosion; limit access; remove walks	
	Picnic area	VE(15)	D2	ME-16P	Erosion 10-year and 50-year	erosive loss	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	

Table 5. Potential adaptation strategies by asset type for Popham Beach State Park.

2.9 Regulatory Boundary Implications for Adaptation

In the past, the dynamic nature of the Morse River led to cyclical growth and loss of over 600 feet of beach and dune. For the most part, the dune that has eroded is mapped as a regulated "frontal dune", or D1, per the Coastal Sand Dune Geology map (Slovinsky and Dickson, 2011) for the Popham Beach area, as shown in Figure 21. Per the Coastal Sand Dune Rules (Chapter 355 of the Natural Resources Protection Act), certain activities in the frontal dune, such as placement of permanent engineering structures, are restricted, while they are permitted in the "back dune", or D2, area of the mapped sand dune system.

Extensive erosion in 2010 resulted in complete loss of the front dune, such that the new "shoreline" was located within the mapped back dune. However, at some point in the near future when the abandoned sand bars and barrier island will likely weld back onto the beach, a wide frontal dune will likely return.

One consideration could be whether or not such ephemeral movement of the dune system warrants systematic remapping of the regulatory lines. For example, when all of the past frontal dune system is lost, leaving only back dune, *a section of the back dune* could be remapped as front dune since it is now being acted upon by wave energy. This may have significant regulatory implications for shoreline adaptation strategies, as new permanent engineering structures are only permitted in mapped back dunes. Conversely, when a wide frontal dune reappears, that same area could be remapped back to back dune (to the past regulatory geologic boundary). Thus, it is recommended that Maine DEP and MGS discuss whether or not areas with such dramatic shoreline changes should be regulated differently from the current system.

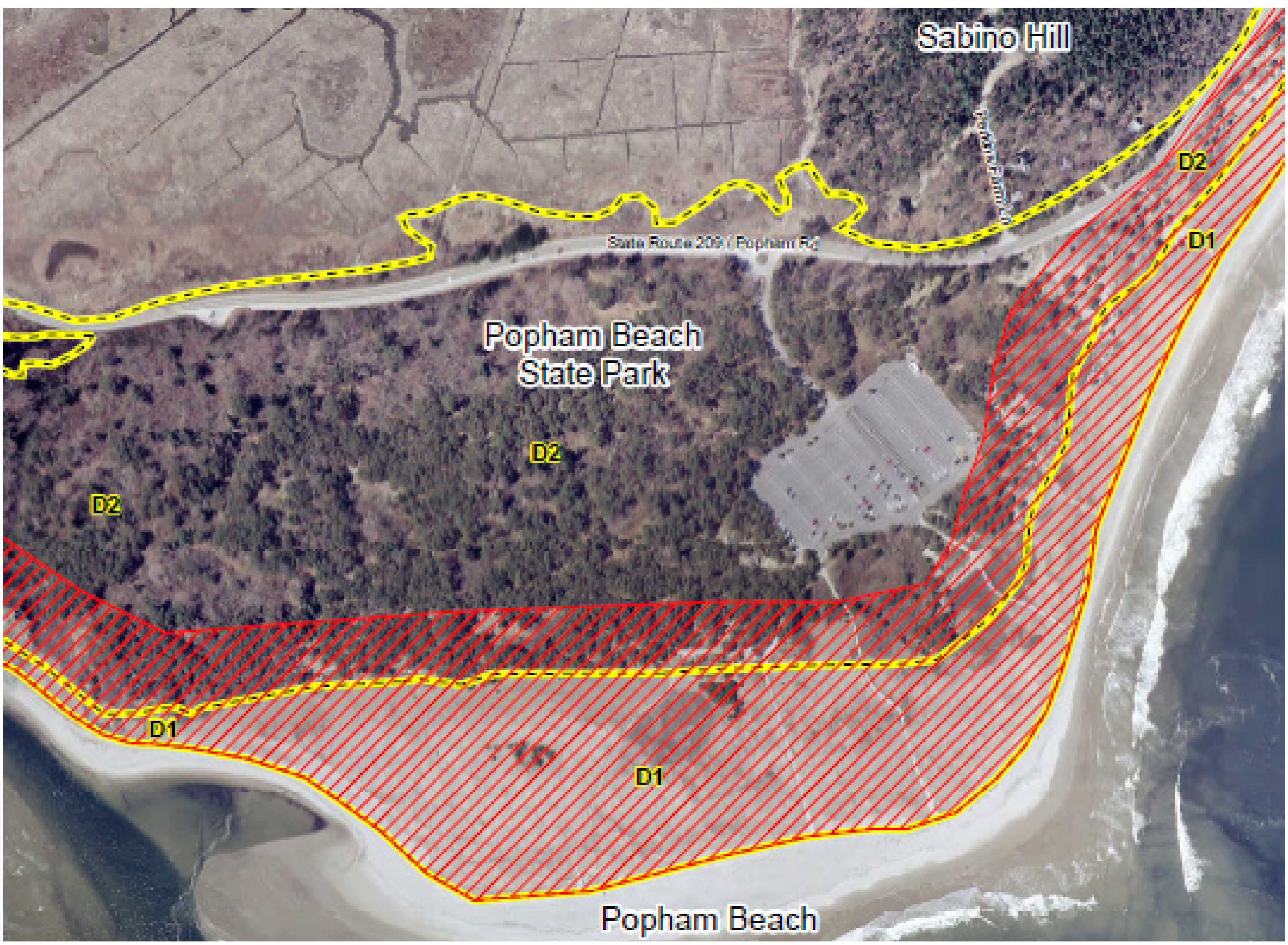

Figure 21. Effective mapped coastal sand dune boundaries for the area of Popham Beach State Park. Shoreline erosion has reached into the back dune and into the erosion hazard area (red hatch). 2001 base imagery.

2.10 Visitor Awareness of Changing Shorelines and Opinions about Adaptation Strategies

2.10.1 Background

MCP hired the University of Maine School of Economics to design and conduct a visitor survey at Popham Beach State Park in August, 2016. The purpose of the survey was: 1) to learn about visitors' perceptions of changing shoreline conditions at the park; 2) to assess the impact of the changing shoreline on the visitor experience; 3) obtain feedback on adaptation and management measures; and 4) to identify visitors' preferences for receiving additional educational materials about the park. The survey was conducted via a series of in-person interviews at the park over nine different days in August, 2016. Out of 571 visitors approached, 334 completed the survey; a 58.8 percent response rate. It should be recognized that these survey results are but a snapshot of a small number of people visiting the park during a designated time period. The survey instrument and technical report are attached as appendices to this document as Appendix I and J, respectively. A compilation of open-ended responses is available from MCP upon request.

2.10.2 Highlights of Survey Results

Connection to Place - Popham Beach State Park is a stunningly beautiful and diverse place and its characteristics make it unique among other Maine beaches and parks. Not surprisingly, many visitors have a special connection to Popham Beach State Park as evidenced by the number of years people have been visiting (sixteen years, on average from the sample) and the number of times they visit each summer (three, on average from the sample). The large size and open, undeveloped nature of the park, scenic views, proximate offshore islands, and the diversity of recreational opportunities were characteristics valued most by respondents. Some respondents (12%) specifically mentioned the ever-changing nature of the park and its shoreline as features of the park that they enjoy. Most respondents were satisfied with their visitor experience, saying that there was nothing the state could do to improve their experience at this time.

Perceptions about Shoreline Change - The majority of respondents (72%) believe the impacts of erosion are being seen now at Popham, with 54% noticing changes in the width, size and shape of beach and shoreline. Other changes noticed by respondents included changes in the flow of, and access to, the ocean and the river. Fewer respondents mentioned noticing changes in vegetation (dune grass and trees). When describing the cause of the changes in their own words, responses included storm events (17.4%), erosion (11.4%), wave action (6.3%), climate change (3.3%) and sea-level rise (1.5%).

How Shoreline Change Affects Visitation - Respondents were asked if their visitor experience would improve, worsen or not change if the width of the beach were reduced by ½ over all tidal cycles. Fifty-one said their experience would be worse (more crowded; fewer options for walking/playing), 47% replied "no effect", and 1% said their experience would improve. With respect to improvements, a shorter walk to parking and facilities was cited as the reason.

Visitor Opinions about Adaptation Strategies - Forty-nine percent of respondents favored the state taking management actions to address the changing shoreline, while 40% favor "letting nature take its course" and 11% were uncertain. Reasons for taking action included keeping the beach open and accessible (25%), taking responsibility for human-driven problems (19%), preserving the area for future generations (13%), protecting infrastructure (11%), preference for science and expert-driven management (10%), and protecting habitat (7%). For those who favored letting nature take its course 53% said "nature knows best"/"can't fight nature". Twenty-one % prefer a natural beach, and 6% said management intervention might have unintended consequences.

Out of state (non-Maine) US residents were more likely to favor active management as were households with children and those who reported that a future erosion event would negatively affect their visits to Popham. Frequent visitors to Popham were less likely to support the state taking management actions.

In general, respondents favored actions that focus on making infrastructure (parking and bathhouses) more resilient via a retreat strategy (moving inland) instead of those involving active intervention in environmental processes. The results below also suggest that gaining visitor and perhaps more broad support from the general public for active management at Popham may be challenging.

Interviewees were provided a list of potential state management actions and asked to rate each as high, medium or low priority action.

High Priority in Ranked Order

- Relocating bathhouses (27%)
- Relocating parking (27%)
- Building a seawall (12%)
- Moving sand (beach scraping) (11%)
- Bring sand from offsite (9%)
- Altering the Morse River channel (4%)

Ranked Order if the Medium and High Priority Ratings Were Combined

- Relocating bathhouses (54%)
- Relocating parking (52%)
- Moving sand (beach scraping) (45%)
- Building a seawall (35%)
- Bringing sand from elsewhere (29%)
- Altering channel of Morse River (13%)

Low Priority in Ranked Order

- Altering the channel of the Morse River (66%)
- Bringing in sand from offsite to widen the beach (66%)
- Building a seawall (57%)
- Moving sand from one place to another (beach scraping) (49%)
- Relocating parking inland (42%)
- Moving bathhouses inland (40%)

When analyzing the above results, it should be noted that interviewers did not provide respondents any further information about the management options (e.g. effectiveness, cost, impacts, etc.), and the responses were likely based on limited understanding of the concepts.

2.10.3 Visitors' Interest for More Information about Shoreline Change and Adaptation at Popham Beach State Park

We were interested in understanding how aware visitors were of existing information posted at the park including tide stage information and warnings about accessing the island (provided at the entrance kiosk) and signage about dunes, erosion and nesting birds that are posted on the beach. Keeping visitors from trampling dune vegetation and plover nesting areas, and providing visitors with information about tides and safety have been a focus for park managers in recent years. A majority of respondents (62%) reported seeing signs about erosion and dune protection at the park and 52% reported checking information about tides before visiting Popham. Of those who checked the tidal stage, the majority (33%) checked online

The on-site interviewers who conducted the survey noted how engaged and inquisitive respondents were. Fifty-six percent of respondents noted they wanted more information about changing shorelines at Popham. Topics of interest were as follows: scientific research and baseline information (24%), environmental impacts of adaptation options (13%). Four percent were interested in understanding how management decisions are made and how they could get involved.

In terms of furthering target audiences for additional outreach, regression analysis showed that:

- Respondents who know erosion is happening now and those who indicated that a smaller beach width would decrease their enjoyment were likely to want more information.
- Respondents with higher household incomes were less likely to want more information.
- Participants who favor active management and those who did not were equally as likely to want more information.

Respondents favored email and websites (17% and 13%, respectively) as ways to get information following by signage/onsite displays (6%), pamphlets via mail (5%), mass media (3%), other e.g. through their kids (3%) and Facebook (1%).

Using sources other than Project of Special Merit funds, the Coastal Program (with BPL) is using the survey results, park manager needs and other information to develop messaging for park interpretive information.

2.11 Fort Popham and Popham Colony

In the following section of this report, we present the study results for both Fort Popham and Popham Colony. Assets for each are shown in Figure 22. Overall vulnerabilities for both sites are shown in Table 6.

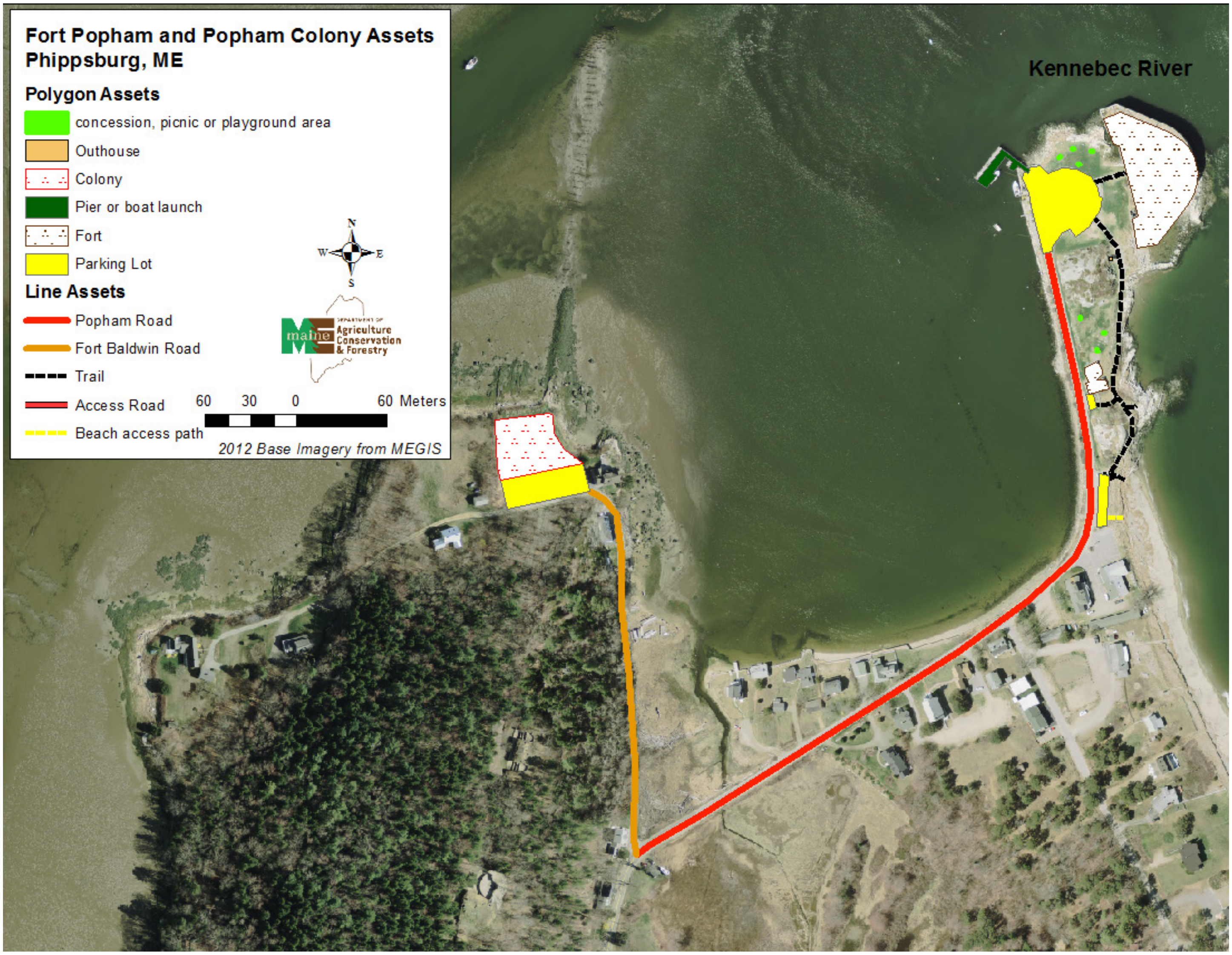

Figure 22. Assets at Fort Popham and Popham Colony

2.11.1 Fort Popham

This five acre state historic site is located along the Kennebec River in Phippsburg, ME. Fort Popham is a semi-circular granite fort that was never completed, though construction began in 1862 for use during the Civil War. Modifications were made and the fort was subsequently used in the Spanish American War and in World War 1. Historical records conclude that fortifications, probably wooden, existed here and protected the Kennebec settlements during the Revolutionary War and the War of 1812. It was nearby that the English made their first attempt to colonize New England in 1607. The site is built on a narrow rocky headland that extends southwards and turns into front and back sand dunes. Popham Road extends along the cove side of the headland, and provides access to the site. In 2004, Fort Popham had the most visitor days – over 81,000 – of any historic site in Maine. Note that no shoreline change analyses were completed for Fort Popham.

Inundation Analyses – Fort Popham and its access via Popham Road are especially vulnerable to inundation. All of the facilities on the property are mapped within an existing AE or VE special flood hazard area (Figure 23). Access to the Fort begins to be compromised at 1 foot of sea level rise, which could result in almost monthly inundation of Popham Road (both on and off the property). With 2 feet, large sections of the access road, Fort, and parking lots become inundated, and inundation simply becomes worse under higher scenarios (Figure 24). Under a Category 1 hurricane scenario, large sections of Popham Road would be inundated, severely inhibiting access to and from the Fort (Figure 25).

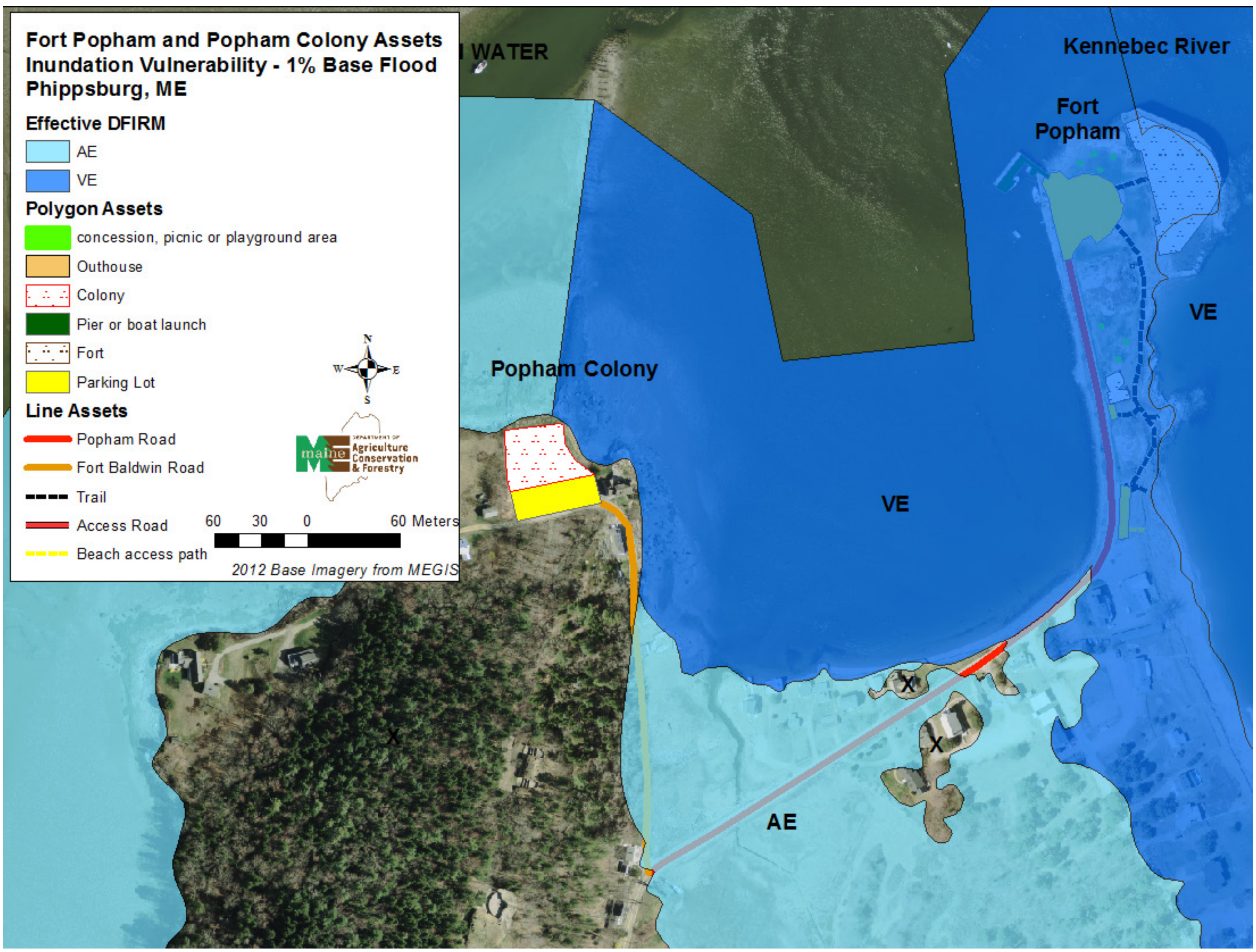

Figure 23. Inundation vulnerability for Fort Popham and Popham Colony under base flood conditions.

2.11.1 (Continued)

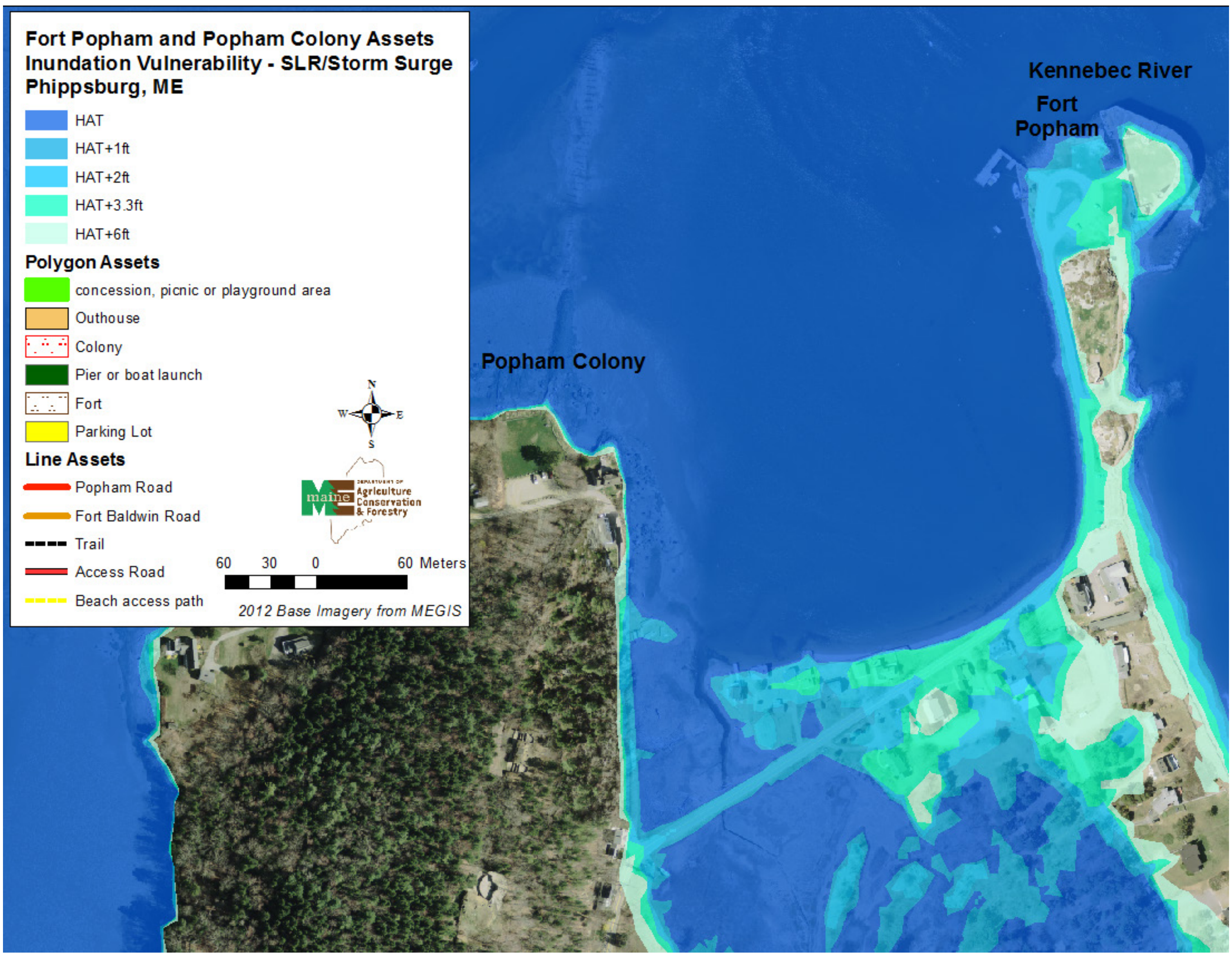

Figure 24. Inundation vulnerability for Fort Popham and Popham Colony under sea level rise or storm surge conditions.

2.11.1 (Continued)

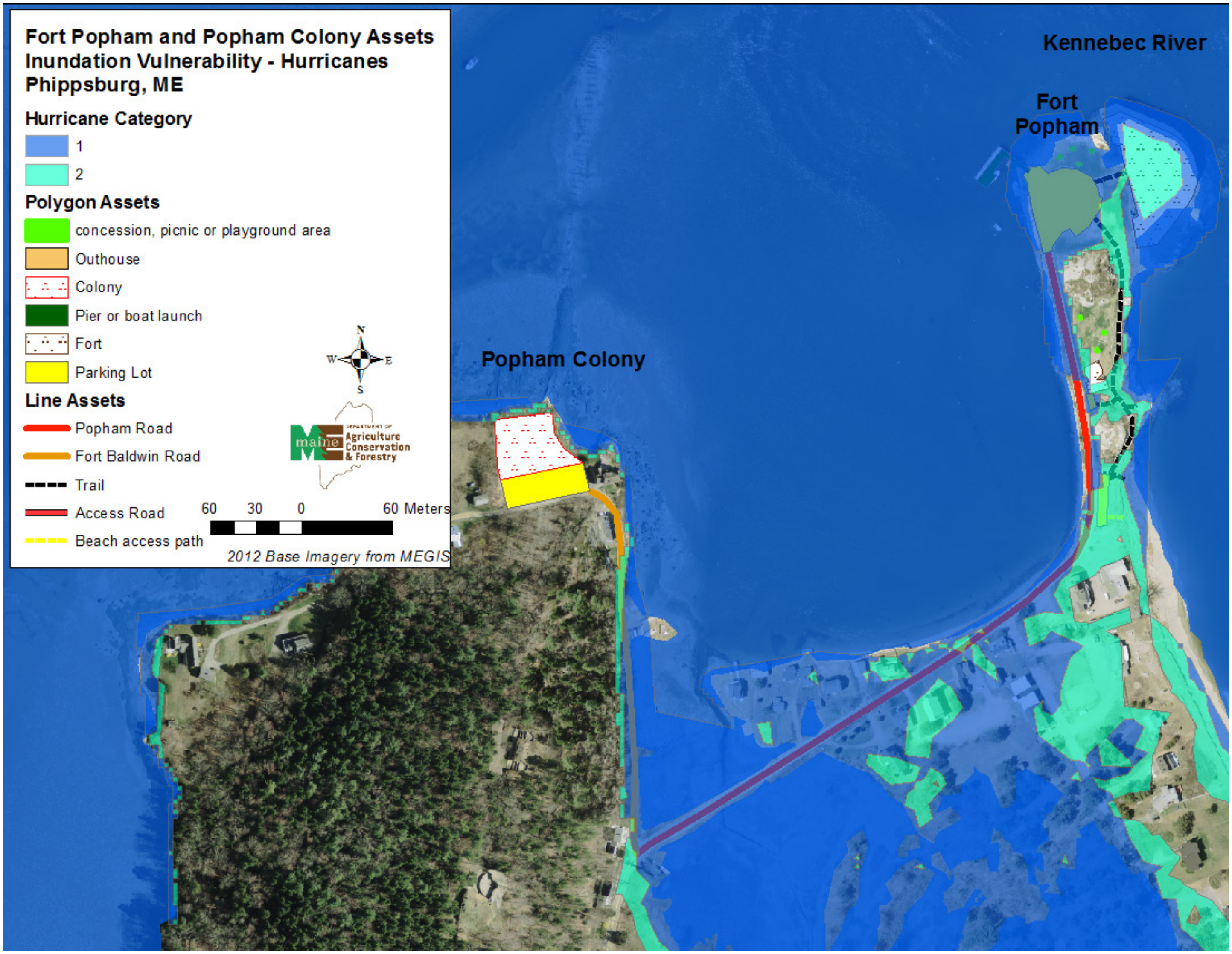

Figure 25. Inundation vulnerability for Fort Popham and Popham Colony under hurricane conditions.

2.11.2 Popham Colony

Popham Colony – This 0.9 acre state historic site was the first organized attempt by the English to establish a colony on the shores of what we now know as New England. It was established at the mouth of the Kennebec River in the summer of 1607 and lasted for little over a year until it was abandoned in the fall of 1608. To return home to England, the colonists constructed the first ship ever built in North America. The failure of the Popham Colony to endure has rendered it a nearly forgotten historical footnote. Its failure, however, was an important step in the ongoing experience of English colonization and the lessons learned contributed directly to the ultimate success of the Pilgrims. The site contains portions of two former forts – Fort St. George (active 1607-1608) and the much larger Fort William (active during World War I).

Inundation Analyses – Popham Colony is located along relatively high bluffs, and is not susceptible to inundation under the scenarios examined. However, access to the Colony via Fort Baldwin Road, directly adjacent to the water, is mapped within the 1% floodplain (Figure 23), and starts to become compromised at 1 foot of storm surge or sea level rise, and significantly impacted after 2 feet of storm surge or sea level rise (Figure 24). Similar to Route 209, Fort Baldwin Road would likely be inundated on an almost monthly basis after just 1 foot of sea level rise. In addition, Fort Baldwin Road is at-risk to inundation during a Category 1 Hurricane (Figure 25).

Long-term Shoreline Change Analyses – Shoreline changes calculated from 1964 to 2003 were used to project shoreline positions over the next 50 years. There are several small pockets of projected erosion that may have some impacts on the property, but generally, impacts are minimal (Figure 26). This erosion threatens the former location of an outbuilding of Fort William (northern portion of the property). It is not clear whether any archaeological deposits of Fort St. George underlie the Fort William outbuilding foundation. Note that no short-term data was available for analysis.

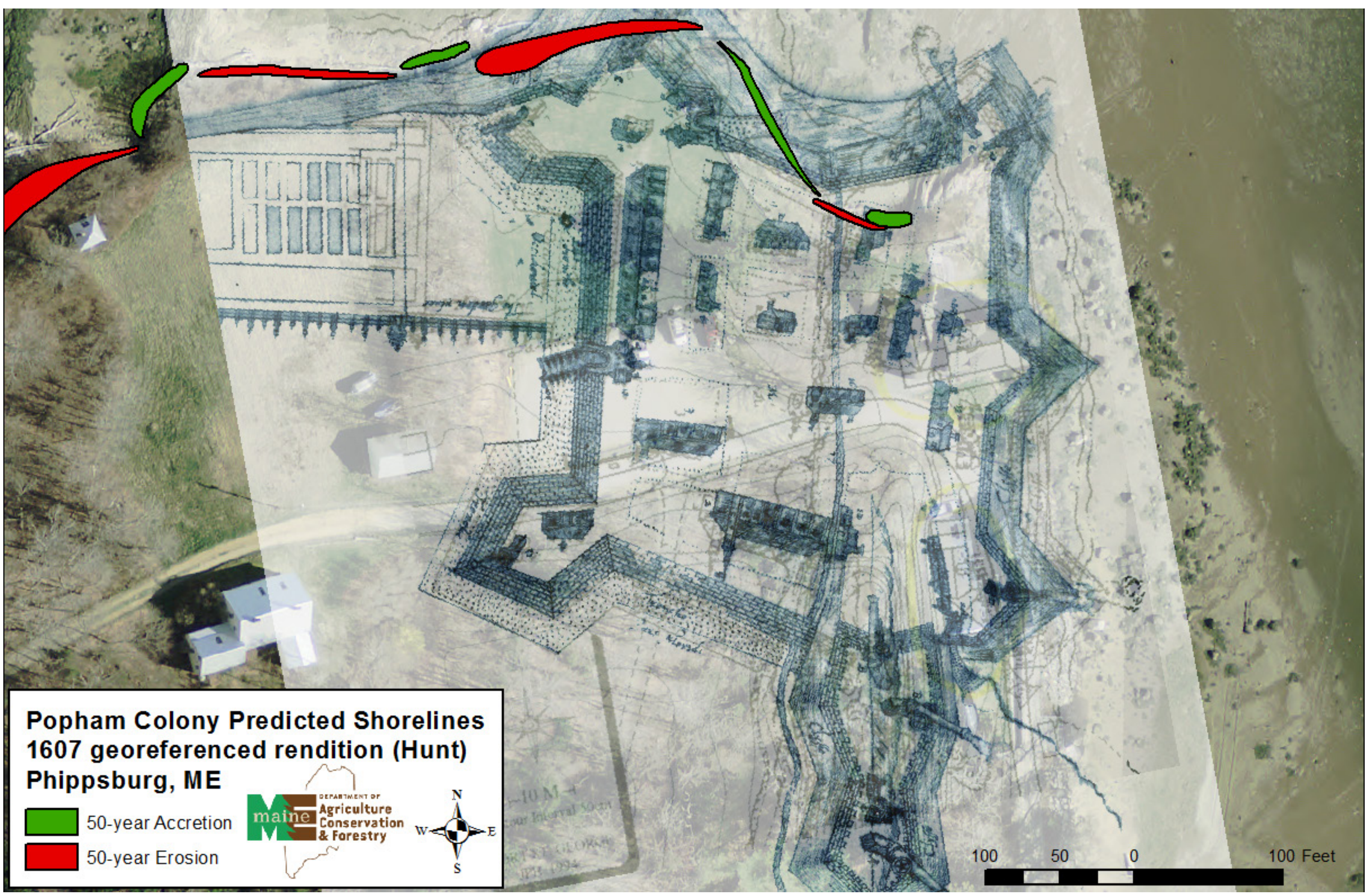

Figure 26. Potential future shoreline positions based on long-term shoreline change data at Popham Colony. Note potential erosion along the northern side. Rectified map from 1607. 2012 base imagery from MEGIS.

2.11.2 (Continued)

Overall vulnerabilities for Fort Popham are listed in Table 6a, and for Popham Colony in Table 6b.

Property	Asset	Mean Elev* (ft NAVD)	Length, area or number	Mapped Flood Zone (Effective)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**							Shoreline Change	
					D1	D2	EHA	CBRS	HAT (6.3ft)	HAT+1 (7.3ft)	HAT+2 (8.3 ft)	CAT 1 (9.2 ft)	HAT+3.3 (9.6 ft)	HAT+6 (12.3 ft)	CAT 2 (12.9 ft)	10 year ST trend	50 year LT trend
Fort Popham	Pier	unknown	.06 ac	VE (12) - 100%						100%	100%	100%	100%	100%	100%	Not completed (armored)	
	Parking lot 1	7.3	.06 ac	VE (12) - 100%						58%	100%	100%	100%	100%	100%		
	Fort	8.3	0.77 ac	VE(12,15) - 100%						34%	44%	49%	53%	100%	100%		
	Popham Rd (outside Park)	8.6	312 m	AE(9) - 88%		71%				31%	67%	96%	100%	100%	100%		
	Recreational - picnic tables	varies	7	VE(12) - 100%						14%	57%	57%	57%	57%	57%		
	Popham Rd (in Park)	8.5	246 m	AE(9); VE(12) - 100%		40%	40%			3%	43%	97%	100%	100%	100%		
	Parking lot 2	8.2	0.42 ac	VE(12) - 100%						2%	76%	100%	100%	100%	100%		
	Parking lot 3	8.6	.01 ac	VE(12) - 100%							1%	100%	100%	100%	100%		
	Small fort house	13.0	.05 ac	VE(12) - 100%							1%	10%	10%	48%	60%		
	Parking lot 4	10.0	.06 ac	VE(12) - 100%	14%	86%	100%					11%	63%	100%	100%		
	Recreational - trails	varies	249 m	VE(12) - 100%	11%		11%					11%	18%	62%	72%		
	Recreational - beach paths	varies	11 m	VE(12) - 100%	82%	18%	100%							100%	100%		
	Recreational - outhouse	11.5	1	VE(12) - 100%										100%	100%		

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

Green	Not present or not inundated (0%)
Yellow	Minimally present or inundated (<25%)
Orange	Moderately present or inundated (25-50%)
Red	Extremely present or inundated (>50%)

Table 6a. Vulnerability of assets at Fort Popham. Note that all assets are located in the 1% floodplain.

Property	Asset	Mean Elev* (ft NAVD)	Length, area or Number	Mapped Flood Zone (Effective)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**							Shoreline Change	
					D1	D2	EHA	CBRS	HAT (6.3ft)	HAT+1 (7.3ft)	HAT+2 (8.3 ft)	CAT 1 (9.2 ft)	HAT+3.3 (9.6 ft)	HAT+6 (12.3 ft)	CAT 2 (12.9 ft)	10 year ST trend	50 year LT trend
Popham Colony	Fort Baldwin Road	7.5	250 m	AE(9); VE(12) - 68%						17%	56%	70%	67%	78%	79%	Not completed	
	Colony	19.4	0.41 ac											<1%	<1%		
	Parking lot	24.2	0.26 ac														

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

Green	Not present or not inundated (0%)
Yellow	Minimally present or inundated (<25%)
Orange	Moderately present or inundated (25-50%)
Red	Extremely present or inundated (>50%)

Table 6b. Vulnerability of assets at Popham Colony. Note access to the Colony via Fort Baldwin Road is at risk.

2.12 Historic and Cultural Resources and Adaptation Strategies for Fort Popham and Popham Colony

2.12.1

Fort Popham – The historic resource most at risk is the physical fort itself, circa 1861. However, there is little that can be done to protect it. The fort is built from large granite blocks on bedrock, and will likely continue to be resilient in the face of future inundation (there are no resources within the fort that can be readily damaged by flooding). A recommendation to BPL is to develop an interpretive sign or post representing past and potential future sea levels in reference to the fort.

Property	Impacted Asset	Flood Zone	Dune System	CBRS Unit	Hazard or Scenario	Potential Impact	Protection Strategy	Accomodation Strategy	Retreat Strategy	Park Operations Strategy	Notes
Fort Popham	Pier	VE(12)	N/A	N/A	1 ft or more SLR/SS; Cat 1 or 2	flooding	N/A	allow flooding; elevate	relocate	allow flooding; limit use	coastal wetland
	Parking lot 1 (near pier)	VE(12)	N/A	N/A	1 ft or more SLR/SS; Cat 1 or 2	flooding	temporary protection	allow flooding	relocate	allow flooding; limit use; temporary protection	N/A
	Access road (Popham Rd)	AE(9); VE(12)	D2	N/A	2 ft of SLR/SS or more; Cat 1 or 2	flooding	green infrastructure, wall	allow flooding	abandon	allow flooding; limit use; temporary protection	need MEDOT
	Parking lot 2 (large lot)	VE(12)	N/A	N/A	2 ft of SLR/SS or more; Cat 1 or 2	flooding	green infrastructure, wall	allow flooding	relocate	allow flooding; limit use; temporary protection	N/A
	Fort	VE(12,15)	N/A	N/A	2 ft of SLR/SS or more; Cat 1 or 2	flooding	green infrastructure, wall, floodproofing	allow flooding	N/A	allow flooding; limit use; temporary protection	historic structure
	Parking lot 3 (near house)	VE(12)	N/A	N/A	3 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, wall	allow flooding	relocate	allow flooding; limit use; temporary protection	N/A
	Fort house/stadium	VE(12)	N/A	N/A	3 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, wall, floodproofing	allow flooding	N/A	allow flooding; limit use; temporary protection	historic structure
	Parking lot 4 (near beach)	VE(12)	D1, D2	N/A	3 ft or more SLR/SS; Cat 1 or 2	flooding	dune and beach restoration	allow flooding	relocate	allow flooding; limit use; temporary protection	N/A
	Picnic tables	VE(12)	N/A	N/A	2 ft of SLR/SS or more; Cat 1 or 2	flooding	N/A	N/A	relocate	limit use; move during events	N/A
	Trails	VE(12)	D1, D2	N/A	3 ft or more SLR/SS; Cat 1 or 2	flooding	N/A	allow flooding	relocate	allow flooding; limit use	N/A
	Beach access paths	VE(12)	D1, D2	N/A	3 ft or more SLR/SS; Cat 1 or 2	flooding	dune and beach restoration	allow flooding	relocate	allow flooding; limit use	N/A
	Outhouse	VE(12)	N/A	N/A	6 ft or more SLR/SS; Cat 2	flooding	green infrastructure, wall	N/A	relocate	temporary protection	N/A
Popham Colony	Ft. Baldwin Rd	AE(9); VE(12)	N/A	N/A	1 ft or more SLR/SS; Cat 1 or 2	flooding	rip-rap, wall, green infrastructure	allow flooding; elevate	relocate	allow flooding; limit use during events	need MEDOT

Table 7. Adaptation strategies for the historic sites of Fort Popham and Popham Colony. Note that access to both sites is at risk via Popham Road (for Fort Popham) and Fort Baldwin Road (for Popham Colony).

2.12.2

Popham Colony – Remnants of Fort St. George, which existed from 1607 to 1608, and Fort William, which was active primarily during World War I, are the main features at risk, mainly to erosion. A military cartography drawing of Fort St. George (from 1607) overlain onto a more recent aerial image is shown in Figure 27. This image shows the current locations of the parking lot and Fort Baldwin Road in reference to the Fort. The area where Fort William used to exist has eroded, and according to our analysis, may continue to erode.

Protection strategies could include erosion control along the northern shoreline. This could include traditional armoring approaches such as rip-rap (similar to what is used at Colonial Pemaquid, for example), or newer living shoreline or hybrid shoreline approaches. It is a recommendation to BPL to explore these options as a potential pilot site for protection of historic resources.

Table 7 summarizes potential adaptation strategies for identified vulnerable assets at Fort Popham and Popham Colony.

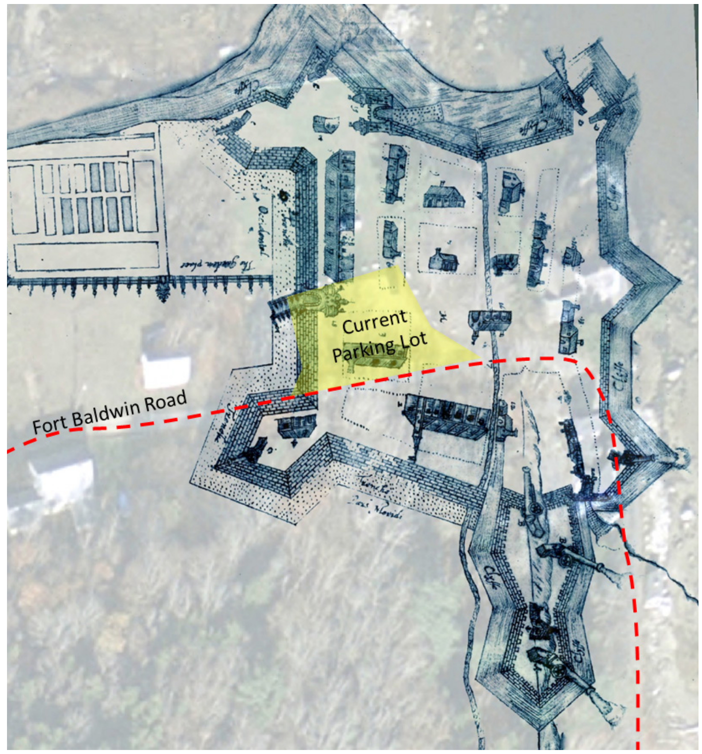

Figure 27. Cartographic depiction of Fort St. George (1607) overlain onto a 2012 base image. Fort Williams was at the northern end of the site.

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Appendices

Appendix A: Data Development and Limitations for Hazard Scenarios

Appendix B: Colonial Pemaquid Complex Vulnerability and Adaptation

Appendix C: Reid State Park Vulnerability and Adaptation

Appendix D: Crescent Beach Complex Vulnerability and Adaptation

Appendix E: Additional Figures Supporting Analysis of Roads and Buildings at the Popham Complex

Appendix F: Water Resources Investigation

Appendix G: Natural Resources Inventories

Appendix H: Popham Beach State Park Time Series Google Earth Imagery, 1997-2016

Appendix I: Popham Beach Survey Instrument

Appendix J: Popham Beach Survey Results Technical Report

Appendix A

Data Development and Limitations for Hazard Scenarios

Development of Inundation Data

Using ArcGIS, National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Service tide table data along the Maine coast, available Light Detection and Ranging (LiDAR) data from 2006 and 2010, and data from the NOAA Vertical Datums Transformation (VDATUM) tool, MGS developed storm surge/sea level rise levels for scenarios of 1, 2, 3.3, and 6 feet of sea level rise or storm surge on top of the 2015 Highest Annual Tide (HAT) (MGS, 2015). MGS also used inundation scenarios associated with Category 1 and 2 hurricanes making landfall at mean high tide (MGS, 2015a). This data was developed in conjunction with the US Army Corps of Engineers using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model. These scenarios included the spatial extent of potential inundation in addition to the potential inundation depths on the land surface. Special Flood Hazard Area (SFHA) data from effective Federal Emergency Management Agency (FEMA) Digital Flood Insurance Rate Maps (DFIRMs) or preliminary digital maps (if effective maps were paper), was also used to map the extent of the 100-year (1%) floodplain. These datasets were clipped to the boundaries of each coastal property – and buffered in order to account for potential access to and from properties – for further analysis of potential impacts to infrastructure and habitats.

It’s important to understand the assumptions or limitations of each of these different inundation datasets. MGS storm surge/sea level rise data uses a “bathtub” model for simulating inundation. That is, water levels are calculated using the 2015 Highest Annual Tide as a start and adjusted using NOAA VDATUM data, and are then simply interpolated and draped over a static topographic surface (LiDAR), and anything below that water level is considered inundated. This method results in stillwater elevations that do not account for potential erosion, accretion, shoreline changes, precipitation, or dynamic processes like waves. This dataset includes inundation of low-lying areas that may not be clearly tidally connected - this may be indicative of areas with drainage issues during heavy precipitation events.

The SLOSH model outputs storm tide elevations, a combination of predicted tide and storm surge for Category 1 and 2 tropical events making landfall at mean high tide. It uses outputs called the Maximum of Maximum Envelopes of Water, or MOMs, which are derived from synthetic model runs that result in the highest storm tides for multiple transects along a coastline. SLOSH outputs do not account for the potential impacts from waves, extreme tides, freshwater flow, precipitation, or future scenarios of sea level rise. Similar to the sea level rise data, these SLOSH outputs were interpolated and draped over the LiDAR land surface to determine areas that would be inundated. Unlike FEMA SHFA mapping, SLOSH data do not have calculated recurrence interval probabilities. SLOSH data removed small low-lying areas that did not have clear tidal connections.

FEMA SFHA DFIRM data define areas that have a 1% chance of flooding in any given year. These data are derived using historic storms, and combine tides with storm surge and wave action to determine 1% base flood elevations, or BFEs. FEMA DFIRMs do not account for future sea level rise, but may take into account erodibility of primary frontal dunes if they are below a certain size. Effective FEMA DFIRMs were used, as possible. However, effective data for Cumberland County dates to 1992 – thus, a preliminary map was used for the Crescent Beach Complex. The following table summarizes the sources of DFIRM data used for this study.

State Park or Property	Town	County	FEMA DFIRM Status	Date
Colonial Pemaquid Complex	Bristol	Lincoln	Effective	7/16/2015
Reid State Park	Georgetown	Sagadahoc	Effective	7/16/2015
Popham Beach Complex	Phippsburg	Sagadahoc	Effective	7/16/2015
Crescent Beach Complex	Cape Elizabeth	Cumberland	Preliminary	11/5/2013

Table A-1. FEMA Digital Flood Insurance Rate map data used for vulnerability analysis.

These different datasets use different mapping methodologies, assumptions, and hence have different limitations. FEMA DFIRMs include wave action, while the other mapping methods do not. Thus, in many cases, if the 1% event is used to define risk of assets, many more assets would be at "risk" than the other scenarios inspected. *Thus, for BPL to get a sense of the true **existing** risk of the assets to existing storms (including tides, surge, and waves), we recommend that the 1% SFHA data be used.* For risk to future stillwater flooding of assets from daily or monthly future tidal events (after sea level rise), we recommend using the sea level rise scenarios.

Development of Shoreline Change Data

MGS developed long-term shoreline change datasets at Popham Beach State Park and Popham Colony, Reid State Park, and Crescent Beach and Kettle Cove State Parks. This was done by scanning and rectifying available historic aerial images from the MGS library to the most recent base imagery available from the Maine Office of GIS, and then digitizing the seaward edge of the dune vegetation. Reid State Park included shorelines from 1964, 1980, 1986, 1991, 2003, and 2014. Popham Beach State Park included shoreline from 1953, 1964, 1980, 1986, 1991, 2003, and 2016, while Popham Colony included shorelines from 1964, 1980, 1986, and 2003. Crescent Beach and Kettle Cove included shorelines from 1964, 1980, 1991, 1995, 2003, and 2014.

Short-term shoreline change datasets were created at Popham Beach State Park, Reid State Park, and Crescent Beach and Kettle Cove State Parks using data collected by MGS as part of its Maine Beach Mapping Program (MBMAP). This program uses Real Time Kinematic Global Positioning Systems (RTK-GPS) to survey the seaward edge of dominant dune vegetation on an annual basis. Shoreline positions were available from 2010 to 2015 for Popham and Reid State Parks, and from 2007 to 2014 for Crescent Beach and Kettle Cove State Parks.

MGS used the USGS Digital Shoreline Analysis System (DSAS, Thieler and others, 2009) to calculate the linear regression rate (LRR) at 10 meter spacing along the beach using both short and long-term shoreline positions. These rates were then used to project potential future shoreline positions (based on the 2014 shoreline position) for 10 (based on short-term data, typically 2010 to 2015) and 50 years (based on long-term data).

Development of Infrastructure Data

MGS reviewed available infrastructure GIS data from BPL and found that only simple point feature class data was available, and that it did not include all potentially at-risk infrastructure. Thus, using the best available ortho-imagery from the Maine Office of GIS (typically 2012 and 2015 imagery), MGS digitized infrastructure at each coastal property into polygon and/or line features, as applicable. In order to determine the elevations of infrastructure, available LiDAR data was extracted using these polygon or line features. This data was supplemented with RTK-GPS elevation surveys of key pieces of infrastructure, as needed. Additional infrastructure, such as key roads that link coastal state park properties (for example, Route 209 in Phippsburg), was added to the infrastructure database for vulnerability analysis. For the Popham Beach Complex, additional infrastructure including roads and building footprints on the entire Popham peninsula was developed for further analysis of potential regional impacts.

Infrastructure Vulnerability Analysis

ArcGIS was then used to determine which infrastructure and habitats might be at risk due to flooding under the following scenarios: existing highest annual tide; scenarios of 1, 2, 3.3, and 6 feet of sea level rise or storm surge; the 1% (or 100-year) effective or preliminary mapped special flood hazard area (SFHA); and Category 1 and 2 hurricanes. The percent of inundation of each asset and the average inundation depth (in feet) was also determined for each scenario. In addition, for those properties with projected future shoreline positions, potential impacts to infrastructure due to erosion were noted.

In addition, available Coastal Sand Dune Geology mapping data from MGS (MGS, 2011) was used to determine whether or not infrastructure was located within mapped frontal dune (D1), back dune (D2), or Erosion Hazard Area (EHA) boundaries. These maps support Maine's Coastal Sand Dune Rules, Chapter 355 of the Natural Resources Protection Act. This has regulatory implications in terms of managing, building, rebuilding, or potentially adapting different kinds of infrastructure.

Significant Natural Feature Vulnerability Analysis

Polygons for ecological and botanical natural features including rare and exemplary natural communities (Gawler and Cutko, 2010) and rare plant species (MNAP, 2014) were mapped in ArcGIS using a combination of ground-truthed GPS data and recent ortho-imagery. Polygons for rare animal occurrences, Essential Wildlife Habitats, and Significant Wildlife Habitats were provided by the Maine Department of Inland Fisheries and Wildlife. Vulnerability analyses were completed in part by overlaying the four sea level rise scenarios as referenced above on the respective features and noting the varying degrees of inundation. Ecological considerations for each of the features was combined with the respective inundation results to predict potential changes and to assess their vulnerability.

Appendix B
Colonial Pemaquid Complex Vulnerability and Adaptation

The Colonial Pemaquid Complex is a 21 acre site is comprised of the historic properties of Colonial Pemaquid and Fort William Henry (Figure B-1). In 2015, the complex saw over 57,000 visitors; seasonal attendance reached more than 100,000 in 2001. (Personal communication BPL/DACF.)

Figure B-1. Properties of the Colonial Pemaquid Complex include the historic sites of Colonial Pemaquid and Fort William Henry.

Colonial Pemaquid **–** This state historic site is comprised of 9 parcels totaling 20 acres, and is located on a small peninsula on the Pemaquid River in Bristol, ME. It is bound by the Pemaquid River to the north and west, Pemaquid Harbor to the east, and the mainland to the south. Access is via Huddle Road and Old Fort Road to the south. Home to Native Americans dating back at least one thousand years, Colonial Pemaquid later became the site of a very early English outpost and fishing station. Much of the shoreline along the property has been stabilized with rip-rap to minimize erosion. The site is currently developed with several access roads, paved parking lots, a historic museum and gift shop, waterfront restaurant, and boat launch. The Colonial Pemaquid complex also includes the following assets (Figure B-2):

Fort William Henry - Directly adjacent to Colonial Pemaquid sits Fort William Henry. Originally built in 1692, this historic fort sits on a 1.1 acre property. Built on the site of two previous forts, the current stone structure was built in 1907 as part of the 300th Anniversary of Colonial Pemaquid. It is a replica of the 1692 Fort William Henry, the third fort constructed on this site. The tower of the fort contains interpretive panels and artifact exhibits as well as a beautiful view of the area from the roof.

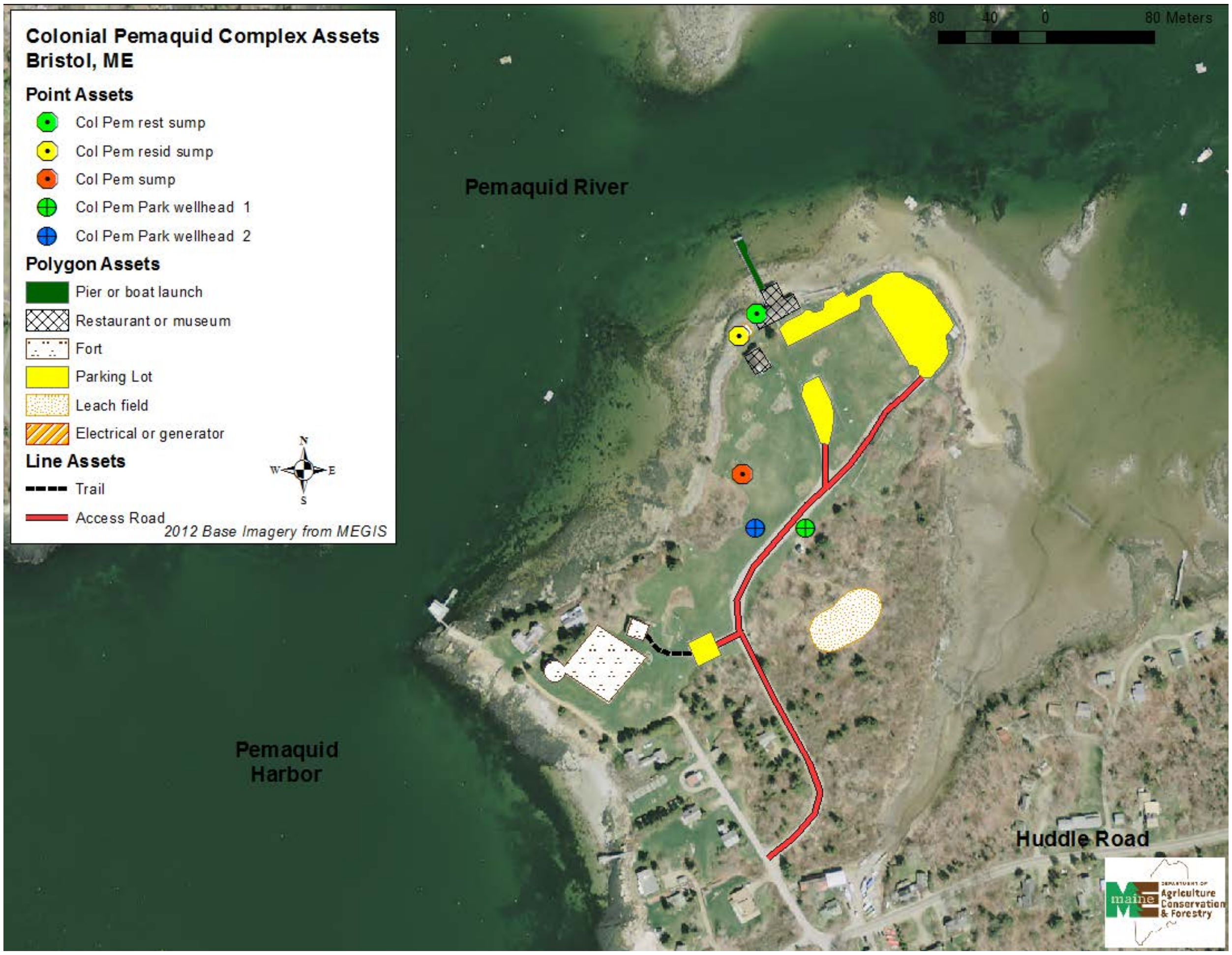


Figure B-2. Assets of the Colonial Pemaquid Complex.

Other Features at the Site -- *Fort House* - This restored Federal-style home dates to 1790 and contains a research library, archaeology lab, and interpretive information and artifact storage from the many archaeological digs that have been conducted at Pemaquid.
Village - This collection of stone building foundations reveals the locations and size of structures from various periods of the village's history.
Burial Ground - Gravestones in this burial ground date back well into the early 1700s and this is likely the site of burials for settlers dating back to the original British arrival in the 1620s.
Museum - The museum houses dozens of exhibits on the history of Pemaquid from ancient Native American life here through the colonial period. It also includes a large diorama of the Pemaquid village.

Angel Gabriel – Angel Gabriel was a galleon that was destroyed by a hurricane while anchored at Pemaquid in 1635. In 2010, descendants of the survivors dedicated a bronze plaque at the site commemorating the wreck.
Gift Shop – Operated by the Friends of Colonial Pemaquid, it offers history-related items to visitors.

Shoreline Change Analysis – Shoreline change analyses were not performed due to an armored shoreline. Colonial Pemaquid is not part of the Maine Coastal Sand Dune System, or the CBRS.
Inundation analyses – according to effective DFIRM data, the restaurant, pier, small leach field, and portions of the lower parking lot are located in AE-zone with a 100-year BFE of 10 feet NAVD. This same infrastructure is also at-risk to flooding due to most storm surge or sea level rise scenarios. At the higher scenarios (6 feet of sea level rise or storm surge) and under both of the hurricane scenarios, the sewage sump, and pump stations are also potentially at risk. Access to the properties via Huddle Road may be compromised in Category 1 or 2 events or under higher sea level scenarios. See Figures B-3 a, b, and c and Table B-1. Repairs to the pier and adjacent float were completed in 2014 at a cost of about $206,000. Without further investigation, it is unclear whether additional adaptation measures could have been designed and incorporated into the repairs. Funding for that addition of adaptive measures would have exceeded the available budget.

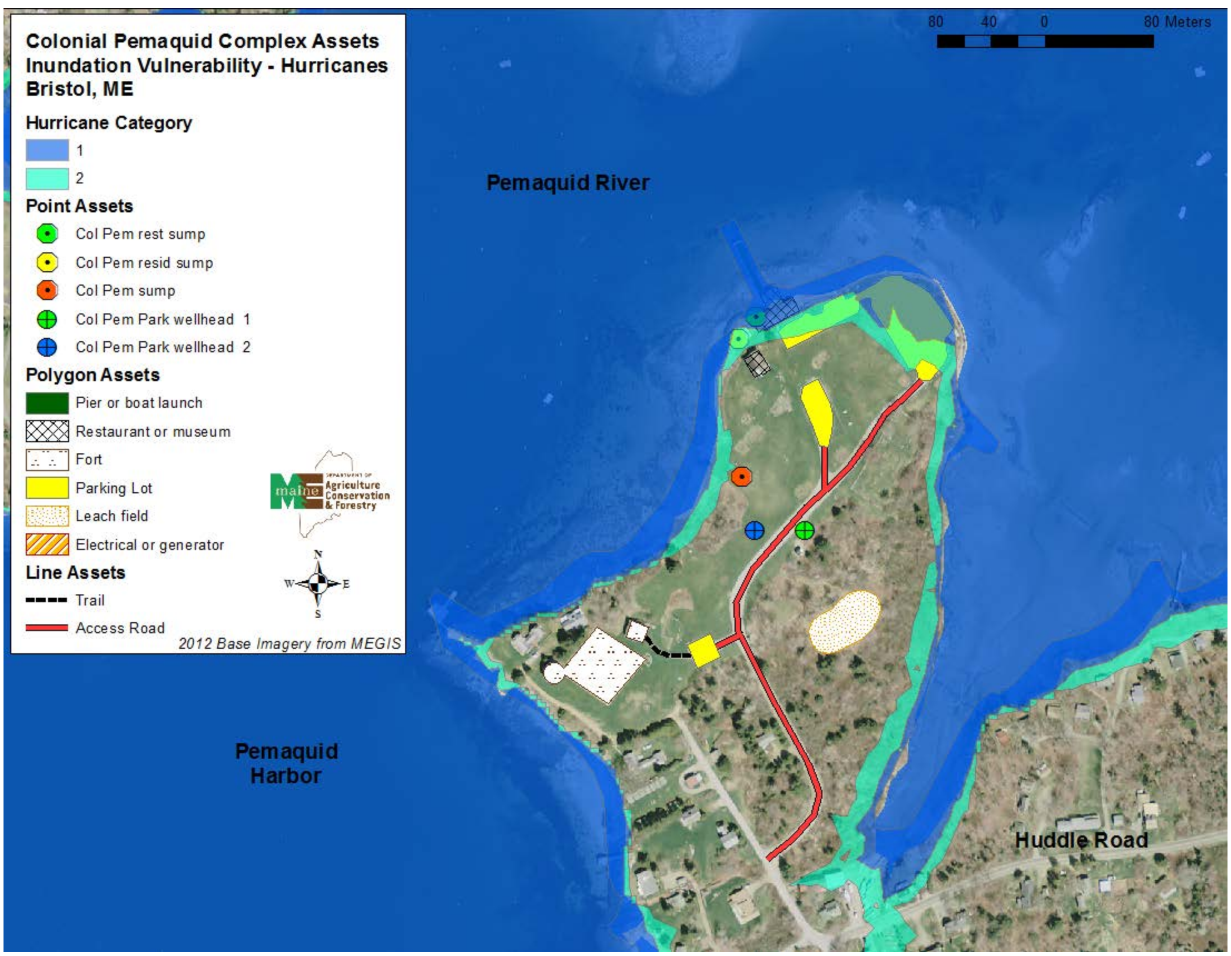


Figure B-3a. Potential hurricane inundation.

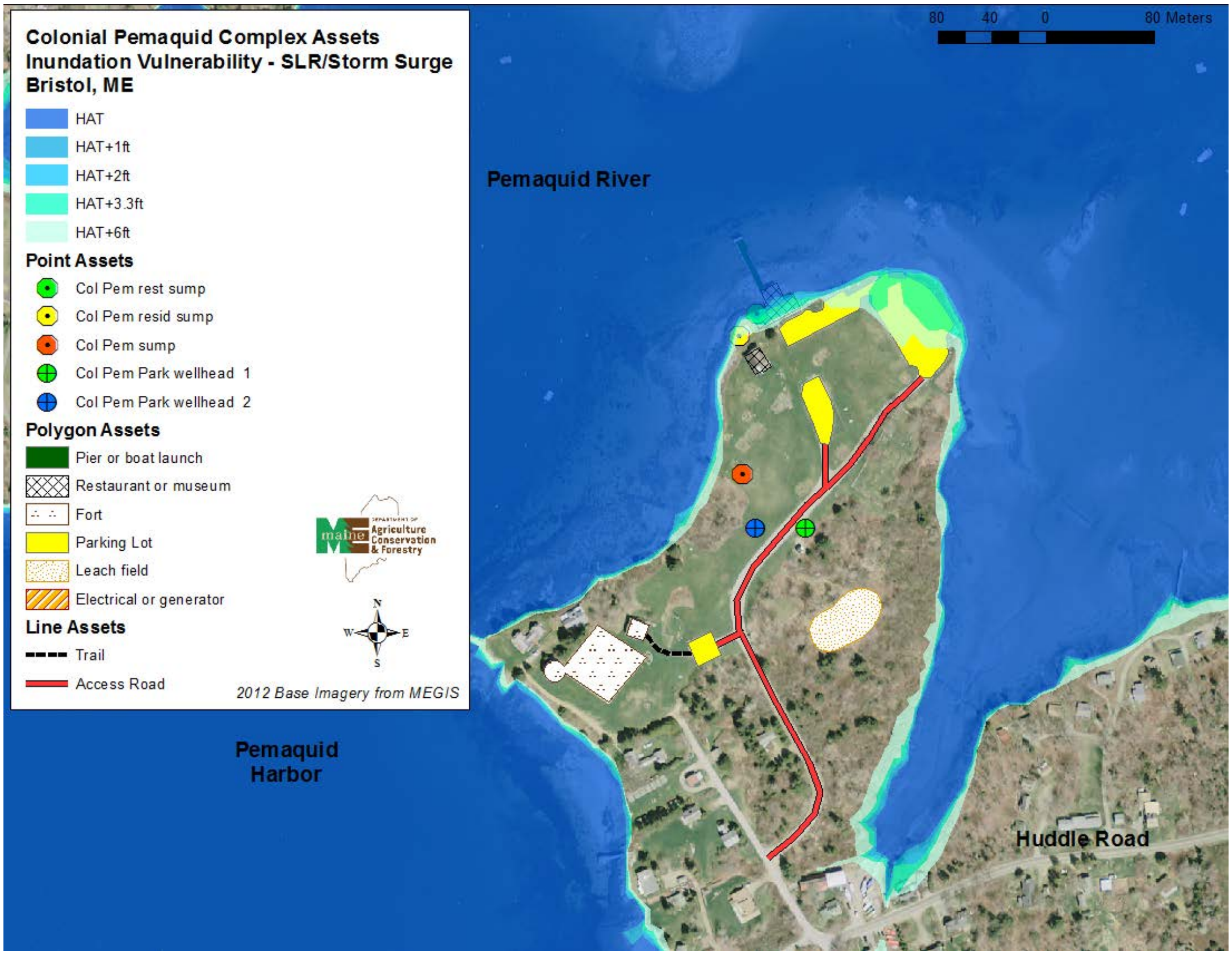


Figure B-3b. Potential sea level rise and/or storm surge inundation.

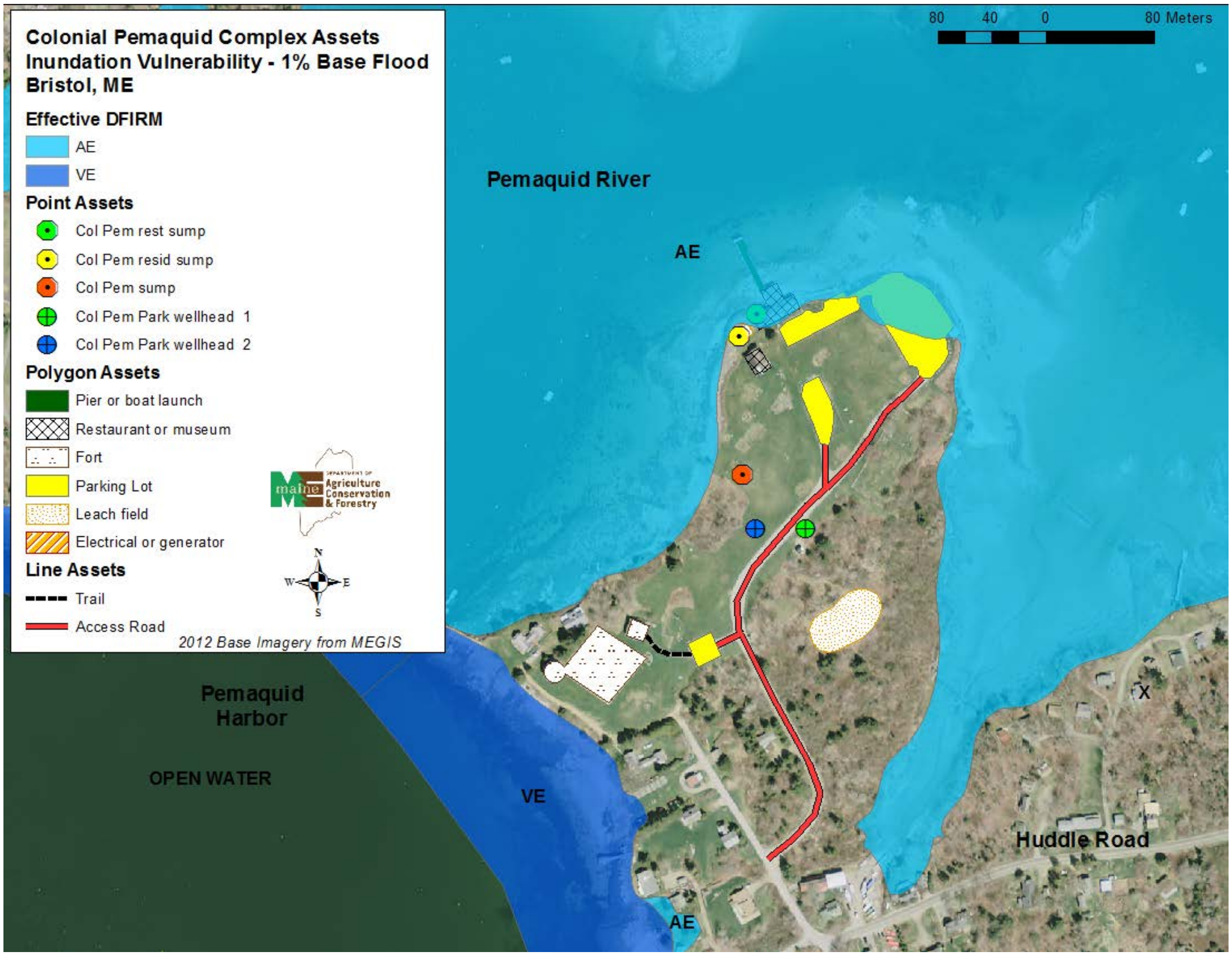


Figure B-3c. Effective 1% storm SFHA for Colonial Pemaquid Complex properties. Note potential breaching of Huddle Road.

Adaptation

Assets - Potential adaptation strategies identified for assets of Colonial Pemaquid are provided in Table B-2.

Natural Resources - A Natural Resource Inventory was not conducted for this site. The Park was designated and managed as a cultural and historic site.

Historic and Cultural Features - The threatened resources of concern at this site include circa 1650-1690 structure foundations and other features near the shoreline west of the restaurant. Shoreline stabilization (shown below in Figure B-4) was completed in 2009 at a cost of $387,437 (including the septic system). This shoreline should be monitored and consideration given to evaluating the success of the stabilization project, including the design life of the improvement. Alternative designs could be considered if merited.


Figure B-4. Colonial Pemaquid Rip Rap on west shoreline (photo: Art Spiess).

Property	Asset	Mean Elev* (ft NAVD)	Length, Area or Number	Mapped Flood Zone (Effective)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**						
					D1	D2	EHA	CBRS	HAT (6.1ft)	HAT+1 (7.1ft)	HAT+2 (8.1 ft)	HAT+3.3 (9.4 ft)	CAT 1 (10.0 ft)	HAT+6 (12.1 ft)	CAT 2 (14.5ft)
Colonial Pemaquid	Restaurant sewage sump	N/A	N/A	AE(10) - 100%					100%	100%	100%	100%	100%	100%	100%
	Wood ramp	7.5	N/A	AE(10) - 100%					10%	40%	100%	100%	100%	100%	100%
	Restaurant	7.9	0.15 ac	AE(10) - 100%							46%	87%	100%	100%	100%
	Pier	8.2	0.05 ac	AE(10) - 100%							45%	100%	100%	100%	100%
	Large parking lot	10.3	0.74 ac	AE(10) - 69%							3%	41%	65%	80%	100%
	Parking lot - small 1	13.0	0.25 ac										24%	24%	90%
	Leach field small	11.5	0.02 ac										2%	82%	100%
	Residence sewage sump	12.0	N/A											100%	100%
	Pump station	12.5	N/A												100%
	Huddle Road	18.6	N/A												5%
	Old Fort Road	19.6	489 m												
	Parking lot - small 2	29.6	0.18 ac												
	Museum	20.7	0.05 ac												
	Leach field large	26.2	0.39 ac												
	Park well head 1	18.0	N/A												
	Park well head 2	24.0	N/A												
	Trails	varies	41 m												
Fort William Henry	Fort	25.3	0.05 ac												
	Park office	37.7	0.04 ac												
	Parking lot	29.9	0.09 ac												

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

(green)	Not present or not inundated (0%)
(yellow)	Minimally present or inundated (<25%)
(orange)	Moderately present or inundated (25-50%)
(red)	Extremely present or inundated (>50%)

Table B-1. Asset vulnerability at the Colonial Pemaquid Complex. . Included is percent of the asset that is present within: the effective FEMA flood zone; sea level rise, storm surge, and SLOSH inundation scenarios; and ten-year short-term and fifty-year long-term projected shoreline changes.

Property	Impacted Asset	Flood Zone	Dune System	CBRS Unit	Hazard or Scenario	Potential Impact	Protection Strategy	Accomodation Strategy	Retreat Strategy	Park Operations Strategy	Notes
Colonial Pemaquid	Restaurant sewage sump	AE(10)	N/A	N/A	1 ft or more SLR/SS; Cat 1 or 2	flooding	N/A	retrofit and elevate	relocate	do nothing	
	Restaurant wooden ramp	AE(10)	N/A	N/A	1 ft or more SLR/SS (significant @ 2 ft); Cat 1 or 2	flooding	N/A	allow flooding; elevate; limit access	relocate	limit access during event; elevate	coastal wetland
	Restaurant and Pier	AE(10)	N/A	N/A	2 ft or more SLR/SS (significant @ 3 ft); Cat 1 or 2	flooding	temporary protection	elevate	relocate	limit access during event; temporary protection	coastal wetland
	Boat ramp and parking lot (lower)	AE(10)	N/A	N/A	2 ft or more SLR/SS (significant @ 3 ft); Cat 1 or 2	flooding	wall, green infrastructure	allow flooding	relocate	limit access during event; temporary protection	coastal wetland
	Parking lot (upper)	N/A	N/A	N/A	3 ft or more SLR/SS; Cat 1 or 2	flooding	wall, green infrastructure	allow flooding	relocate	limit access during event; temporary protection	
	Parking Lot (upper, small)	N/A	N/A	N/A	6 ft or more SLR/SS; Cat 1 or 2	flooding	wall, green infrastructure	allow flooding	relocate	limit access during event; temporary protection	
	Leach field (small)	N/A	N/A	N/A	6 ft or more SLR/SS; Cat 1 or 2	flooding	wall, green infrastructure	??	relocate	temporary protection	
	Residence sewage sump	N/A	N/A	N/A	6 ft or more SLR/SS; Cat 1 or 2	flooding	wall, green infrastructure	??	relocate	temporary protection	
	Pump station	N/A	N/A	N/A	Cat 1 or 2	flooding	wall, green infrastructure	elevate	relocate	temporary protection	
	Huddle Rd./Old Fort Rod.	N/A	N/A	N/A	Cat 2	flooding	green infrastructure; walls	allow flooding	relocate	limit access during event; temporary protection	need MEDOT
	Museum	N/A	N/A	N/A	Cat 2	flooding	green infrastructure; walls	elevate	relocate	temporary protection	historic structure

Table B-2. Potential adaptation strategies at the Colonial Pemaquid Complex.

Appendix C

Reid State Park Vulnerability and Adaptation

Reid State Park is located at the southern tip of the Georgetown Peninsula. The park, Maine's first state-owned saltwater beach, is comprised of 3 parcels totaling approximately 697 acres (Figure C-1). Based on 2004 visitation, it averages approximately 105,000 visitor days, which is fourth overall for all of Maine's state parks. The overall park is bound by the ocean to the south, Griffith Head and the Sheepscot River to the east, the Little River to the west, and wetlands and uplands to the north. The park is comprised of forested uplands, tidal and freshwater wetlands, rocky headlands, sand dunes, and beaches. The park has approximately 1.2 miles of beach, comprised of two smaller pocket beaches. At the eastern side of the park is Mile Beach, bound by Griffith Head (to the east) and Todd's Point (to the west). Half Mile Beach stretches from Todd's Point to the Little River (to the west).

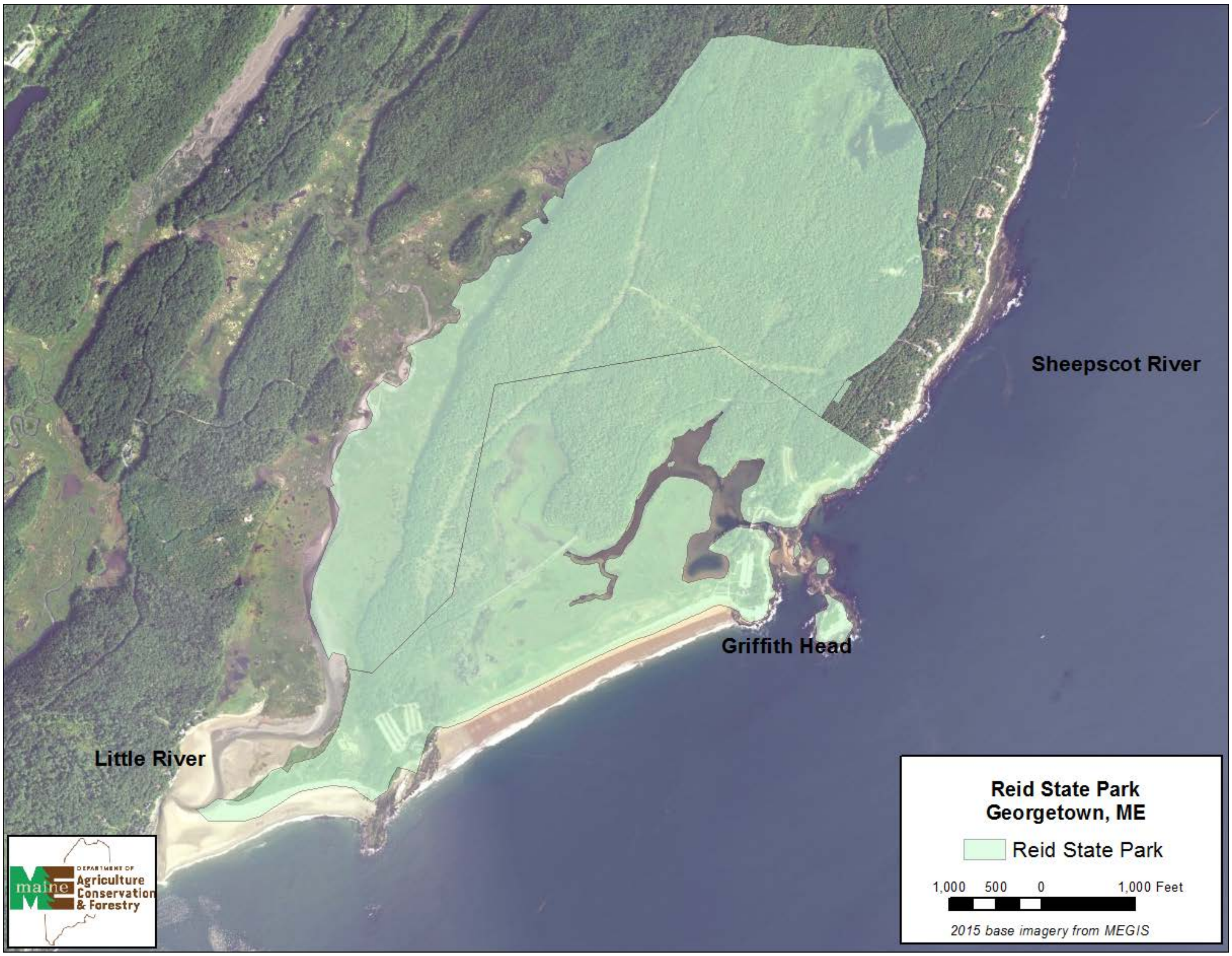


Figure C-1. Properties of Reid State Park.

Some major built assets at the park include the paved Seguinland Road, several large parking lots, several bathhouses with running water, leach field, and pump station (Figure C-2).

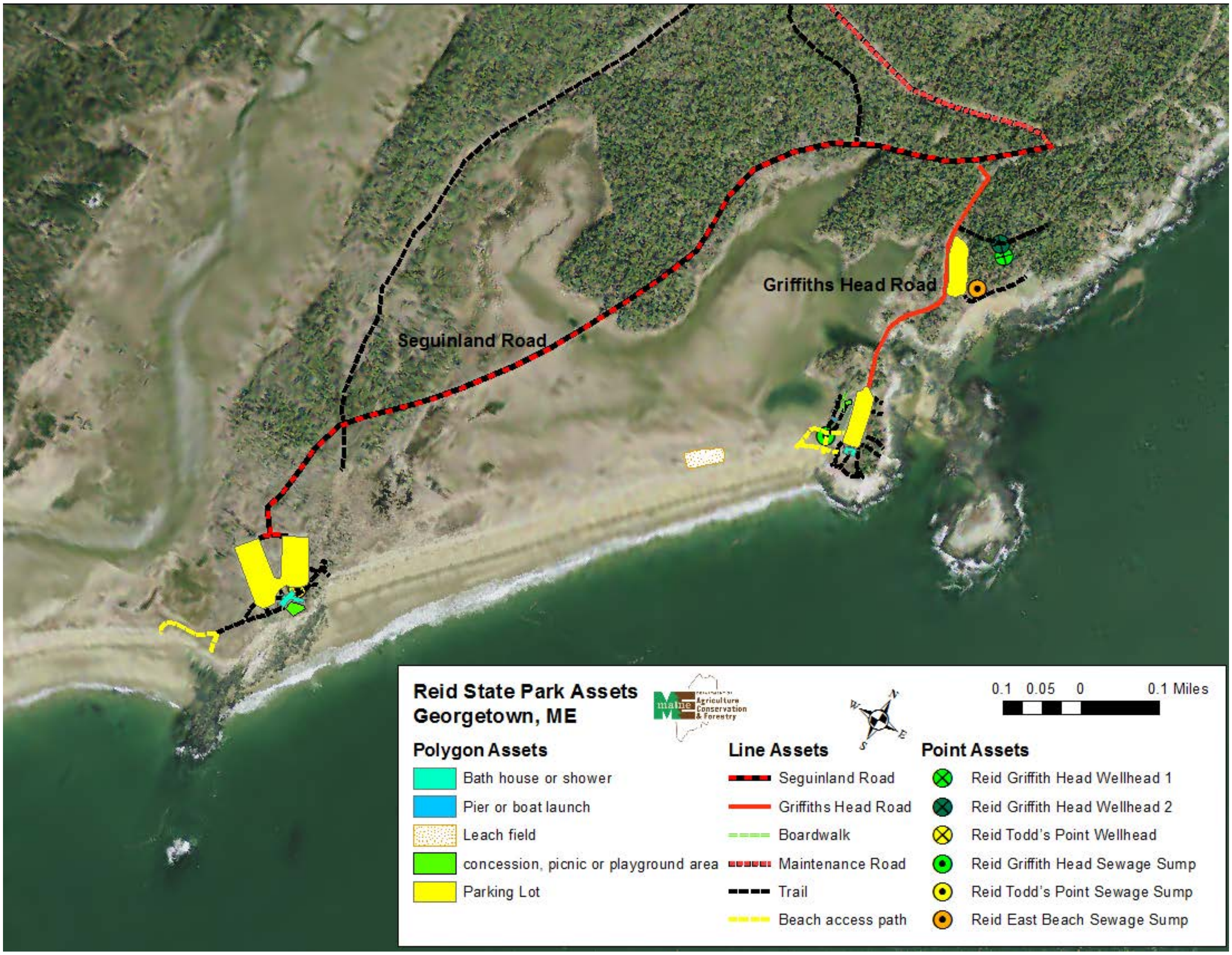


Figure C-2. Infrastructure assets at Reid State Park.

Long-term Shoreline Change Analyses – Based on long term linear regression rates from shoreline position data from 1964 to 2014, the shoreline along the beaches has been markedly stable to slightly accretive. There has been some slight erosion at the southwestern end of Mile Beach. Overall, Mile Beach had a mean shoreline change rate of 0.1 feet per year, while Half Mile Beach had a mean rate of 0.3 feet per year. Based on this data, future 50-year shoreline change trends would have no impact to existing infrastructure or habitat at Reid State Park (Figure C-3)

Figure C-3. Long-term shoreline change rates along Reid State Park.

Short-term Shoreline Change Analyses – Based on available data derived from shoreline positions from 2010 to 2015, Mile Beach grew. It had small pockets of slight erosion at its eastern end, and grew (upwards of 4-5 feet per year) along its western end, near Todd's Point. Half Mile Beach grew more near its spit at the Little River than it did near Todd's Point (Figure C-4). This data shows that 10-year predicted shorelines would not impact infrastructure or habitats, so no figures are shown.

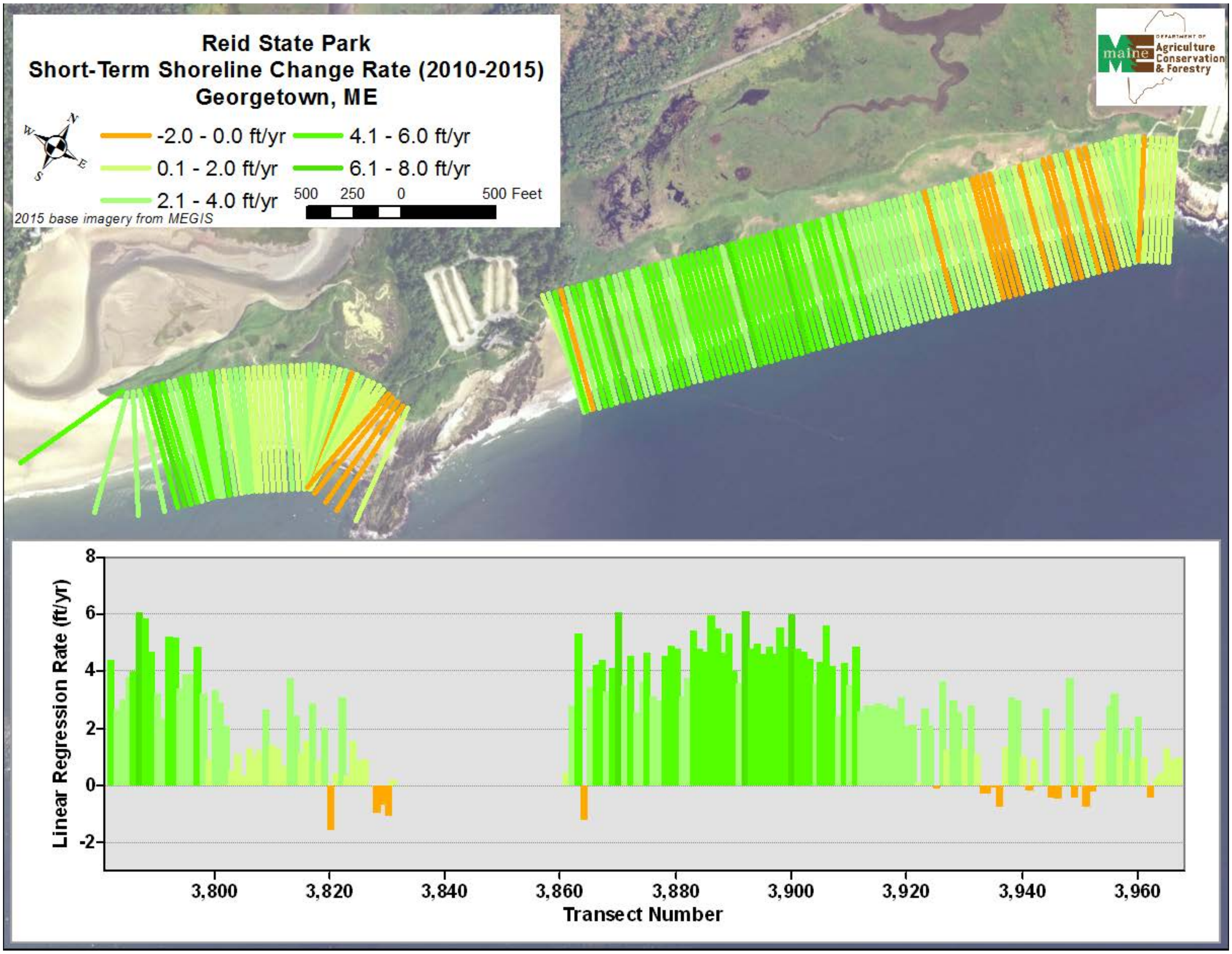


Figure C-4. Short-term shoreline change rates along Reid State Park.

Inundation analyses – Based on existing DFIRM data, Reid's access roads and one of its parking lots are within existing AE flood zones. The leach field, several trails, and pump stations are located within a mapped VE zone (Figure C-5).

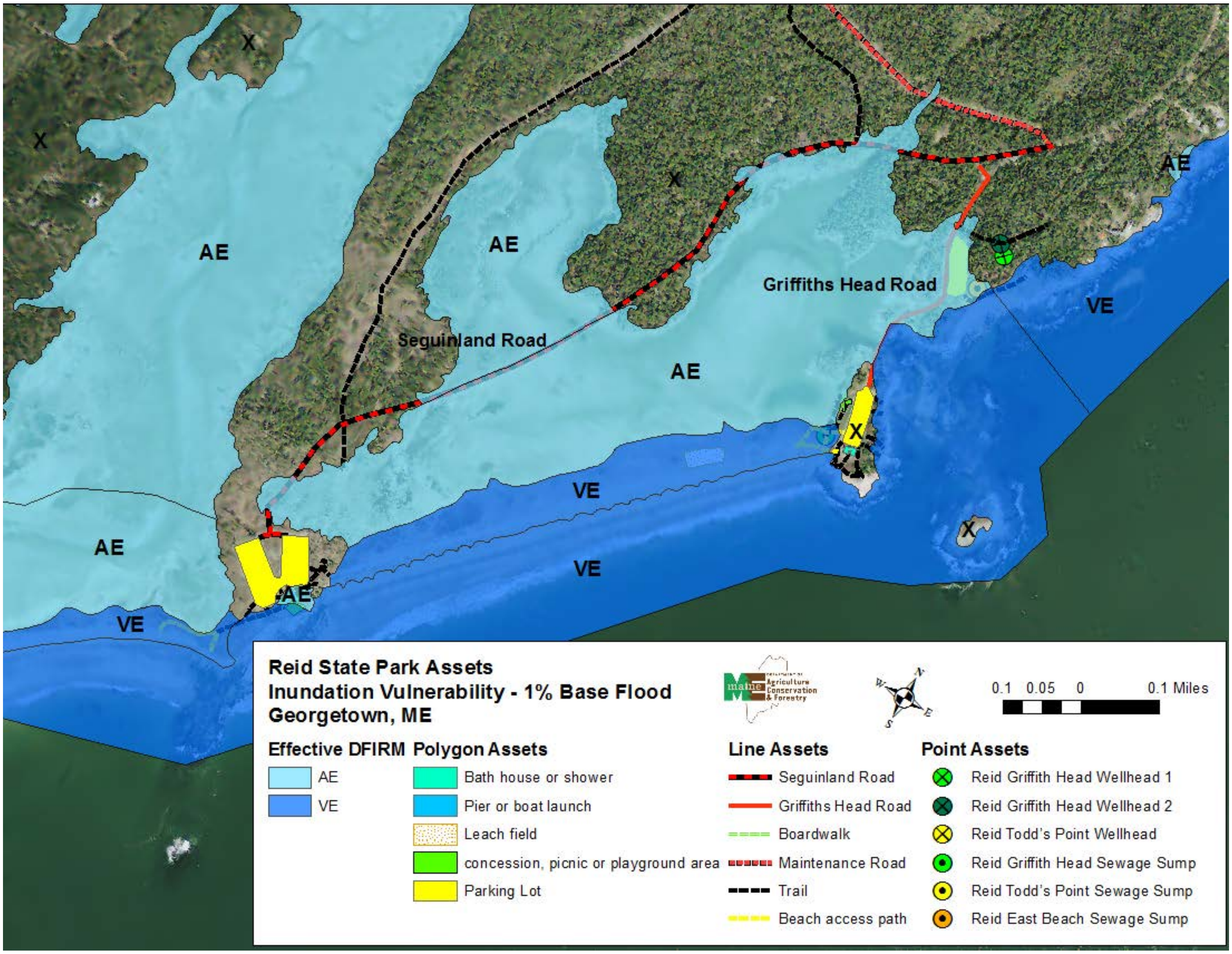


Figure C-5. Mapped 1% SFHA Base Flood areas along Reid State Park.

However, based on stillwater sea level rise scenarios, the majority of Reid State Park's built infrastructure appears to not be vulnerable to potential inundation except under the highest simulated scenarios. The most at-risk infrastructure appears to be Seguinland Road, which provides public access to park facilities and the beaches at Todd's Point (Figure C-6). The road is low-lying in two sections as it crosses an area of saltmarsh. These two sections appear to be at risk from flooding starting at a scenario of 1 foot of sea level rise, which could result in monthly inundation of the road. Under a 2-foot scenario, over 460 meters of the road will be inundated. Under a 3.3 foot scenario, about 25% of the road will be inundated, with an average depth of 1.5 feet. Under a scenario of 3.3 or 6 feet of SLR or storm surge (and both hurricane scenarios, Figure C-7), access to the park itself via Griffiths Head Road will be vulnerable to inundation, as will be the maintenance parking lot, and the pump station and sewage sump at Griffiths Head. Of note is that the elevation of the bridge connecting to Griffith's Head is unknown – this should be further investigated to determine its vulnerability to the scenarios herein.

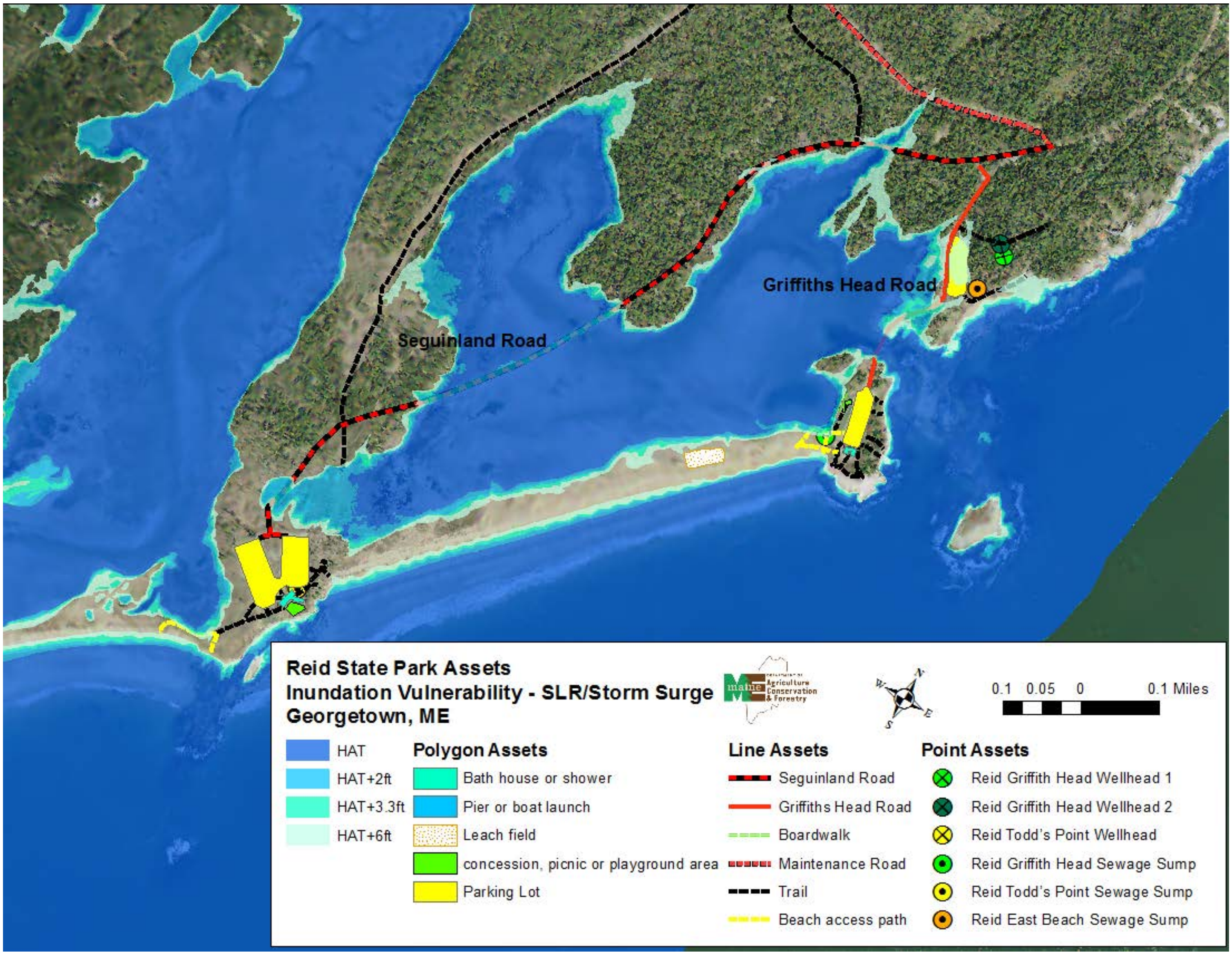


Figure C-6.. Sea level rise and/or storm surge scenarios along Reid State Park.

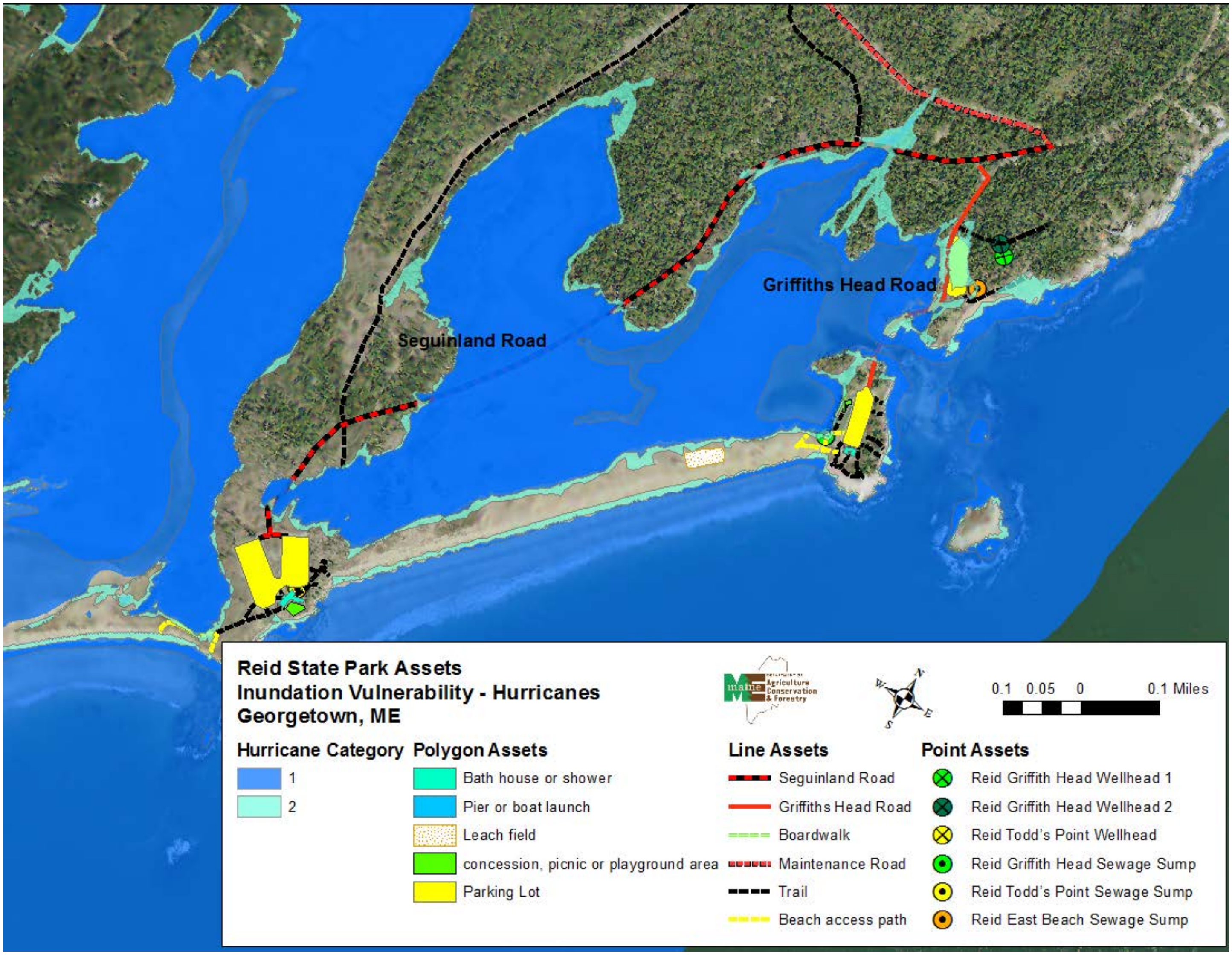


Figure C-7. Hurricane inundation scenarios along Reid State Park.

Coastal Sand Dunes – The leach field, Griffith Head sewage sump, and several beach access paths are in the mapped sand dune system and erosion hazard areas (Figure C-8). No other infrastructure is in the dune system. However, many assets are mapped within CBRS ME 15-P (Table C-1). Summarized vulnerable assets are in Table C-1, while potential adaptation strategies for Reid State Park assets are listed in Table C-2.

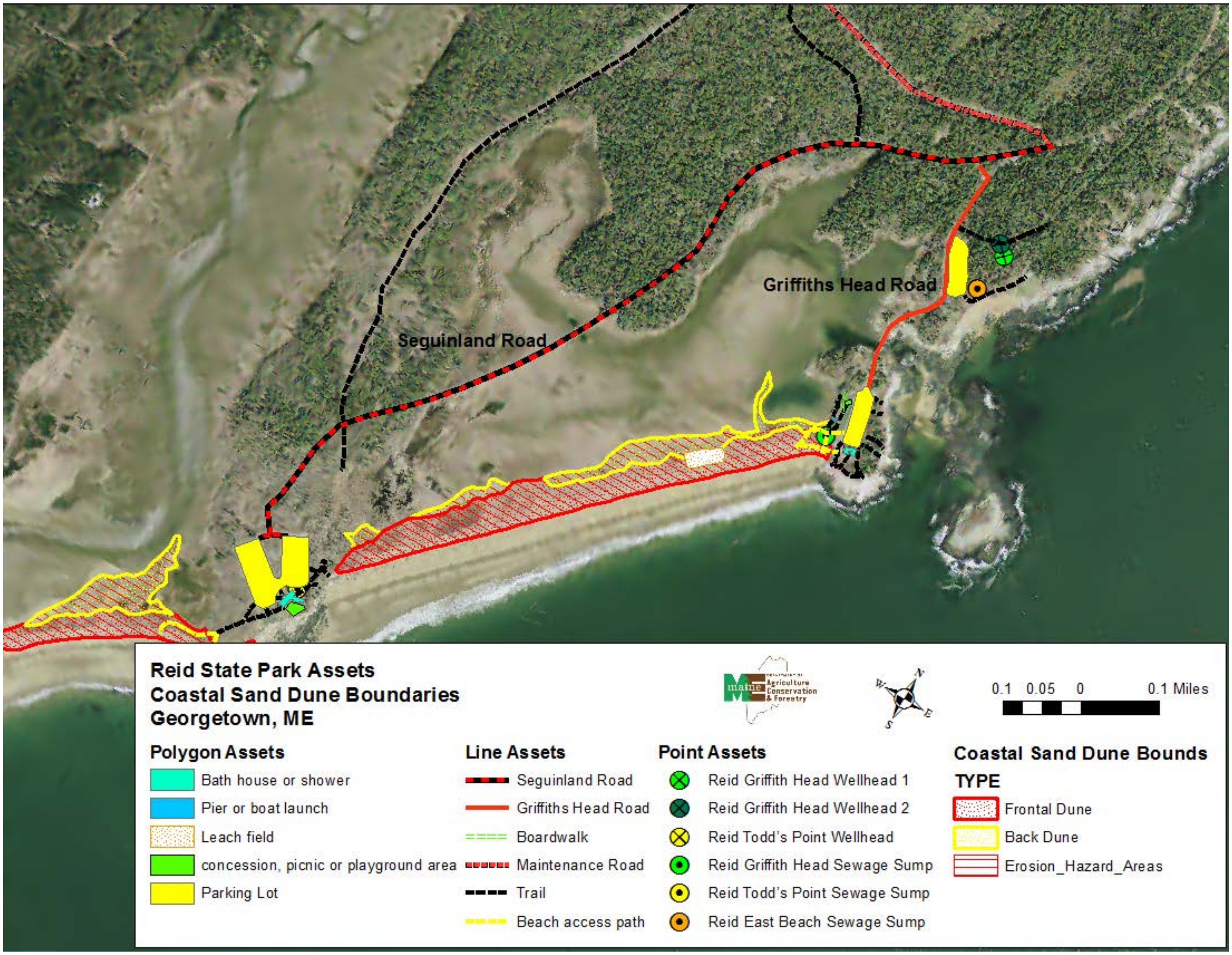


Figure C-8. Mapped Maine coastal sand dune boundaries and erosion hazard areas at Reid State Park.

Property	Asset	Mean Elev* (ft NAVD)	Length, area or Number	Mapped Flood Zone (Effective)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**							Shoreline Change	
					D1	D2	EHA	CBRS	HAT (6.3ft)	HAT+1 (7.3ft)	HAT+2 (8.3 ft)	CAT 1 (9.4 ft)	HAT+3.3 (9.6 ft)	HAT+6 (12.3 ft)	CAT 2 (12.7 ft)	10 year ST trend	50 year LT trend
Reid	Seguinland Road culvert	unknown	1	AE(15)				ME-15P	100%	100%	100%	100%	100%	100%	100%		
	Seguinland Road	7.3	2012 m	AE(15) - 36%				ME-15P		14%	23%	25%	25%	33%	35%		
	Griffith's Head kayak launch	varies	0.02 ac	AE(15) - 70%				ME-15P		4%	5%	42%	42%	63%	71%		
	Recreational - Beach paths	varies	421 m	VE(16) - 93%	66%	13%	79%	ME-15P			5%	14%	12%	32%	26%		
	Recreational - Trails	varies	3297 m	AE(15,21) VE(15,16,21,26) - 18%		<1%	<1%	ME-15P			2%	3%	3%	5%	5%		
	Griffith's Head Road north	11.1	633 m	AE(15, 21) - 57%								10%	16%	30%	66%		
	Griffith's Head pump stations	11.0	2	VE(16) - 100%	63%	37%	100%	ME-15P						100%	100%		
	Griffith's Head sewage sump	14.0	1	VE(16) - 100%		100%	100%	ME-15P						100%	100%		
	Griffith's Head maint. parking	12.1	1.1 ac	AE(15) - 100%										66%	78%		
	Griffith's Head Road south	17.3	78 m					ME-15P						5%	26%		
	Maintenance roads	varies	669 m	AE(15) - 2%										2%	2%		
	East Beach sump	13.0	1	AE(15) - 100%											100%		
	Recreational - boardwalks	varies	42 m	AE(15) - 45%				ME-15P							38%		
	Griffith's Head shelter	12.9	.03 ac	VE(26) - 100%											10%		
	Griffith's Head wellhead 1	30.0	1														
	Griffith's Head wellhead 2	27.0	1														
	Griffith's Head main parking lot	23.1	1.1 ac					ME-15P									
	Griffith's Head concession buildin	19.7	0.03 ac					ME-15P									
	Griffith's Head bath house	25.3	0.07 ac					ME-15P									
	Mile Stretch Beach leach field	17.0	0.65 ac	VE(16) - 100%	85%	15%	100%	ME-15P									
	Todd's Point parking lots	27.0	3.3 ac					ME-15P									
	Todd's Point bath house	18.2	0.17 ac	AE(21) - 100%				ME-15P									
	Todd's Point picnic area	16.7	0.17 ac	VE(21), AE (21) - 100%				ME-15P									
	Todd's Point sewage sump	19.0	1	AE(21) - 100%				ME-15P									
	Todd's Point wellhead	55.0	1														

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

Green	Not present or not inundated (0%)
Yellow	Minimally present or inundated (<25%)
Orange	Moderately present or inundated (25-50%)
Red	Extremely present or inundated (>50%)

Table C-1. . Asset vulnerability at Reid State Park. Note the number of assets that are within the mapped 1% floodplain in contrast with the same assets being impacted by inundation due to sea level rise or hurricanes. The 1% floodplain may give a better indication of existing risk for inundation.

Property	Impacted Asset	Flood Zone	Dune System	CBRS Unit	Hazard or Scenario	Potential Impact	Protection Strategy	Accomodation Strategy	Retreat Strategy	Park Operations Strategy	Notes
Reid	Seguinland Road/culvert	AE(15)	N/A	ME-15P	1 ft or more SLR/SS (sign. @ 2 ft); Cat 1 or 2	flooding	N/A	resize culvert; allow flooding; elevate; limit access	relocate	limit access during event; culvert improvement	coastal wetland
	Griffiths Head Road (north)	AE(15); VE(21)	N/A	N/A	6 ft or more SLR/SS; Cat 1 or 2	flooding	temporary protection	allow flooding; elevate; limit access	relocate	limit access during event; temporary protection	
	Griffiths Head Road (south)	AE(15); VE(21)	N/A	ME-15P	6 ft or more SLR/SS; Cat 2	flooding	temporary protection	allow flooding; elevate; limit access	relocate	limit access during event; temporary protection	
	Parking Lot 3 (mainland)	AE(15)	N/A	ME-15P	6 ft or more SLR/SS; Cat 2	flooding	wall, green infrastructure	allow flooding	relocate	limit access during event; temporary protection	
	Griffiths Head pumps, sewage sump	VE(16)	D1, D2	ME-15P	6 ft or more SLR/SS; Cat 2	flooding	green infrastructure, dune restoration	N/A	relocate	temporary protection	
	East Beach sewage sump, leach field	VE(16)	D1, D2	ME-15P	Cat 2	flooding	green infrastructure, dune and beach restoration	N/A	relocate	temporary protection	
	Todds Point Bath House	AE(21); VE(21)	N/A	ME-15P	Cat 2	flooding	wall, temporary protection	allow flooding; elevate; limit access	relocate	temporary protection	
	Shelter	VE(26)	N/A	N/A	Cat 2	flooding	temporary protection; wall construction	elevate	relocate	temporary protection	
	Kayak launch	AE(15)	N/A	ME-15P	1 ft or more SLR/SS (significant @ 2 ft); Cat 1 or 2	flooding	N/A	allow flooding	relocate	limt access during event	
	Beach access paths	VE(16); VE(21)	D1, D2	ME-15P	2 ft or more SLR/SS (significant @ 6 ft); Cat 1 or 2	flooding	dune and beach restoration	allow flooding; limit access	relocate	limit access during event	
	Access roads	AE(15)	N/A	ME-15P	2 ft or more SLR/SS (significant @ 6 ft); Cat 1 or 2	flooding	green infrastructure; walls	allow flooding	relocate	limit access during event; temporary protection	
	Boardwalks	VE(16)	D1, D2	ME-15P	6 ft or more SLR/SS; (significant @ Cat 2)	flooding	N/A	limit access	relocate	remove during event	

Table C-2. Potential adaptation strategies for assets at Reid State Park

Habitat Management Considerations for Reid State Park

Under current conditions, the Dune Grassland and the nesting habitats of Least Tern and Piping Plover are the only significant natural features at the Reid State Park that require active management, which is already taking place. Signage and judicially placed fencing keep visitors from both trampling sensitive dune vegetation and from harming the nesting birds. Other near term activities that could benefit sensitive features at the park includes:

- Periodic monitoring for pests and invasive species, particularly in the Pitch Pine Woodlands, Dune Grasslands, and Spartina Saltmarsh. These natural communities currently have little to no colonization of invasive species, and will benefit from being kept free of these pests.
- Periodic monitoring of sensitive areas for impacts from recreational activity, particularly the Dune Grasslands. This community currently receives very little visitor use. If usage patterns change to the detriment of the community they should be addressed.
- Allowing natural succession and disturbance processes to occur unimpeded in unmanaged areas with exceptions for public safety.
- Investigating the degree to which free tidal flow is restricted by the culvert under Seguinland Road in anticipation of any opportunity to address the restriction if warranted.
- Incorporation of information on vulnerable rare species into park planning particularly Piping Plover, Least Tern, Saltmarsh Sparrow, and Saltmarsh Tiger Beetle.

In regards to climate change, multiple rare natural features within the park are vulnerable to impacts from sea level rise and increased storm intensity and frequency due to a warming climate. The Bureau of Parks and Lands has a high responsibility for several features within the park because of their extreme rarity within the state, and their disproportionate occurrence on state park lands. Those features include Dune Grasslands, Piping Plover (E) - Least Tern (E) Essential Habitat, Saltmarsh Sparrow, and Saltmarsh Tiger Beetle. The Spartina Saltmarsh along the Little River both within and adjacent to the park is also considered significant on a statewide basis due to its intact condition, never having been ditched or modified, as has been the case with nearly all of Maine’s larger saltmarshes.

While the habitats unable to adapt to sea level rise such as Pitch Pine Bog will likely be lost, other habitats such as Beach Strands, Dune Grasslands, and Spartina Saltmarsh may be able to adapt to sea level rise by migrating inland. The mechanics allowing each coastal habitat to move inland are different. At Reid State Park the Spartina Saltmarshes will provide room for the landward movement of the dune formation and the associated Dune Grassland. There is relatively less room for the Spartina Saltmarshes themselves to migrate landward as sea level rises, and if some or all of the existing marsh cannot keep up with the continued tidal elevation increases, areas of marsh will be lost.

Appendix D

Crescent Beach Complex Vulnerability and Adaptation

This complex is located in Cape Elizabeth, and is comprised of Crescent Beach and Kettle Cove State Parks totaling approximately 251 acres (Figure D-1). Combined, these state parks account for approximately 120,000 visitor days (Morris and others, 2006). Note that Two Lights State Park – located just to the east of Kettle Cove – was initially included in this complex; however, it is located completely on bedrock, and has no obvious vulnerabilities to sea level rise or storm surge. Therefore, it was not included in more detailed analyses and will be excluded here.

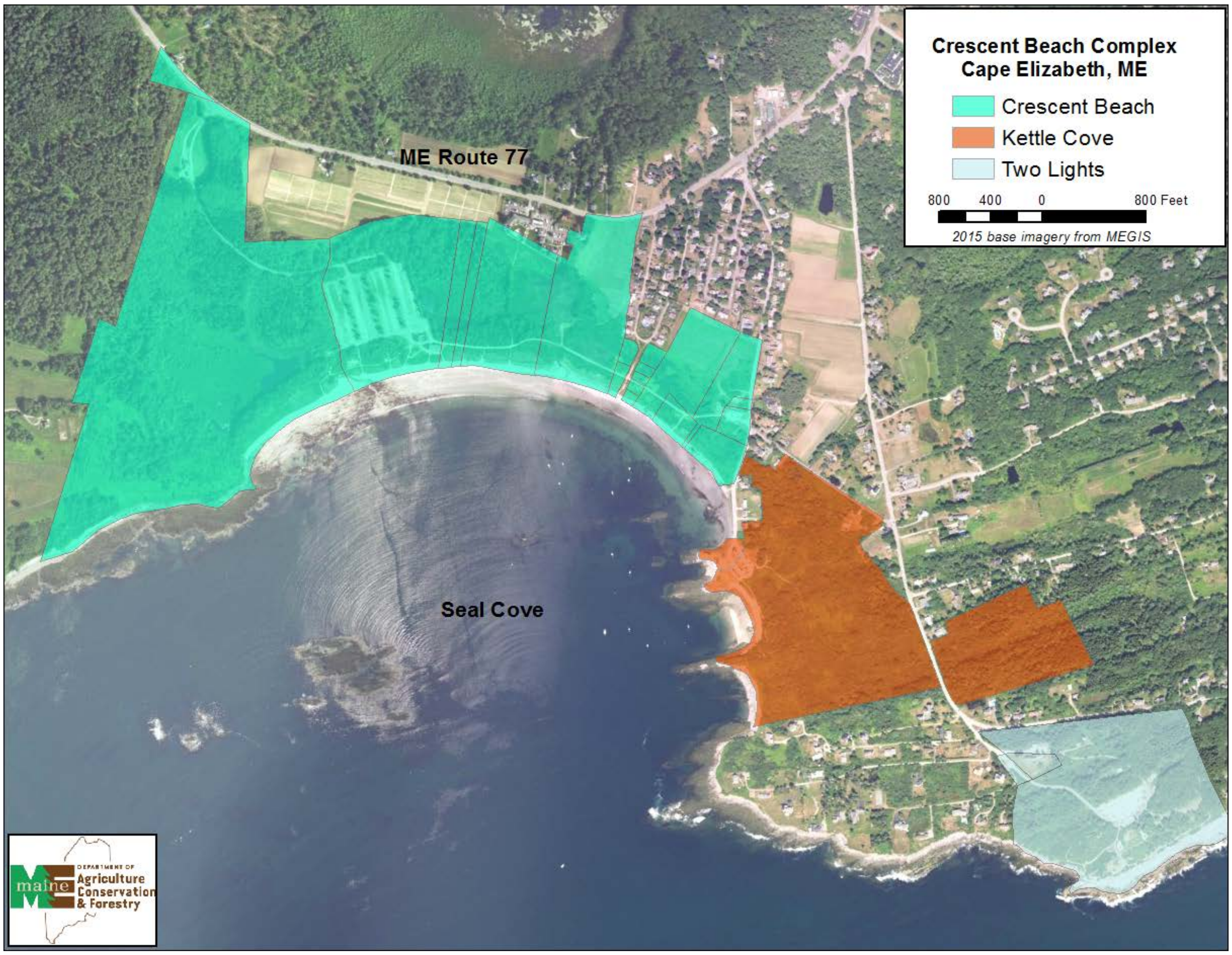


Figure D-1. Properties of the Crescent Beach Complex include Crescent Beach State Park, Kettle Cove State Park, and Two Lights State Park.

Crescent Beach State Park **–** This park, comprised of 20 separate parcels totaling approximately 183 acres, is located along a relatively sheltered bay in the south part of the town of Cape Elizabeth. It includes a pocket beach approximately 0.8 miles in length, bound by rocky headlands and uplands to the east and west, privately farmed uplands and ME Route 77 to the north, and Seal Cove to the south. Based on 2004 data, Crescent Beach was the sixth most-visited park in Maine, with approximately 72,000 visitor days (Morris and others, 2006). The property is comprised of pitch pine woodland, freshwater and tidal wetland, dune, and beach habitats. Mapped dunes on the property average around 80-100 meters in width, divided evenly between front and back dunes.

Major built assets within the park include an 8.2 acre gravel parking lot, an approximate 700 m mixed paved-gravel access road, a bath house with flush toilets, snack bar, pump station, numerous trails and picnic tables, several culverts, a maintenance garage facility, and a gravel maintenance road. Access to the park is via ME Route 77 to the north. Crescent Beach State Park is vulnerable to shoreline erosion and inundation from coastal storms or sea level rise (Figure D-2).

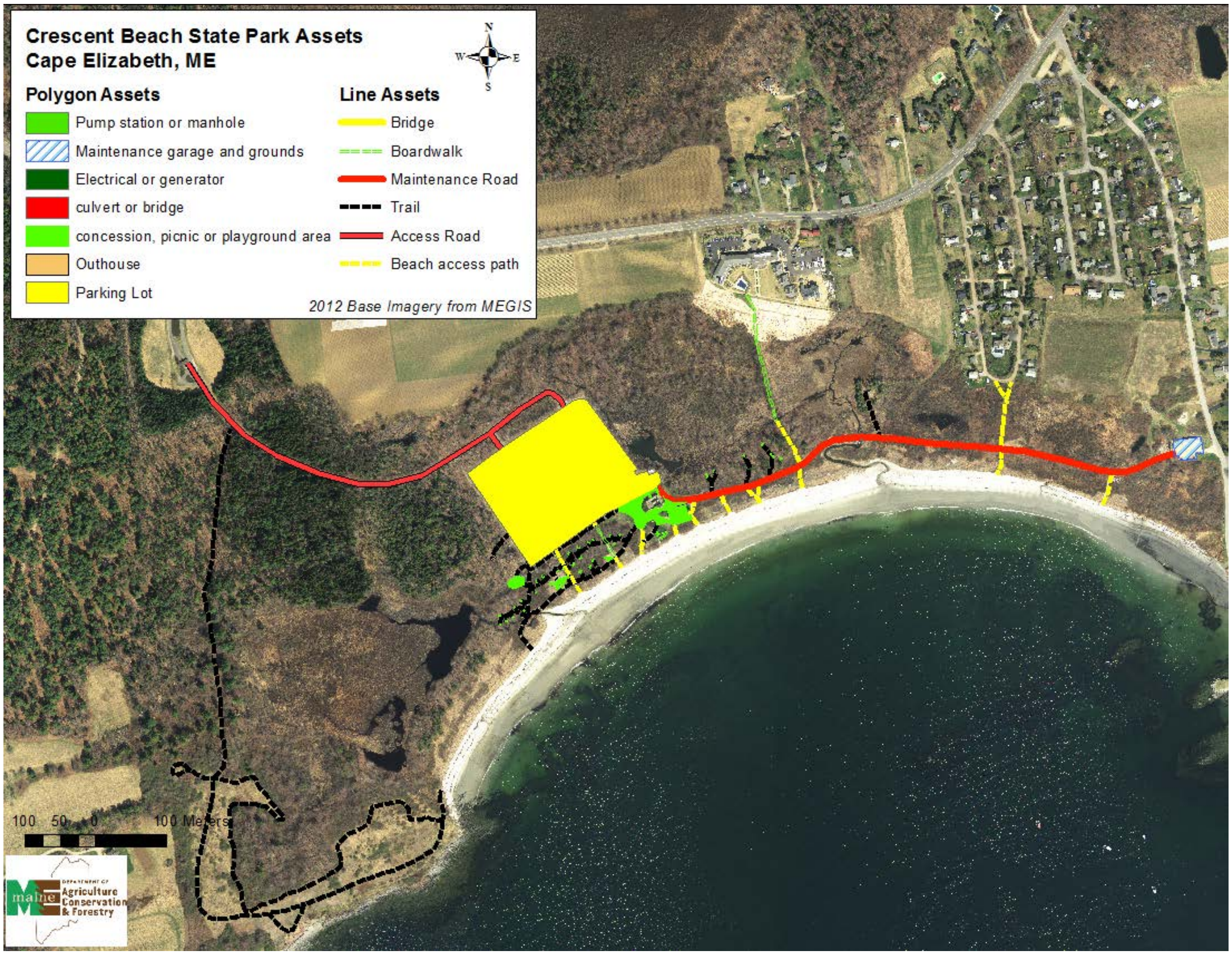


Figure D-2. Major assets of Crescent Beach State Park.

Long-term Shoreline Change Analyses – Analysis of shorelines from 1964 to 2014 showed stability to slight growth in the central portion of the beach, to slight recession (less than a foot per year) of the shoreline at its eastern and western ends. Overall, the shoreline had an average rate of +0.5 feet per year (Figure D-3). Thus, potential future shoreline positions in 50 years showed no negative impacts to infrastructure.

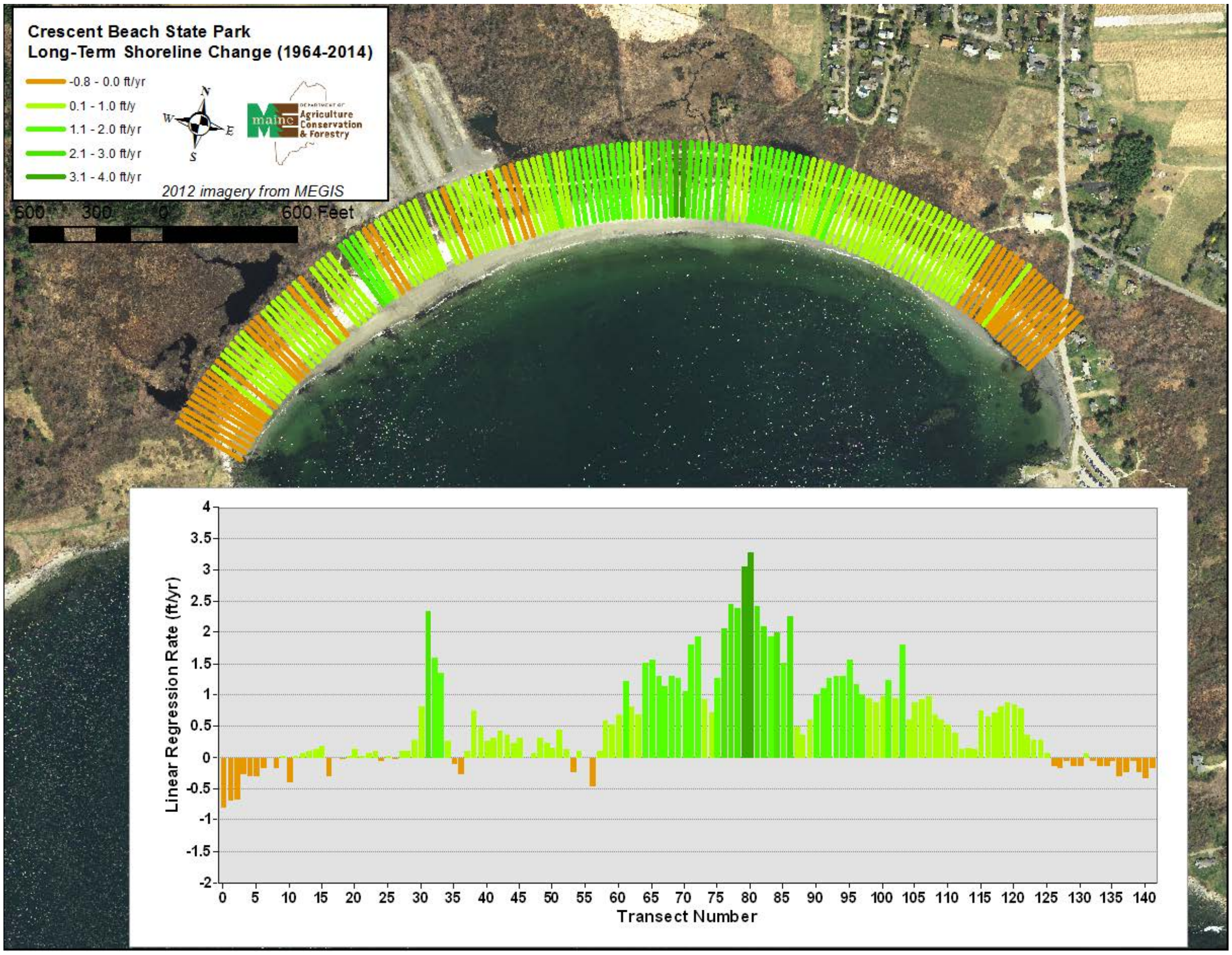


Figure D-3.. Long-term shoreline change data at Crescent Beach State Park.

Short-term Shoreline Change Analyses – Shoreline data from 2007 to 2014 indicated that the shoreline was slightly more erosive in several sections, namely nearest the small tidal channels that tend to meander along the beach, but that overall, the beach was stable to slightly accretive (Figure D-4). Potential future 10-year shoreline positions do not appear to impact any infrastructure.

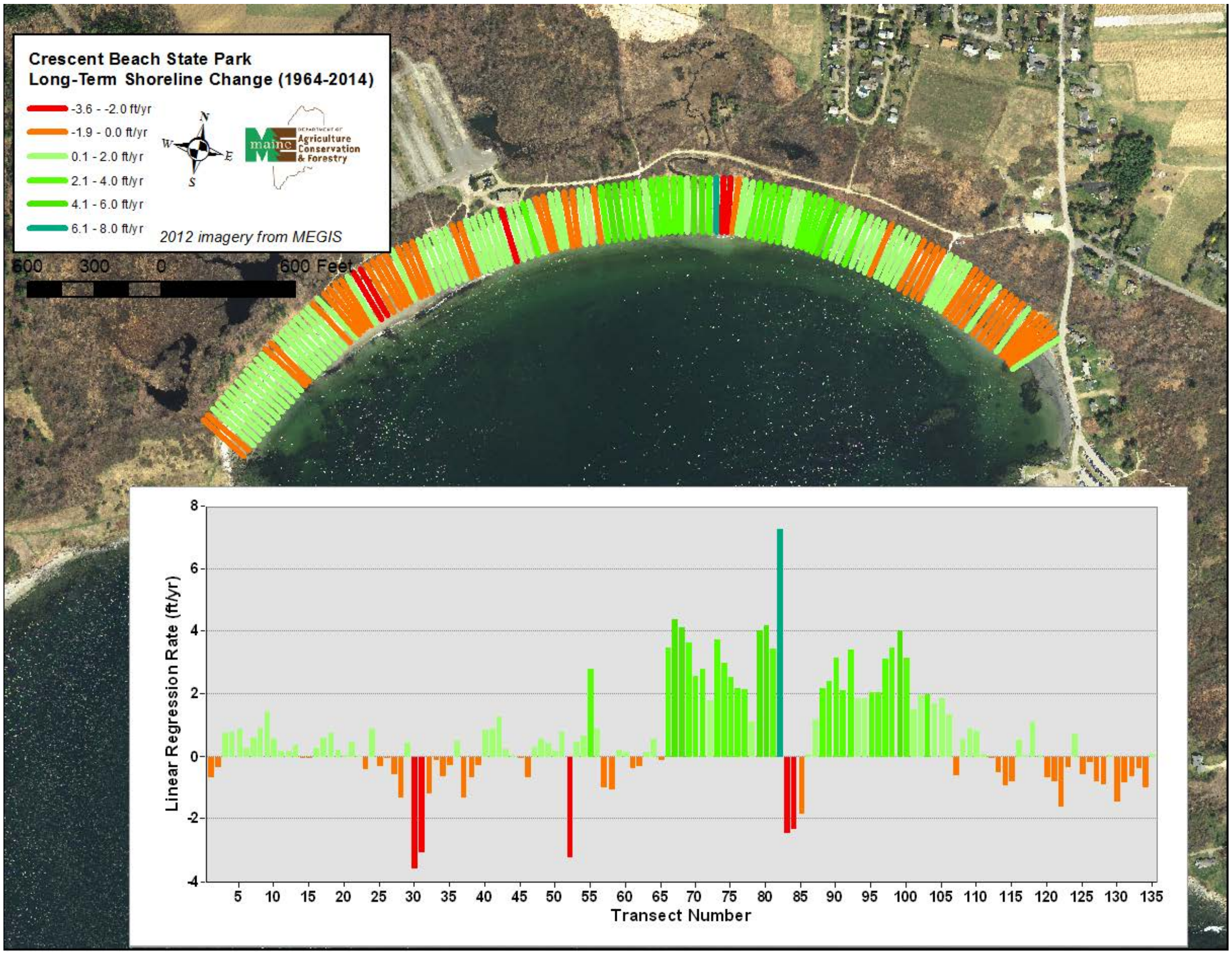


Figure D-4. Short-term shoreline change data at Crescent Beach State Park.

Inundation Analyses – Many assets at Crescent Beach State Park appear to be at risk to inundation – mainly due to tidally connected wetlands that are currently managed through three small culverts. Based on preliminary DFIRMs, significant areas of the property are mapped as AE zones, including the maintenance road, almost half of the parking lot, and numerous recreational facilities. The maintenance road which traverses the property and connects Crescent Beach State Park with Kettle Cove appears to be most at-risk to lower levels of storm surge and sea level rise. Key utilities (electrical, pumps, etc.) are at risk under the highest scenario of storm surge or sea level rise, and under a Category 2 hurricane. The bath house and concession building appear relatively well protected except under the highest scenario. See Figures D-5 to D-7 and Table D-1.

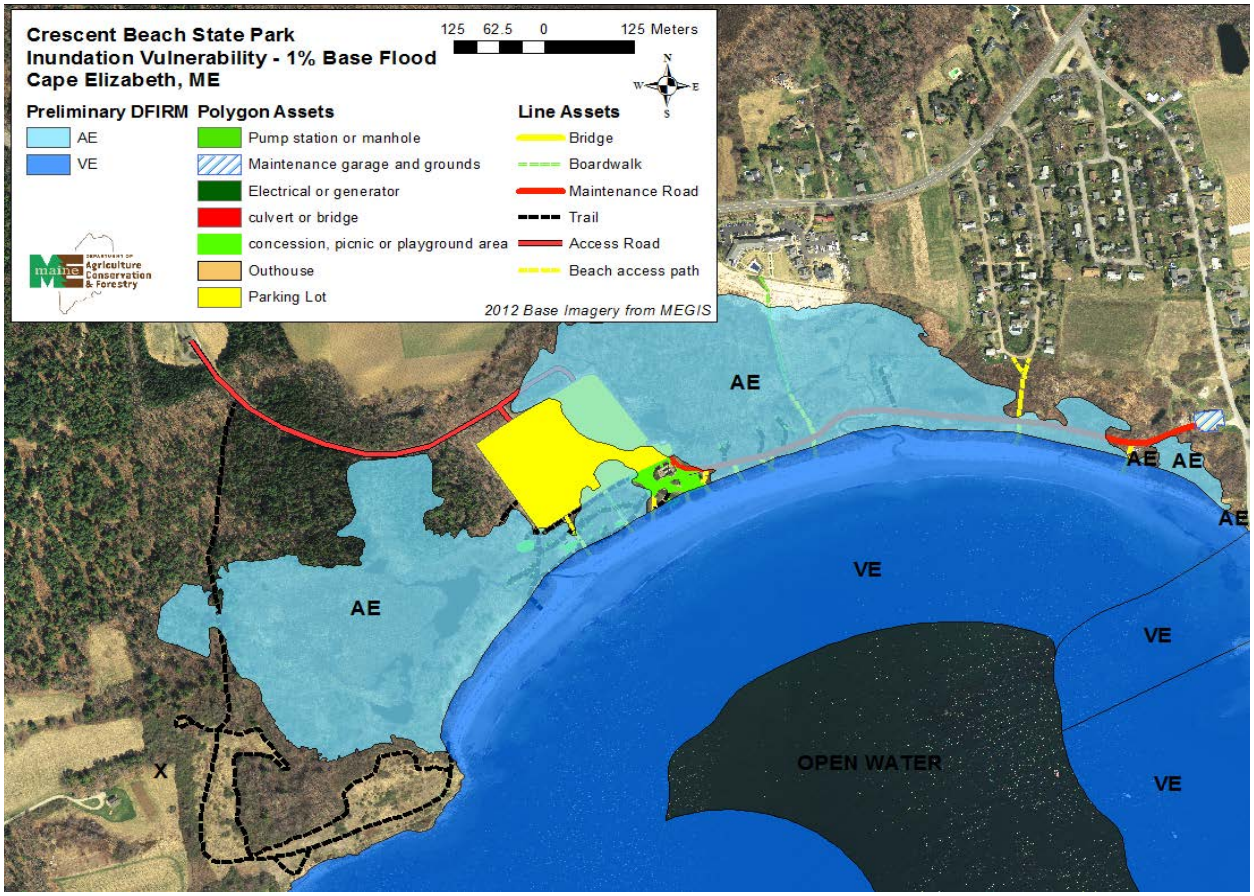


Figure D-5. Asset vulnerability to the 1% base flood elevations at Crescent Beach State Park. Note potential impacts to maintenance road and parking lot.

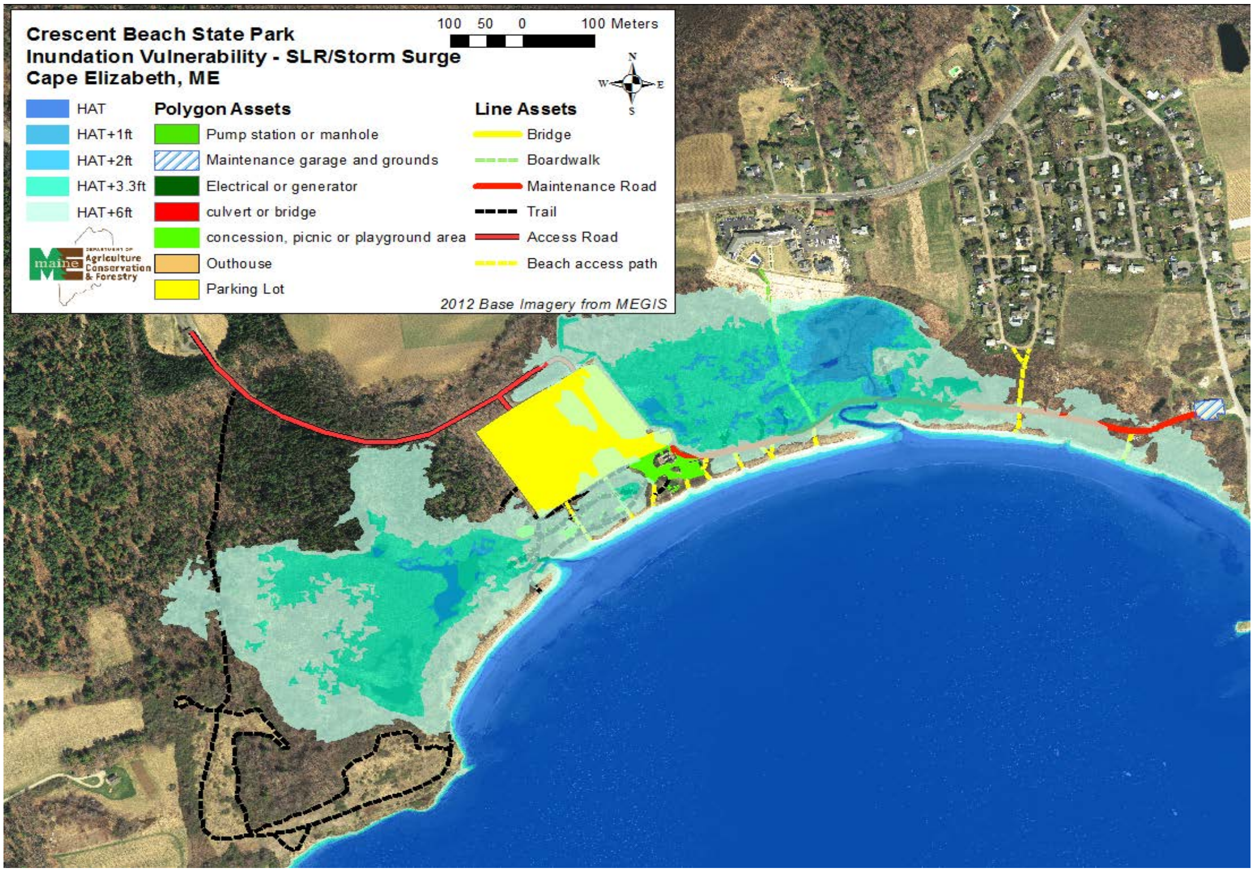


Figure D-6. Asset vulnerability to sea level rise and storm surge scenarios at Crescent Beach State Park. Note potential impacts to maintenance road and parking lot.

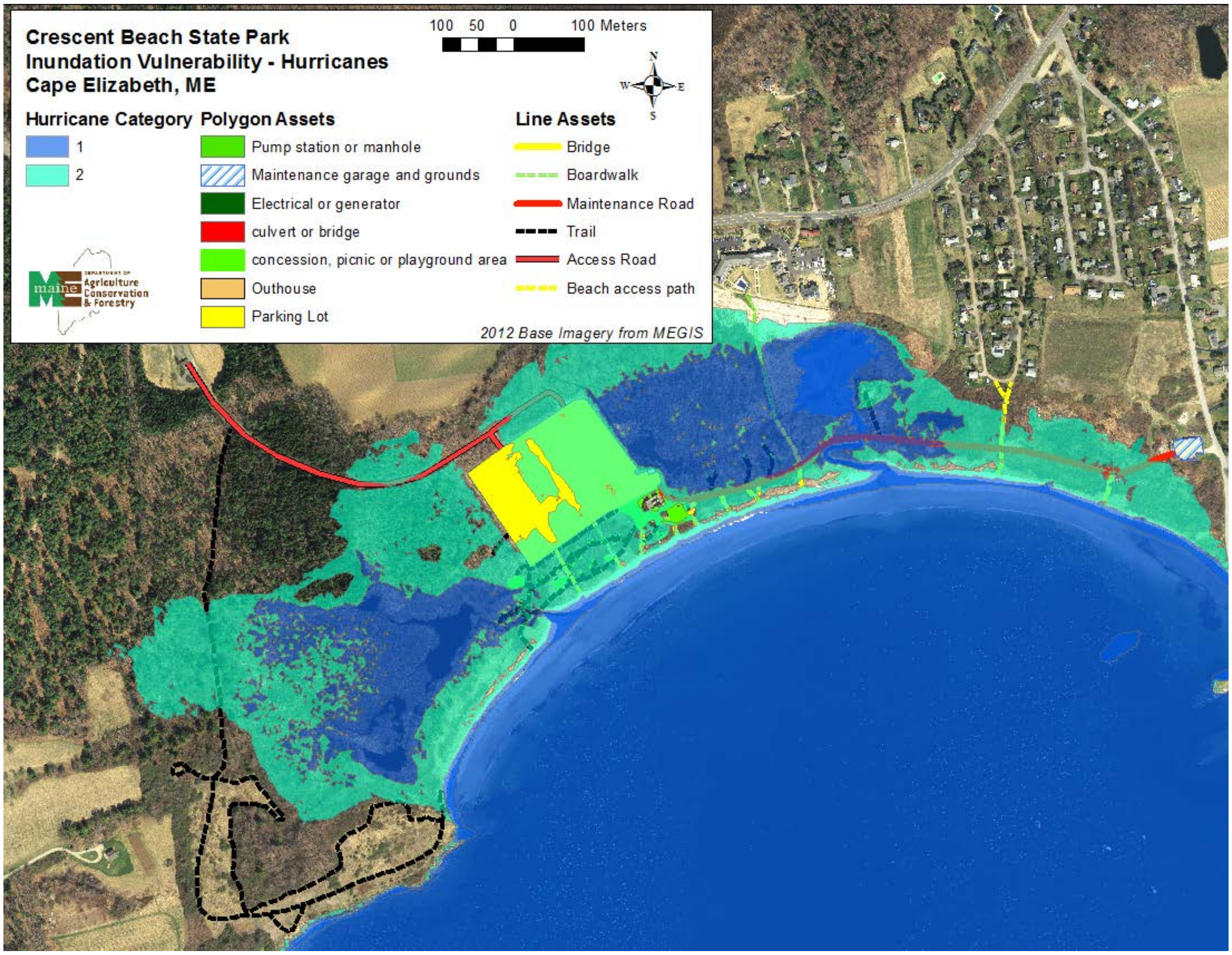


Figure D-7. Asset vulnerability to hurricanes at Crescent Beach State Park. Note potential impacts to maintenance road and parking lot.

Coastal Sand Dunes – Many assets at the park are located within the mapped sand dune system (Figure D-8) and the erosion hazard area, and also within the CBRS ME-19 and ME-19P (Table D-1). Potential adaptation strategies for park assets are provided in Table D-2.

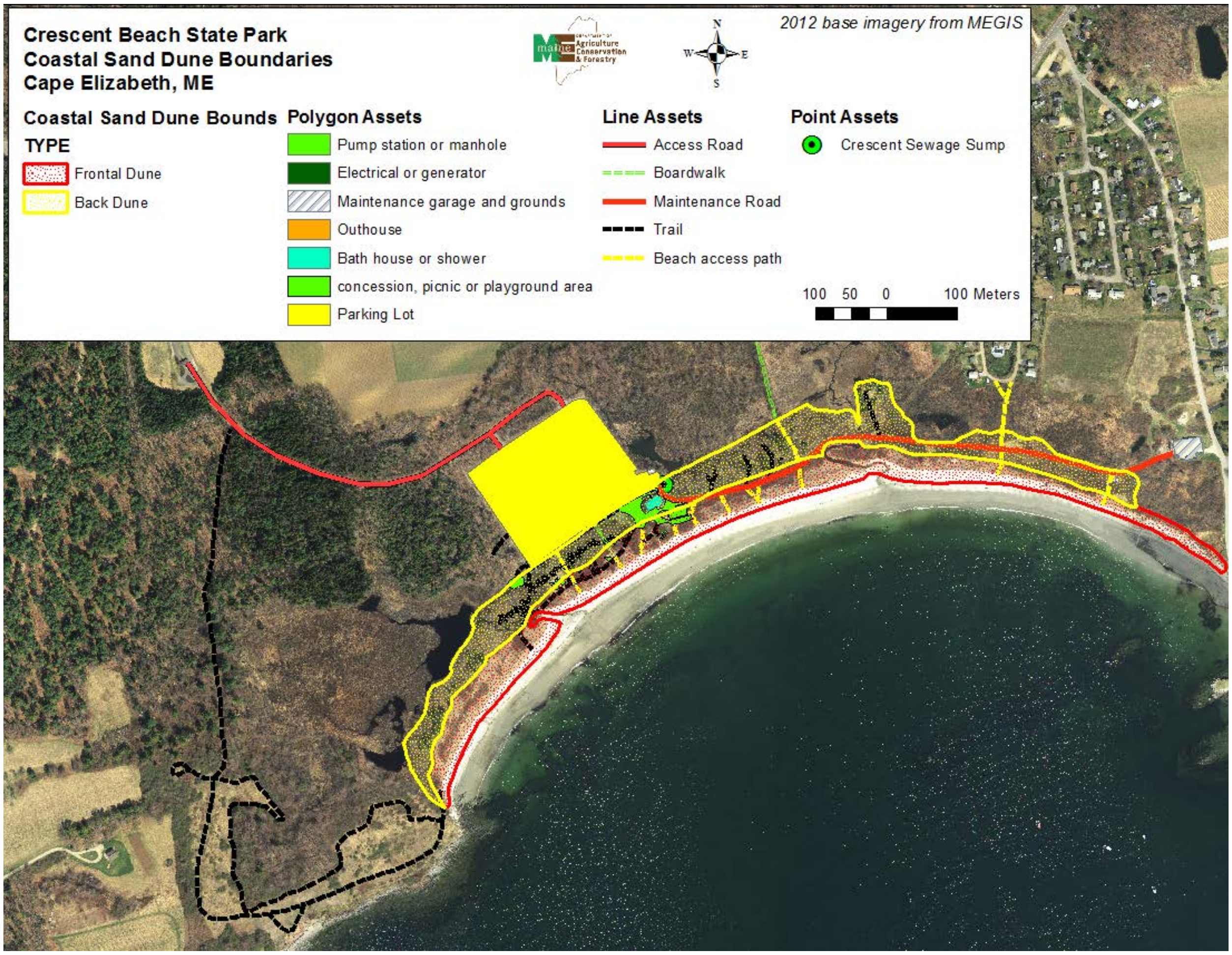


Figure D-8. Locations of infrastructure assets in reference to mapped Coastal Sand Dune boundaries.

Historic Resources – The State Historic Preservation Office identified four prehistoric resources at the property that are eroding. No map was provided. Protection strategies would include erosion control or recovery via archaeological excavation.

Property	Asset	Mean Elev* (ft NAVD)	Length, area or Number	Mapped Flood Zone (Preliminary)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**							Shoreline Changes	
					D1	D2	EHA	CBRS	HAT (6.8ft)	HAT+1 (7.8ft)	HAT+2 (8.8 ft)	CAT1 (9.7 ft)	HAT+3.3 (10.1 ft)	HAT+6 (12.8 ft)	CAT2 (13.7 ft)	10 year ST Trend	50 year LT Trend
Crescent Beach	Culverts	varies	3	AE(12) - 100%	33%	33%	67%	ME-19, 19P			33%	100%	100%	100%	100%		
	Maintenance road	10.6	768 m	AE(12) - 78%	20%	70%	63%	ME-19P			2%	33%	33%	78%	95%		
	Recreational - trails	varies	3320 m	AE(12) - 34%	12%	23%	29%	ME-19, 19P			2%	6%	9%	35%	42%		
	Recreational - boardwalks	varies	238 m	AE(12) - 80%	8%	14%	18%	ME-19P				34%	35%	78%	82%		
	Recreational - picnic tables	varies	57	AE(12) - 96%	41%	59%	86%	ME-19, 19P				16%	29%	73%	100%		
	Recreational - beach paths	varies	578 m	AE(12) - 64%	51%	31%	60%	ME-19, 19P				13%	12%	44%	80%		
	Recreational - grills	varies	24	AE(12) - 100%	25%	75%	79%	ME-19, 19P				4%	30%	100%	100%		
	Sewage sump	11.5	N/A			100%		ME-19P						100%	100%		
	Recreational areas - picnic, play	varies	N/A	AE(12) - 100%	50%	50%	100%	ME-19, 19P						100%	100%		
	Parking lot	12.8	8.1 ac	AE(12) - 33%		0.1%		ME-19P						29%	60%		
	Access road	24.3	671	AE(12) - 14%										6%	20%		
	Pump station	13.1	N/A			100%	100%	ME-19P							100%		
	Recreational - outhouses	N/A	2	AE(12) - 100%				ME-19							100%		
	Electrical	14.0	0.008 ac		87%	13%	100%	ME-19P							75%		
	Concession building	12.5	0.091 ac		80%	20%	100%	ME-19P							7%		
	Bath house	12.5	0.086 ac			100%	100%	ME-19P							0.2%		
	Maintenance garage	21.0	0.054 ac														
	Maintenance grounds	20.3	0.21 ac														
	Maintenance access	21.0	0.04 ac														

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

(green)	Not present or not inundated (0%)
(yellow)	Minimally present or inundated (<25%)
(orange)	Moderately present or inundated (25-50%)
(red)	Extremely present or inundated (>50%)

Table D-1. Asset vulnerability at Crescent Beach State Park. Note the number of assets located within the mapped (preliminary) flood zone and the regulated coastal sand dune system.

Property	Impacted Asset	Flood Zone	Dune System	CBRS Unit	Hazard or Scenario	Potential Impact	Protection Strategy	Accomodation Strategy	Retreat Strategy	Park Operations Strategy	Notes
Crescent Beach	Maintenance road	AE(12)	D1, D2	ME-19P	2 ft of SLR/SS or more; Cat 1 or 2	flooding	temporary protection	allow flooding; alternate route	relocate	temporary protection; consider alternate routes	
	Access road	AE(12)	N/A	N/A	6 ft or more SLR/SS; Cat 1 or 2	flooding	temporary protection	allow flooding; alternate route	relocate	temporary protection; consider alternate routes	
	Parking lot	AE(12)	D2	ME-19P	6 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, dune and beach restoration, wall	allow flooding	relocate	temporary protection	
	Electric generator	N/A	D1	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	green infrastructure, dune and beach restoration	elevate	relocate	temporary protection	
	Pump station	N/A	D2	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	wall, floodproofing	elevate	relocate	temporary protection	
	Sewage sump	N/A	D2	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	wall, floodproofing	elevate	relocate	temporary protection	
	Bath house	N/A	D2	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	floodproofing	elevate	relocate	temporary protection	
	Concessions building	N/A	D1, D2	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	floodproofing	elevate	relocate	temporary protection	
	Culverts	AE(12)	D2	ME-19, 19P	2 ft of SLR/SS or more; Cat 1 or 2	flooding	N/A	increase culvert size	relocate	consider resizing	
	Trails	AE(12); VE(14)	D2	ME-19, 19P	2 ft of SLR/SS or more; Cat 1 or 2	flooding	green infrastructure, dune and beach restoration	N/A	relocate	allow flooding; limit use	
	Beach access paths	AE(12); VE(14)	D1, D2	ME-19, 19P	3 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, dune and beach restoration	allow flooding	relocate	allow flooding; limit use	
	Boardwalks	AE(12)	D1, D2	ME-19P	3 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, dune and beach restoration	allow flooding; elevate	relocate	remove during events	
	Picnic tables and grills	AE(12)	D1, D2	ME-19, 19P	3 ft or more SLR/SS; Cat 1 or 2	flooding	green infrastructure, dune and beach restoration	allow flooding	relocate	move during events	
	picnic area, playground area, pavilion	AE(12)	D1, D2	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	green infrastructure, dune and beach restoration	floodproof	relocate	temporary protection	
	Outhouses	AE(12)	N/A	ME-19	Cat 2	flooding	green infrastructure, dune and beach restoration	elevate	relocate	temporary protection	

Table D-2. Potential asset adaptation at Crescent Beach State Park.

Kettle Cove State Park **–** Kettle Cove, located directly east of Crescent Beach, is comprised of 2 separate parcels totaling 68 acres. Access is via Ocean House Road from ME Route 77. In 2004, Kettle Cove had approximately 48,000 visitor days (Morris and others, 2006). It includes two small pocket beaches with approximately 0.2 miles of sandy shoreline. Habitats include freshwater wetland, upland forest, and sandy dunes and beaches. Its relatively narrow dunes (10-20 meters in width) are backed by freshwater wetlands. The only built assets include a 0.6 acre paved parking lot, a small walking bridge, several boardwalks and trails, benches, and two outhouses (Figure D-9).

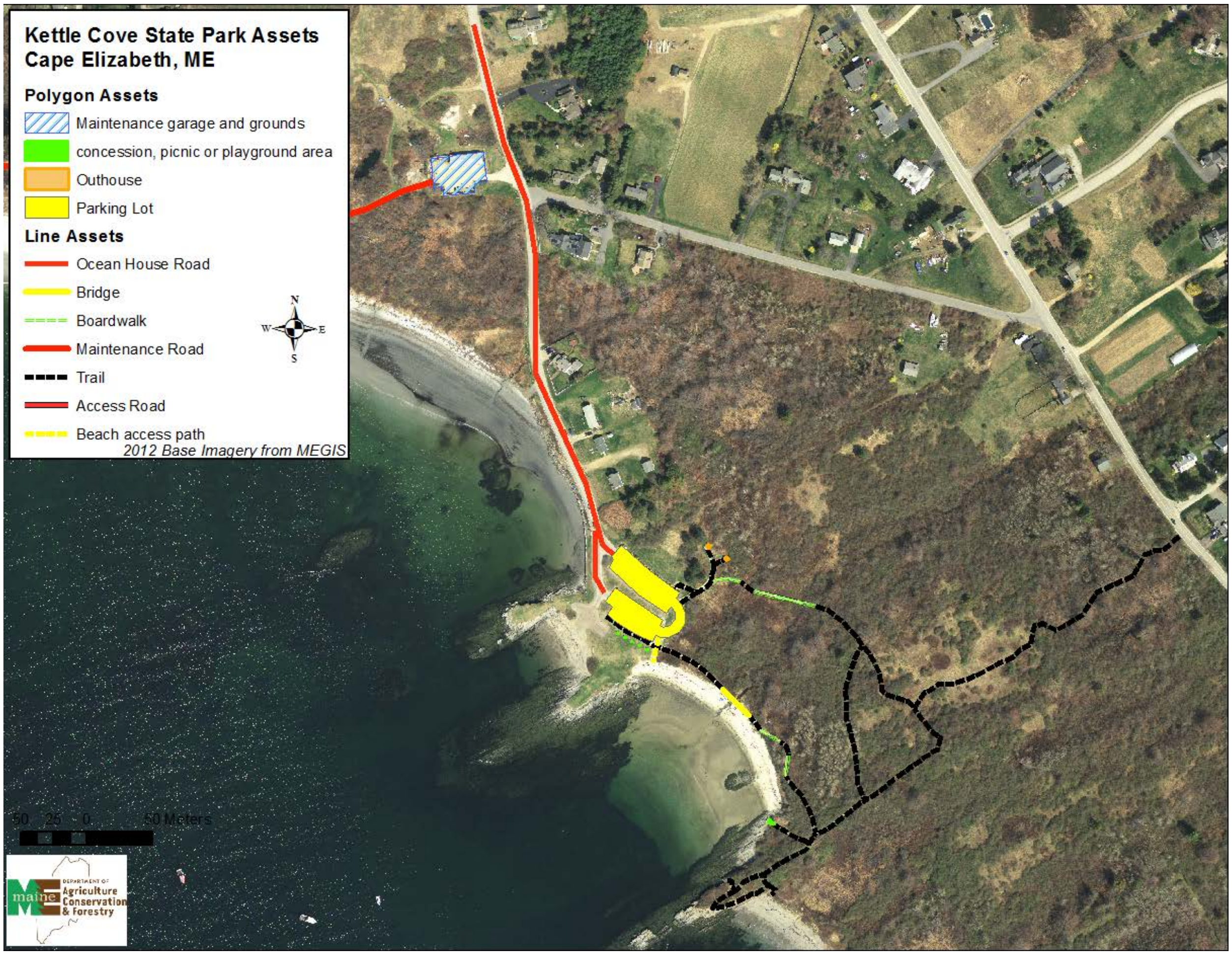


Figure D-9.. Locations of infrastructure assets at Kettle Cove State Park.

Long-term Shoreline Change Analyses – Analysis of historic shorelines from 1964 to 2014 showed slight erosion at the central portion of the main pocket beach at Kettle Cove, nearest the small bridge, where the shoreline receded at a rate of about -0.3 feet per year. Otherwise, the shoreline was stable. The potential future 50 year shoreline position showed increased erosion into this bridged area, otherwise there were no impacts to other infrastructure. No figure is included.

Short-term Shoreline Change Analyses – Shorter-term data indicated that the overall shoreline was stable to slightly accretive, with a mean value of +0.4 feet per year. However, the shoreline on either side of the bridge showed erosion, averaging about -0.5 feet per year. Once again, potential future shoreline changes indicate that the bridge is at risk to future erosion. No figure is included.

Inundation Analyses – Kettle Cove is at-risk to inundation based on preliminary flood hazard information – the majority of the park assets are mapped within the 100-year floodplain, both AE and VE zones (Figure D-10a). This includes a section of Ocean House Road (which provides access to the site), the majority of the parking, lot, large portions of boardwalks and trails, and the two outhouses. Static sea level rise scenarios place very little at direct risk of inundation except under the 6 foot scenario (Figure D-10b). Interestingly, SLOSH mapping indicates similar risk for infrastructure under a Category 2 hurricane as the existing 1% floodplain (Figure D-10c). Overall vulnerabilities are shown in Table D-3.

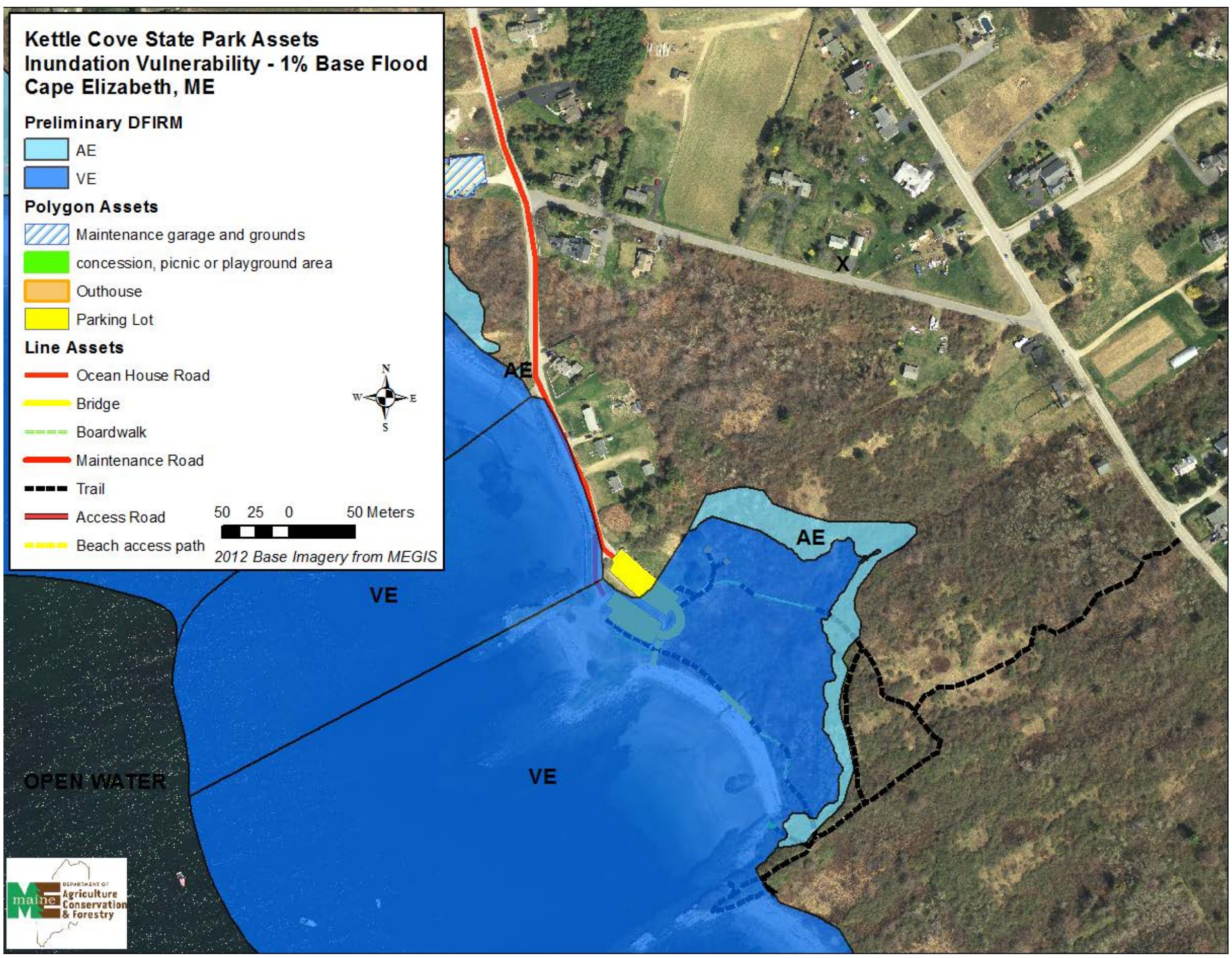


Figure D-10a. Asset vulnerability at Kettle Cove State Park to the 1% base flood.

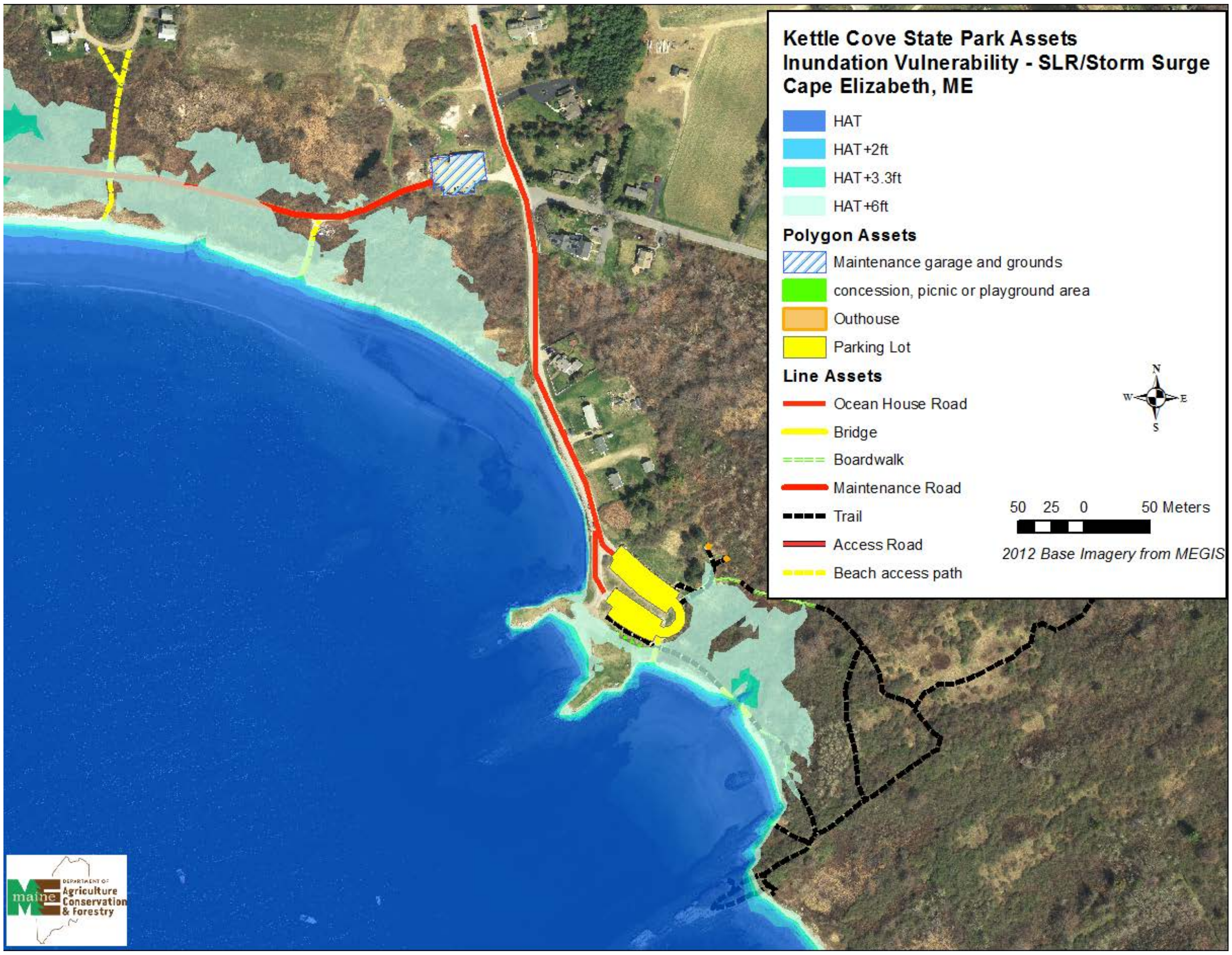


Figure D-10b. Asset vulnerability at Kettle Cove State Park to sea level rise and/or storm surge scenarios.

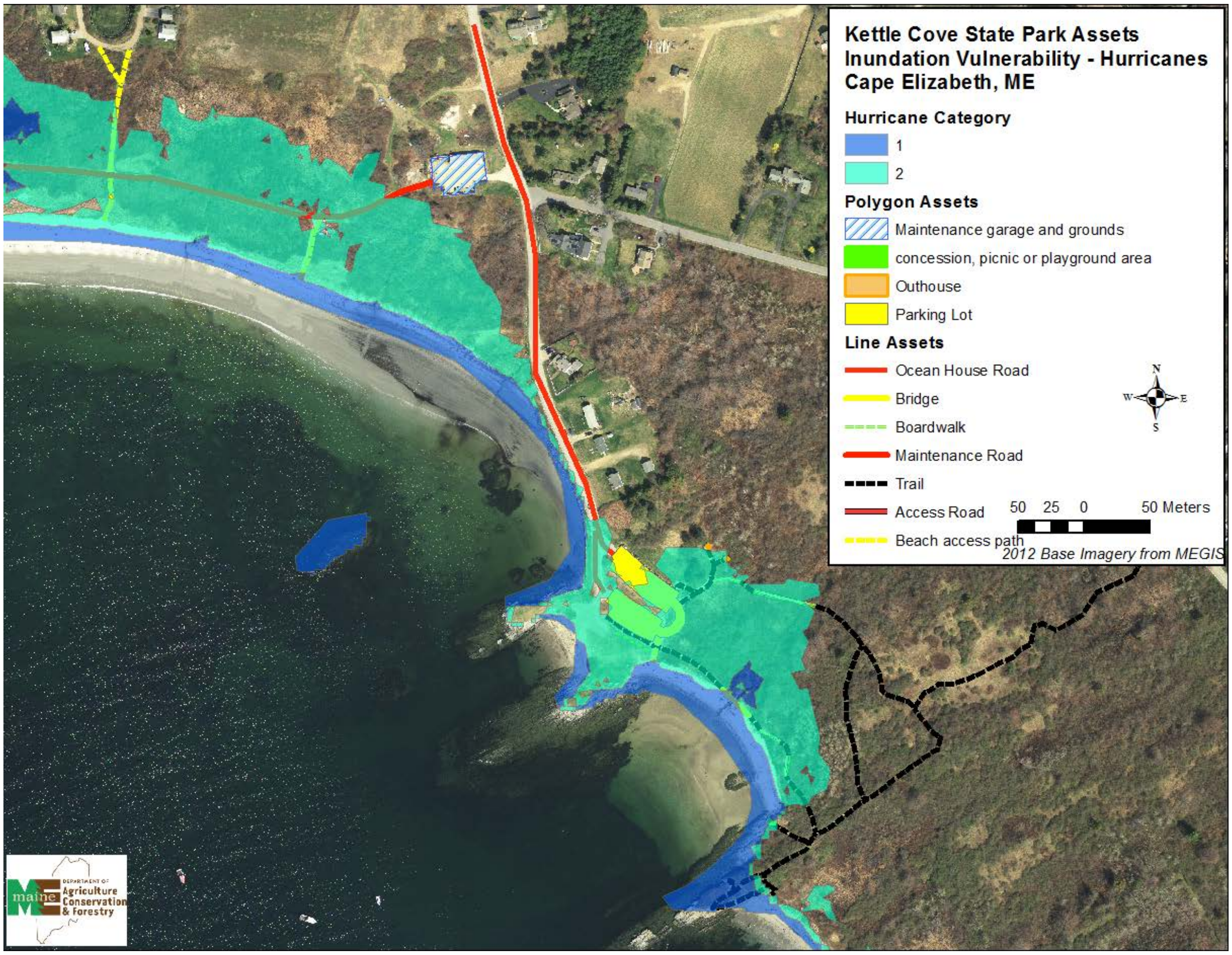


Figure D-10c. Asset vulnerability at Kettle Cove State Park to hurricanes. Ocean House Road, which provides access to the park, is at risk, as is the parking lot and numerous trails.

Coastal Sand Dunes – At Kettle Cove, very few assets are located within the mapped sand dune system aside from the bridge and portions of the boardwalk. However, several assets are located within the CBRS ME-19P. No figure is included, refer to Table D-3. Table D-4 provides adaptation strategies for assets at Kettle Cove.

Property	Asset	Mean Elev* (ft NAVD)	Length, area or Number	Mapped Flood Zone (Preliminary)	Coastal Sand Dunes				Sea Level Rise/Storm Surge/SLOSH**							Shoreline Changes	
					D1	D2	EHA	CBRS	HAT (6.8ft)	HAT+1 (7.8ft)	HAT+2 (8.8 ft)	CAT1 (9.7 ft)	HAT+3.3 (10.1 ft)	HAT+6 (12.8 ft)	CAT2 (13.7 ft)	10 year ST Trend	50 year LT Trend
Kettle Cove	Bridge	varies	28 m	VE(19) - 100%	100%		100%			18%	21%	57%	32%	100%	100%	100%	100%
	Recreational - trails	varies	1140 m	VE(19), AE(19) - 39%	4%		4%			7%	7%	7%	7%	21%	31%		
	Recreational - platform	9.5	N/A	VE(19) - 100%								50%	100%	100%	100%		
	Recreational - beach paths	varies	21 m	VE(19) - 100%								14%		71%	100%		
	Recreational - benches	varies	5	VE(19) - 100%										40%	100%		
	Recreational - boardwalks	varies	102 m	VE(19), AE(19) - 100%	22%		22%	ME-19P						34%	94%		
	Parking Lot	13.1	0.55 ac	VE(19) - 70%				ME-19P							76%		
	Outhouse 1	13.5	N/A	VE(19) - 100%				ME-19P							50%		
	Ocean House Road	18.4	440 m	VE(16) - 33%				ME-19P							11%		
	Outhouse 2	14.1	N/A	VE(19) - 100%				ME-19P									

Notes:

** derived from mean elevation of the entire asset*

*** SLR mapping included low-lying tidally unconnected areas, while SLOSH mapping removed tidally unconnected flooded areas*

LEGEND

Green	Not present or not inundated (0%)
Yellow	Minimally present or inundated (<25%)
Orange	Moderately present or inundated (25-50%)
Red	Extremely present or inundated (>50%)

Table D-3. Asset vulnerability at Kettle Cove State Park. Note all assets are in the preliminary mapped 1% floodplain.

Property	Impacted Asset	Flood Zone	Dune System	CBRS Unit	Hazard or Scenario	Potential Impact	Protection Strategy	Accomodation Strategy	Retreat Strategy	Park Operations Strategy	Notes
Kettle Cove	Bridge	VE(19)	D1	N/A	1 ft or more SLR/SS; Cat 1 or 2	flooding	N/A	allow flooding; alternate route	relocate	remove bridge	
	Bridge	VE(19)	D1	N/A	Erosion 10-year and 50-year	erosion	N/A	allow flooding; alternate route	relocate	remove bridge	
	Trails	VE(19); AE(19)	D1	N/A	min 1-3 ft and Cat 1; 6 ft and Cat 2 sign.	flooding	green infrastructure, dune and beach restoration	allow flooding	relocate	do nothing; reroute	
	Viewing platform	VE(19)	N/A	N/A	2 ft of SLR/SS or more; Cat 1 or 2	flooding	green infrastructure, dune and beach restoration	elevate	relocate	temporary protection	
	Ocean House Road	VE(16)	N/A	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	seawall reconstruction	allow flooding; elevate; close car access	relocate	limit access during event; temporary protection; seawall improvements	need MEDOT
	Parking lot	VE(19)	N/A	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	wall around lot	allow flooding	relocate	temporary protection	
	Outhouses	VE(19)	N/A	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	green infrastructure, dune and beach restoration	allow flooding, close	relocate	temporary protection	
	Boardwalks	VE(19); AE(19)	D1	ME-19P	6 ft or more SLR/SS; Cat 2	flooding	green infrastructure, dune and beach restoration	allow flooding	relocate	remove during events	

Table D-4. Potential adaptation strategies for Kettle Cove State Park.

Habitat Management Considerations at the Crescent Complex

Under current conditions, the Dune Grassland and the New England cottontail habitat are the only significant natural features among the three state parks that require active management, which is already taking place. Signage and judicially placed fencing keep visitors from trampling sensitive dune vegetation. Other near term activities that could benefit sensitive features at the park includes:

- Periodic monitoring for pests and invasive species, particularly in the Dune Grasslands and the Brackish Saltmarsh. The Dune Grasslands currently have some areas colonized by the coastally invasive rugosa rose. This hardy nonnative species can out-compete native dune vegetation to the detriment of the natural habitat. If a practical and effective means to remove it is developed, it would improve the quality and integrity of Dune Grasslands to eradicate it from the site. The Brackish Tidal marsh has some areas dominated by narrow-leaved cat-tail, also a non-native species. This species will not tolerate the full salinity of daily tidal inundation, and will die off as tidal flow increases into the site with rising sea level. It may however, move landward into new areas where brackish conditions develop.
- Periodic monitoring of sensitive areas for impacts from recreational activity, particularly the Dune Grasslands. This community currently receives very little visitor use, but is in close proximity to high numbers of beach users. If usage patterns change to the detriment of the community they should be addressed.
- The New England cottontail habitat at the parks will require periodic maintenance to maintain high stem densities needed by the rabbit for cover. Potential techniques for managing New England cottontail habitat include periodic brushhogging, periodic mowing, fire, and or the selective removal of canopy forming species.
- Park areas not managed specifically for recreation or for New England cottontail will benefit by allowing natural succession and disturbance processes to occur unimpeded. Areas already heavily infested with invasive plant species will likely be limited or slowed in their ability to develop into mature forests.
- Incorporation of information on vulnerable rare species into park planning particularly Piping Plover and New England cottontail.

As noted previously, these State Parks have some of the highest visitation rates, and contain some important and threatened coastal habitats for plants and animals. Some of these habitats are going to change and potentially disappear with sea level rise. Some habitats may be able to adapt by migrating landward as sea level rises, and other more elevated areas may be largely unaffected. Conserving both the environmental and recreational values of these parks will present challenges if predictions regarding sea level rise and coastal storm intensification are correct.

Due to the elevated topography of Two Lights S.P., it will not be significantly impacted by predicted sea level rise in the next 100 years. The rocky headlands that form the interface between the park and the ocean are sufficiently high to accommodate even six feet of sea level rise with no adverse effects to terrestrial habitats within the park.

Kettle Cove S.P. will see significant flooding, especially at the highest investigated scenario of six feet of sea level rise. It will mostly affect the beach and limited dune areas of the two kettle coves. These features will be forced inland, and fortunately, there is no development preventing them from moving. The adjacent area of successional scrubland will shrink, which will decrease the amount of existing habitat available for New England cottontail.

At Crescent Beach S.P., habitats that are unable to adapt to sea level rise including the Pitch Pine Dune Woodland, Brackish Tidal Marsh, and Cattail Marsh may be lost. Other habitats such as beaches and Dune Grasslands may be able to adapt to sea level rise by migrating landward. Along with those changes, new habitats such as Spartina Saltmarsh will likely form in areas formerly occupied by other tidal (Brackish Marsh) and freshwater wetlands. While the mechanics allowing each coastal feature to migrate or to develop new are different, these systems are all similar in that they are confined in their ability to transgress landward by coarse barriers including bedrock outcrops and human development. As previously noted, there is room for landward movement of the beach and dunes where there is low-lying, undeveloped ground, in this case mostly wetlands, and no room where there is upland and development (i.e., the parking lot and other park infrastructure). The future of the Pitch Pine Dune Woodland at Crescent Beach S.P. is very uncertain as it cannot gradually migrate like a beach or dune, and it is already very small and located in a sea level rise inundation zone. The dune that supports it will have to move and then remain static if pitch pine is to become reestablished. Recolonization of pitch pine can be facilitated by planting, or by disturbances that favor it including prescribed fire or scarification.

Coastal dune and wetland systems provide important buffers against storm surges for coastal development. When coastal dune and wetland systems are compromised or lost, the adjacent upland areas and associated development become increasing vulnerable to damage from storms. To reduce the potential for damage and the related costs of repairs, and to allow landward transgression of sensitive dune environments, new park infrastructure should be designed to be adaptable or moveable, or placed in areas where it won't be affected by sea level rise and other climate change impacts.

Invasive Species

Crescent Beach, Kettle Cove, and Two Lights State Parks have significant infestations of invasive plant species, so much so, that there is currently no practical or cost effective way to reduce their impact. Most habitats within these parks have some invasive species. The extensive open meadows, successional fields, successional and maritime shrublands, and early successional forest are mostly heavily infested. The most abundant invasive species are shrubby honeysuckle, Asiatic bittersweet, and black swallowwort (*Cynanchum nigrum*). Black swallowwort is most abundant in Two Lights State Park, where it is found in most habitat types, including the forests. The invasives, Japanese knotweed (*Fallopia japonica*), rugosa rose (*Rosa rugosa*), and multiflora rose (*Rosa multiflora*) are also present and locally abundant but not as ubiquitous and widespread as the aforementioned species. Fortunately, the only rare terrestrial species at these parks, the New England cottontail, seeks refuge in woody invasive species, so long as they provide the right mix of shrubland cover for its survival.

If resources and invasive species management technologies allow, some consideration should be given to limiting the impacts of invasive species in the rare Dune Grassland. Rugosa rose is already abundant at the west end of Crescent Beach and could, overtime spread throughout the Dune Grassland. Invasive shrubby honeysuckle is also capable of colonizing this community type but was not noted there during recent surveys. Periodic monitoring of the Dune Grassland could help prevent the colonization by this species.

Appendix E

Additional Figures Supporting Analysis of Roads and Buildings at the Popham Complex

Figure E-1. Road assets vulnerable to 1% base flood on the Popham Peninsula.

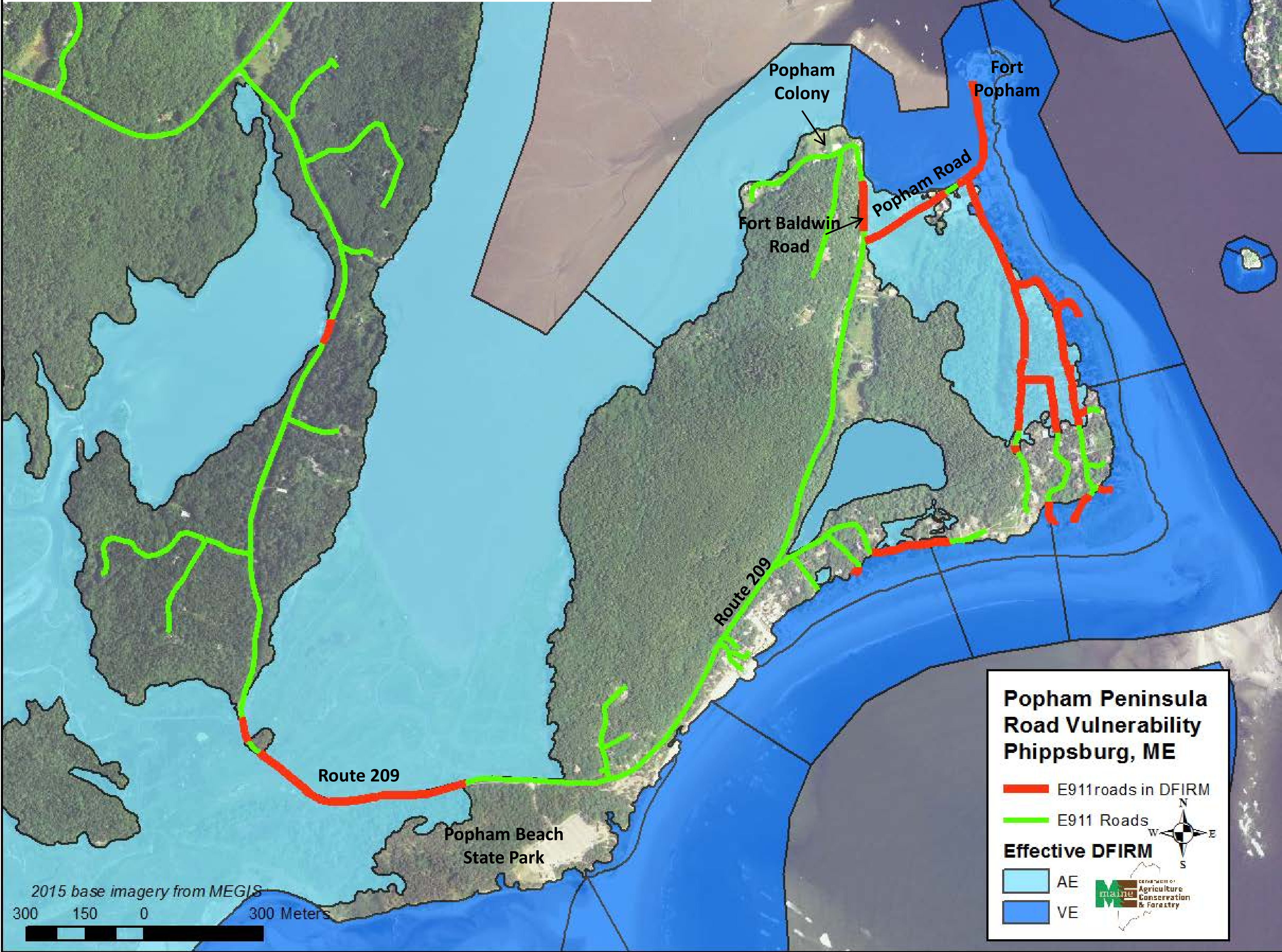


Figure E-2. Road assets vulnerable to sea level rise and/or storm surge on the Popham Peninsula.

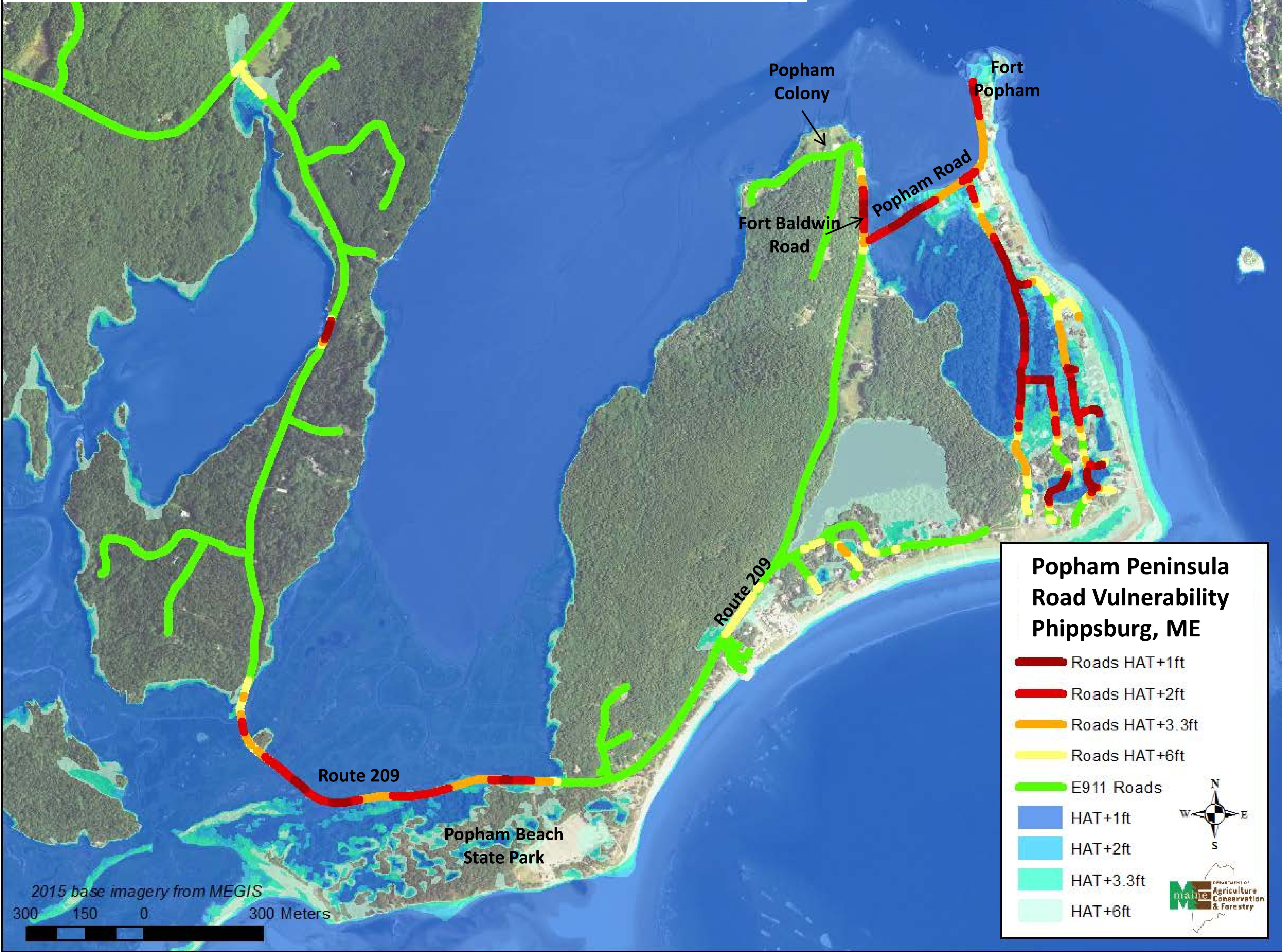
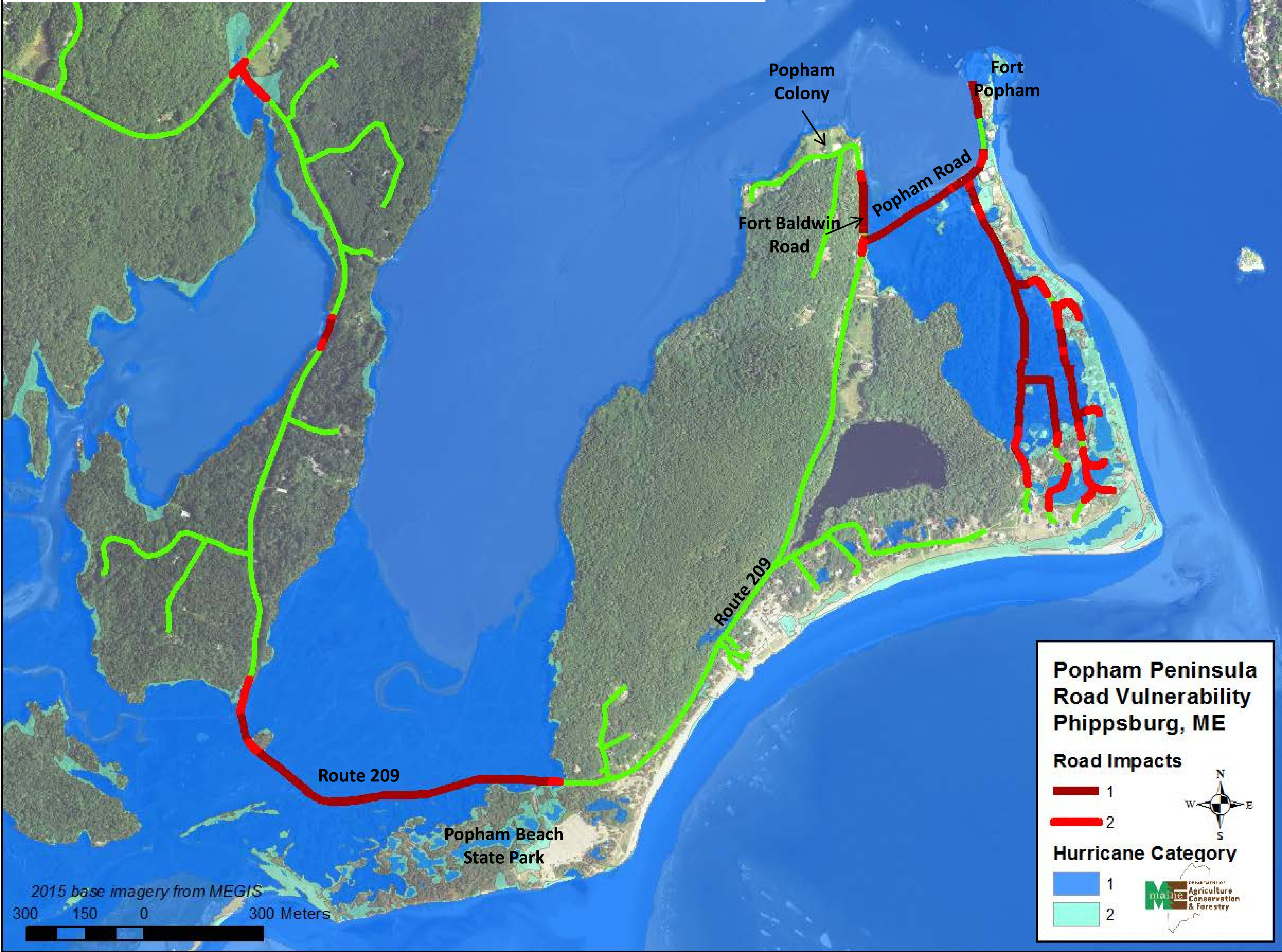


Figure E-3. Road assets vulnerable to Category 1 and 2 hurricanes on the Popham Peninsula.



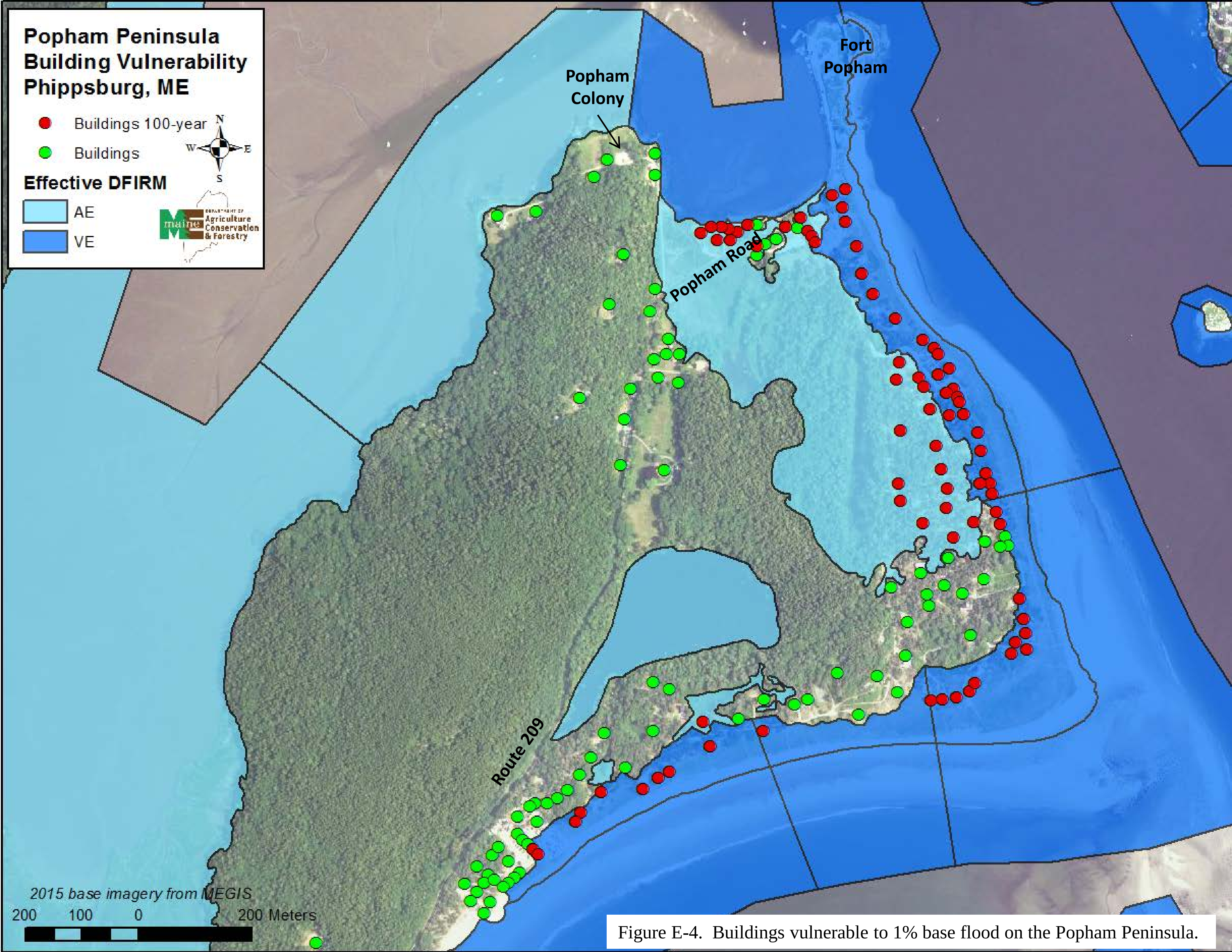


Figure E-4. Buildings vulnerable to 1% base flood on the Popham Peninsula.

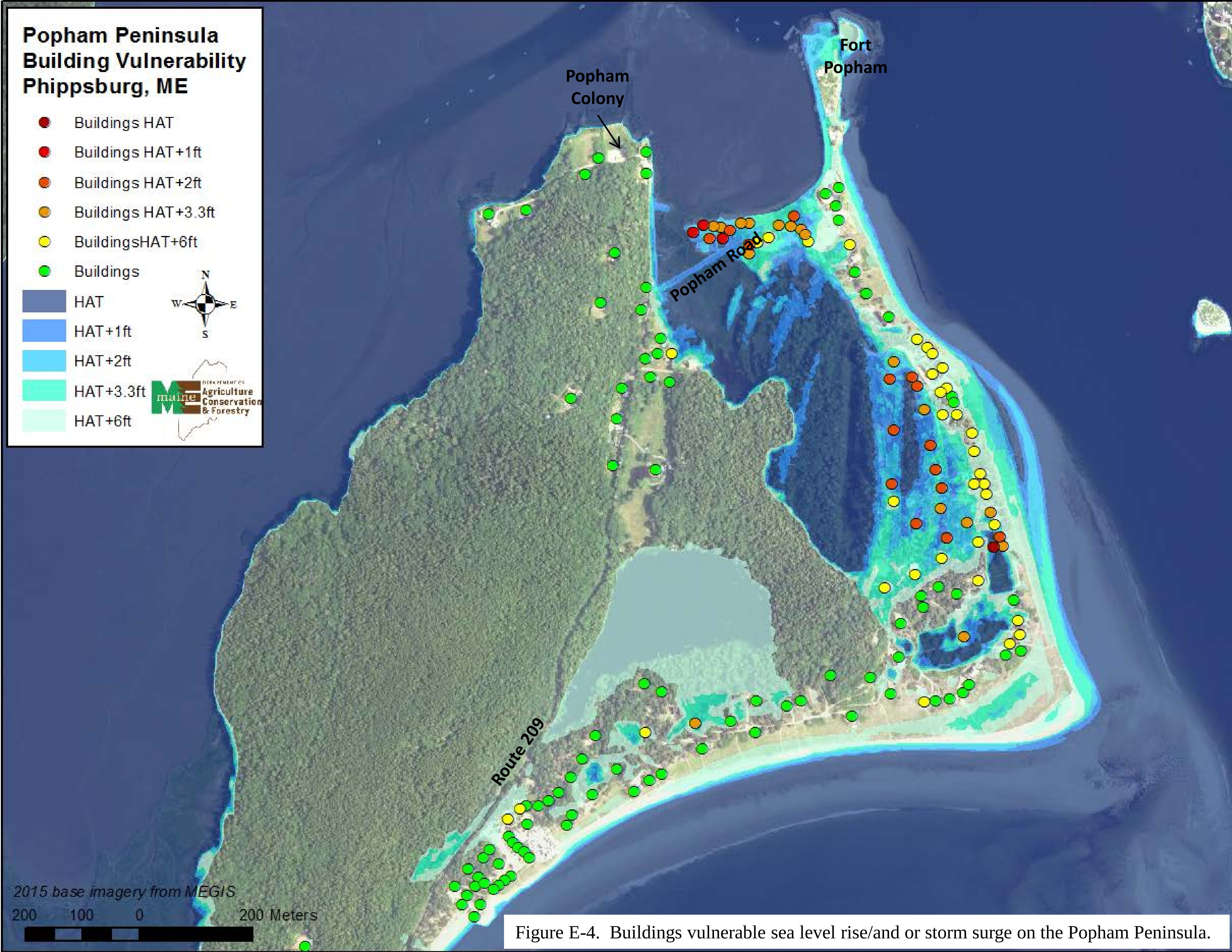


Figure E-4. Buildings vulnerable sea level rise/and or storm surge on the Popham Peninsula.

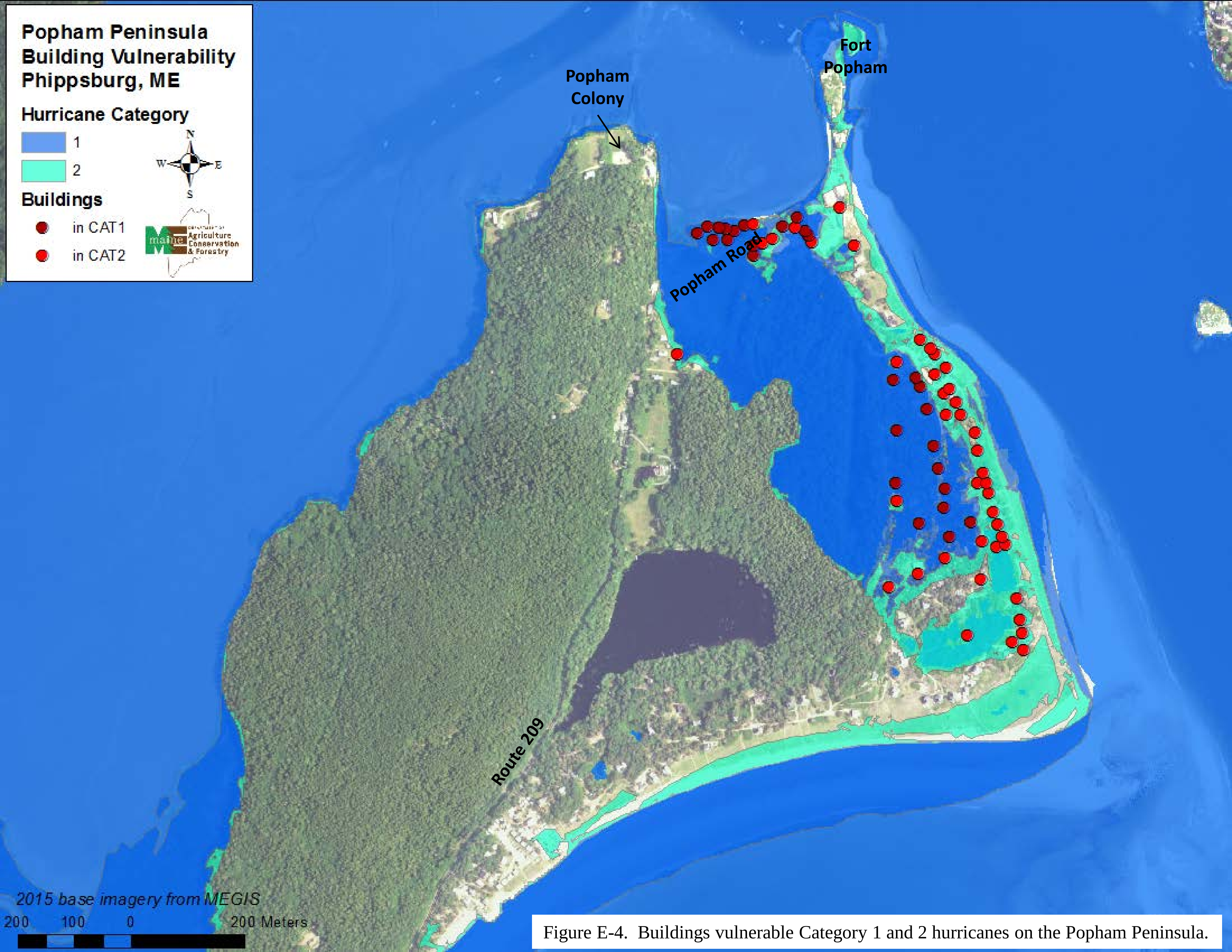
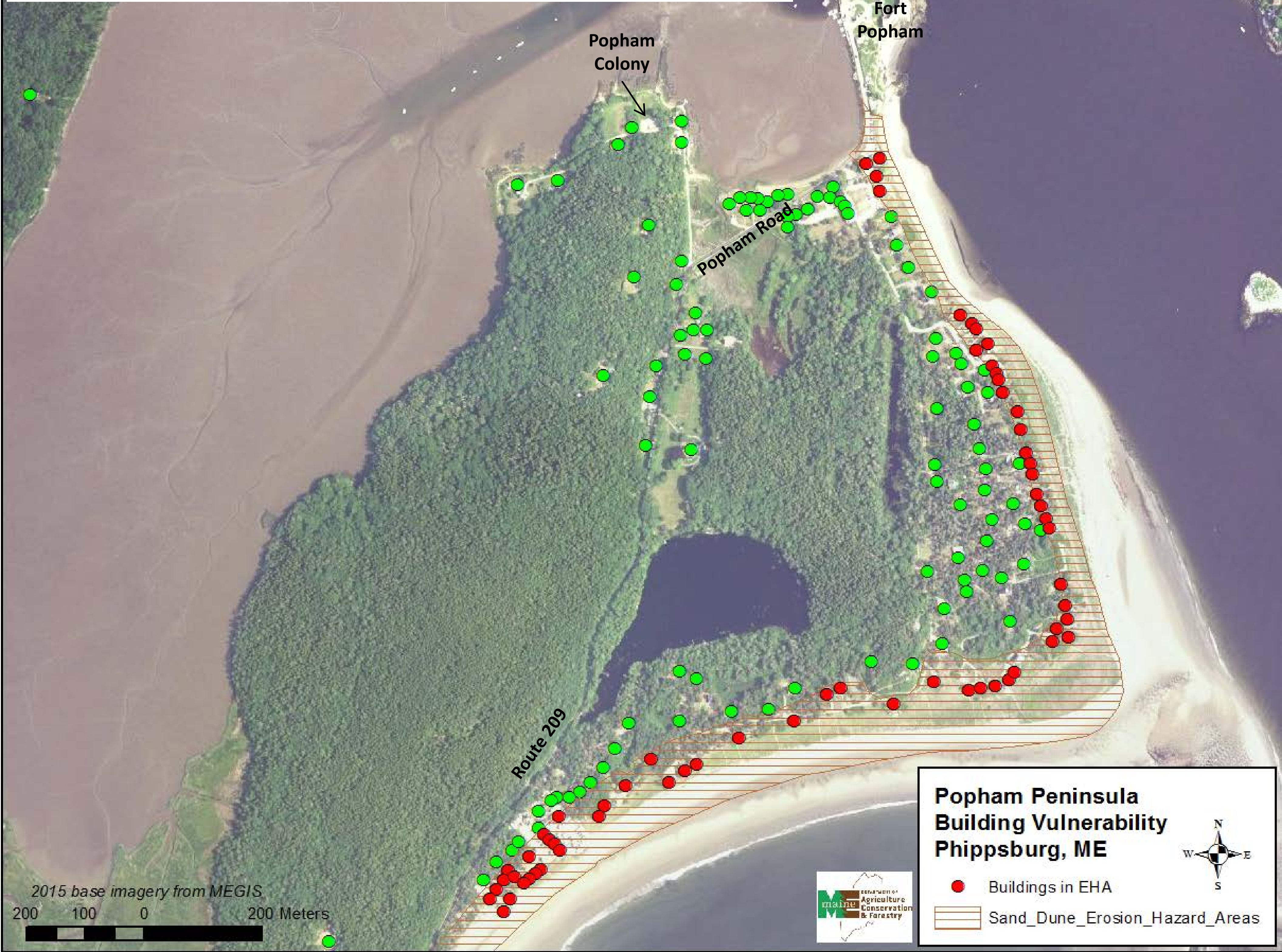


Figure E-4. Buildings vulnerable Category 1 and 2 hurricanes on the Popham Peninsula.

Figure E-5. Buildings located within the mapped Erosion Hazard Area on the Popham Peninsula.



Appendix F
Water Resources Investigation

Introduction

Popham Beach is Maine’s most visited state park, hosting over 175,000 visitors each year. Approximately 2 million gallons of fresh water per year are drawn from a shallow well in the sandy back-dune aquifer. In 2015 and 2016, the Maine Geological Survey (MGS), working with the Maine Coastal Program and the Bureau of Parks and Lands, performed an investigation and modeling study of the water supply and septic system at Popham Beach State Park. The purposes of the study were to understand the recharge and flow of groundwater through the unconsolidated aquifer system, quantify the potential effects of sea-level rise and related environmental changes on groundwater, and to assess the vulnerability of park water resources to changing hydrogeologic conditions, including saltwater intrusion. A network of observation wells was instrumented to watch for indications of saltwater intrusion into the fresh aquifer. Groundwater level observations and geophysical field measurements were used to construct a numerical simulation model of the flow, extraction, and replenishment of fresh and saline groundwater. The numerical groundwater flow model was then used to estimate the risk of saltwater intrusion as seal level rises, precipitation increases, and shorelines change.

Setting and Context of the Study

Water Resources at Popham Beach State Park

In 2008, a new water supply for the park was designed in order to meet the greater demand that accompanied the construction of new bath houses with flush toilets and showers. Previously, the park was served by two shallow, driven well points, which were deemed insufficient to supply the new facilities. The investigation ultimately settled on a single well installed in the unconsolidated sandy aquifer beneath the high dunes. The water supply for the park is now this gravel-pack well, installed in 2008 in an area of forested back dune between the parking lot and Route 209 (Figures F1 and F2).

The supply well was designed for withdrawals that are concentrated in the high-use season between June and Labor Day, when demand may average 15 gpm; however, averaged over a whole year the consumption rate is likely close to 4 gpm. The pump is limited to an instantaneous rate of 60 gpm. During pumping of 15 gpm, drawdown in the well is estimated to be about 3 ft, based on a three-day pumping test of the well (Sevee & Maher Engineers, Inc., 2008b).

The total depth of the well is about 28 ft below the ground surface, which is at approximately 11 ft above mean sea level (MSL). The lowest 4 ft of the well is made of a pre-packed stainless steel screen containing ceramic beads, which increases the hydraulic conductivity immediately surrounding the well and allows water but not sand to be drawn into the well (Sevee & Maher Engineers, Inc., 2008b). Above the screen is a 6-in diameter casing that extends several feet above the ground surface. A submersible, electric pump installed below the water level in the well draws water from the aquifer for public showers, sinks, flush toilets, and drinking water.

Used water is disposed of in septic system and grey-water leach fields adjacent to the parking lot and bath house. The lowest chamber of the septic system is about 4 ft above the estimated seasonal high water table, which is more than enough space to accommodate the expected mounding of the water table beneath the disposal field (Sevee & Maher Engineers, Inc., 2008a). It is important to maintain at least two feet of unsaturated material beneath the disposal field to prevent contamination of the groundwater.

The piezometric or hydraulic head in the vicinity of the supply well is about 4 ft above MSL. Drawdown of the water level close to sea level has the potential to draw saltwater close to or into the well. Fortunately for this system, the season of high-water use is limited to three or four months, and the average annual extraction rate of 4 gpm is low, especially compared with the high rate of freshwater recharge. Nevertheless, the low elevation and proximity of the well to the ocean and salt marsh is enough to cause concern about the potential for saltwater intrusion into the well as sea level rises, or if further erosion of the beach and dunes occurs. The chambers of the septic system are also close enough to the seasonal high water table to cause concern that rising sea levels and increasing precipitation rates will cause the water table to rise and flood the septic system.

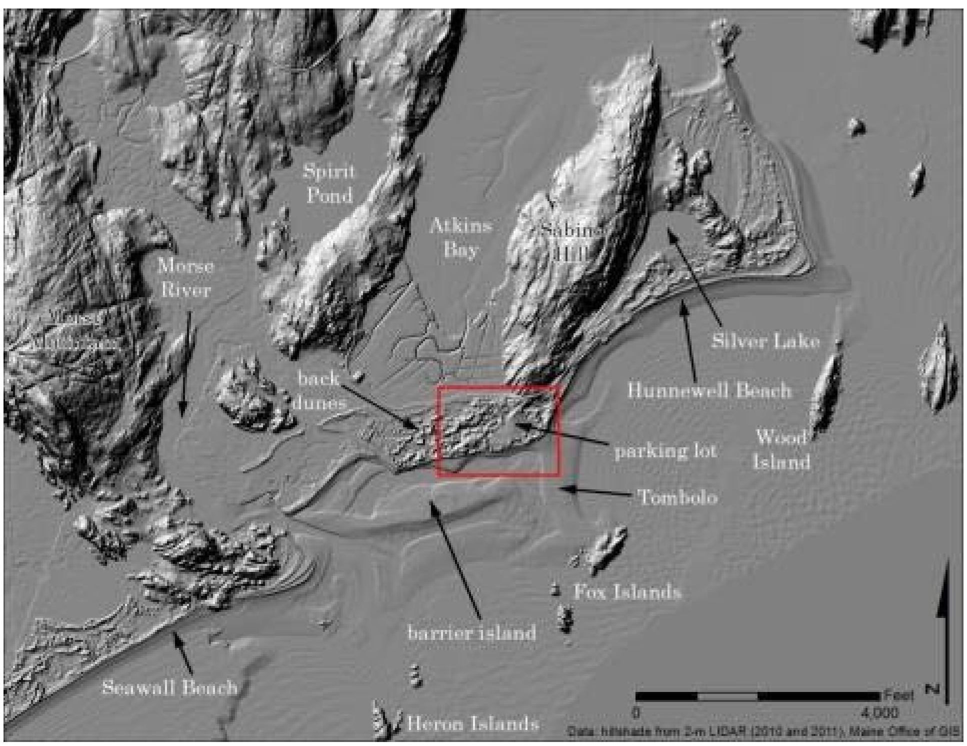


Figure F-1. Topographic hillshade map of the Popham Beach State Park area, with labels for key features. Red rectangle indicates the approximate extent of the map in Figure F2.

Figure F-2. Map of the well field and park infrastructure at Popham Beach State Park, showing the production pumping well and monitoring well locations. Aerial photograph from 2013.

Hydrogeology

The dune and barrier beach system that underlies the lowland portion of Popham Beach State Park is an excellent aquifer. The parking lot, bath houses, and surrounding pitch pine forest are located on top of a thick (in places >80 ft) unconfined aquifer of unconsolidated fine-to-medium sand, which overlies regional bedrock. The freshwater aquifer is located primarily beneath the higher dunes, roughly bound to the east by bedrock of Sabino Hill, to the west by the tidal Morse River, to the north by Atkins Bay, a saline embayment of the Kennebec Estuary, and to the south by the Atlantic Ocean. The bedrock exposed on Sabino Hill and surrounding Spirit Pond is a quartz-biotite-muscovite schist correlated with the Cape Elizabeth Formation (Hussey, 2012). Bedrock on the west side of the study area near the Morse River is a biotite-muscovite granite that intruded the surrounding schist during Devonian to Late Silurian time. The granite also outcrops on the Wood, Fox, and Heron Islands, as well as to the east of Silver Lake and in small exposures on the west side of Sabino Hill (Hussey, 2012). The contact between schist and granite is buried somewhere beneath the Popham barrier beach and saltmarsh system, but its precise location is unknown.

Vibracore and pulse auger sediment cores, as well as ground penetrating radar (GPR) profiles show that the dunes are underlain by at least 30 ft of medium to fine sand over fine sand (Buynevich, 2001; Buynevich et al., 2004). Drilling logs from the installation of monitoring wells and borings confirm these findings, with fine sand and shells found down to 80 ft depth (Sevee & Maher Engineers, Inc., 2008a; 2008b). Seismic refraction work performed by the Maine Geological Survey indicates that the depth to bedrock varies along the dunes, with three measurements between 46 and 81 ft (Sevee & Maher Engineers, Inc., 2008b). Between the back dunes and Atkins Bay lies over one thousand horizontal feet of high salt marsh, underlain by fine organic mud. Sediment cores in the marsh show approximately 15 ft of marsh deposits over organic mud, over 5 ft of medium-coarse sand, over fine sand (Buynevich, 2001). A similar saltmarsh exists to the west of the high dunes, between the dunes and the Morse River. To the south and east of the dunes, the beach and seafloor are composed of fine and medium sand, which becomes finer beyond the bedrock outcrops of the Heron, Fox, and Wood Islands, becoming very fine before reaching Seguin Island (FitzGerald et al., 2000).

Average annual precipitation in the Popham Beach area over the twenty years from 1995 through 2014 is 51 inches (gridded meteorological data from Thornton et al., 2015). Recharge into the sand dunes is 65% of precipitation (estimated using the groundwater model, see below). The remainder is lost through evapotranspiration by trees, plants, and open wetland, and likely a very minor amount of direct runoff into wetlands and ocean. There are no substantial surface water streams, but a small freshwater wetland is located to the northwest of the highest dunes, and there are tidal channels that drain the saltmarsh both on Atkins Bay and the east side of the Morse River.

The water production well for the State Park is located in a higher portion of the forested back dunes, between the parking lot and Route 209 (Figure F2). The ground elevation in this part of the dunes ranges from 5.5 to 26 ft NAVD88, and the groundwater elevation in wells and piezometers ranges between approximately 3 and 5 ft NAVD88. [1] Groundwater flow across the monitoring well field is generally from northeast to southwest. The mounding of groundwater above sea level in the middle of the dunes suggests that there is a substantial lens of freshwater in the aquifer below, and that recharging water from precipitation eventually flows downward and seaward, until it seeps into the ocean below the high-tide line (similar to the idealized Figure F3).

[1] A note on elevations: Unless otherwise specified, elevations are reported in the NAVD88 datum. At Popham Beach, mean sea level (MSL) in 2015 was −0.16 ft NAVD88, while mean higher high water (MHHW) was 4.58 ft and mean lower low water (MLLW) was −4.86 (from NOAA VDatum 3.5, http://vdatum.noaa.gov/). In figures and captions, where “MSL” is used as an elevation, the 2015 value of −0.16 ft NAVD88 is intended.

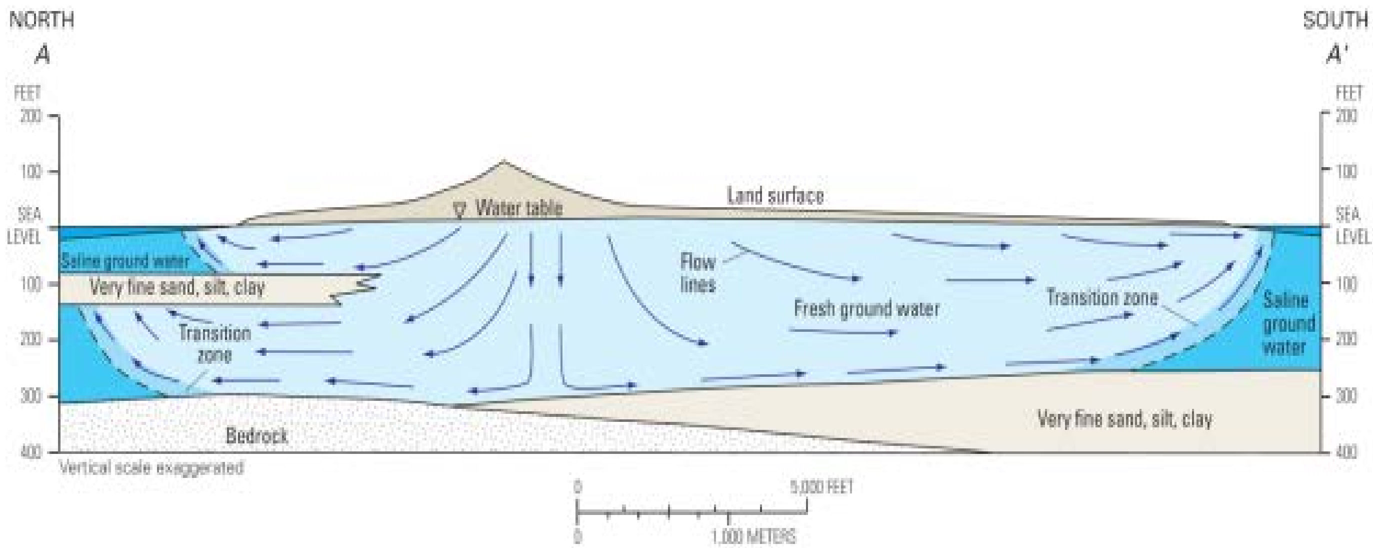


Figure F-3. An idealized, hypothetical cross-section through a low sand spit or island, showing a lens of freshwater and the general directions of groundwater flow through the unconsolidated aquifer (modified from Barlow, 2003).

Saltwater, Freshwater, and Saltwater Intrusion

In an unconfined aquifer adjacent to the ocean or, like the Popham peninsula, surrounded on all sides by bodies of saltwater, there exists a complicated interaction between freshwater and saltwater in the subsurface (Barlow, 2003). Fresh groundwater in Maine is supplied by locally infiltrating precipitation; where the continental shelf is covered by ocean, the groundwater below has salinity similar to that of ocean water (approximately 35,000 mg/L total dissolved solids, while freshwater typically has less than 1000 mg/L). At the coast there is a transition zone between fresh groundwater and saltwater (Figure F4), which, where thin, is approximated as a surface called the saltwater interface. The location and thickness of the transition zone depends upon the flux of freshwater moving through the aquifer, the hydraulic properties of the aquifer material, the depth to bedrock or a confining unit, and dispersive mixing due to tides (Barlow, 2003). In a single-aquifer system, the less-dense freshwater overlies denser saltwater, so that the saltwater interface dips landward. The discharge zone for freshwater is at and usually below the intertidal zone, so that the surface of the saltwater interface meets the upper land surface somewhere offshore.

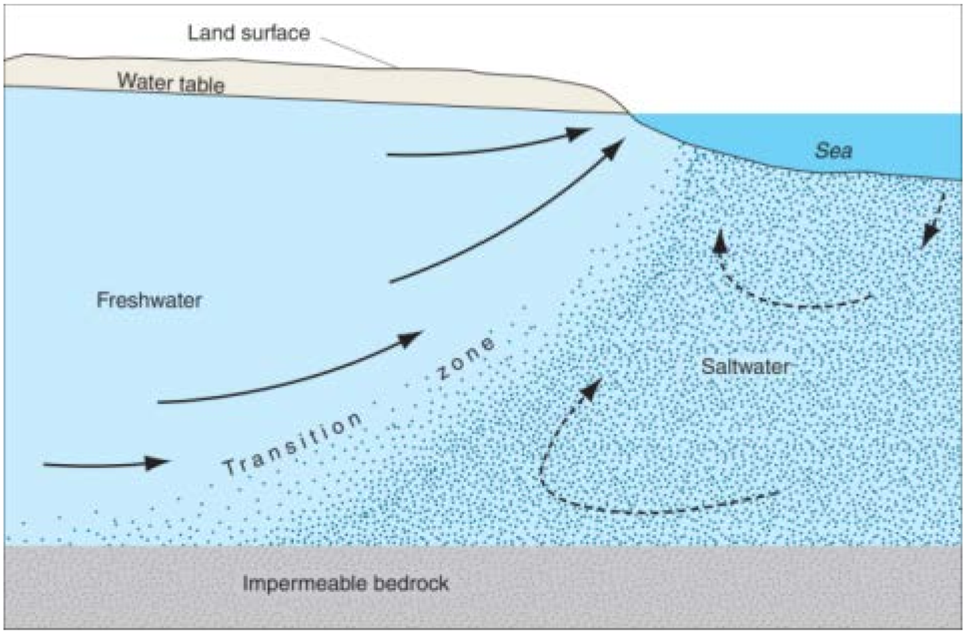


Figure F-4. An idealized illustration of the transition zone between freshwater and saltwater below the coastline. The density of dots is intended to represent salinity. Solid arrows show the movement and discharge of freshwater, while dashed arrows show the recirculation of saltwater, caused by mixing in the transition zone (from Barlow, 2003).

Where the land surface is low and surrounded on most sides by saltwater, such as an island, sand spit, or barrier beach, the freshwater can form a lens that is completely surrounded and underlain by saltwater (Figure F3). This is likely the case at Popham Beach. Although the thickness of the freshwater lens is difficult to know without measuring salinity directly, a simple estimate of the depth to saltwater is given by the Ghyben-Herzberg approximation, which is based on the density difference between freshwater (ρ_f = 1.000 g/cm^3) and saltwater (ρ_s = 1.025 g/cm^3).

The depth below sea level of the saltwater interface (z) is given by:

$$z = \frac{\rho_f}{\rho_s - \rho_f} h = 40h$$

where h is the height of the water table above sea level (Reilly and Goodman, 1985). This calculation for Popham Beach would yield depths to saltwater beneath the dunes of up to 190 ft below the ground surface, although the shallower bedrock complicates this situation. A more rigorous estimate can be achieved using numerical modeling.

Saltwater intrusion occurs when saltwater associated with the ocean moves into an aquifer that was previously saturated with freshwater, and can have detrimental effects on water resources. Saltwater intrusion is typically a problem in regions where groundwater recharge is low and groundwater pumping rates are high close to the coast. However, any changes in aquifer boundary conditions, such as a rise in sea level, a change in the coastline position, or a drop in recharge (e.g., due to development of impervious surfaces) can change the location of the saltwater interface. Figure F5 illustrates two drivers of saltwater intrusion that may occur at Popham Beach, aquifer drawdown due to pumping and sea-level rise. Sea-level rise affects the fresh-water aquifer in two ways, by increasing the height (hydraulic head) of the ocean, and by inundating the coastline, bringing the ocean closer to points on land. Both of these changes can cause saltwater intrusion into the aquifer and a rise in the fresh water table elevation. A rise in the water table, even if fresh, can cause damage to infrastructure such as foundations, septic systems, and road beds.

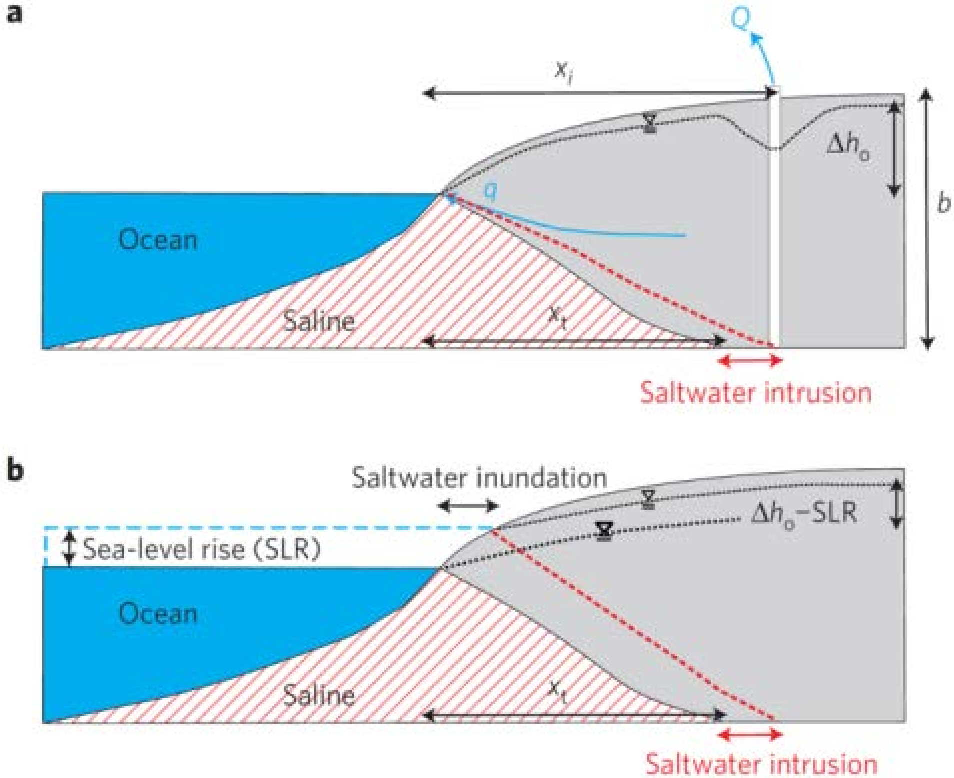


Figure F-5. Two potential drivers of saltwater intrusion: (a) pumping of groundwater (Q) creates a cone of depression in the water table around the well, as well as movement of the saltwater interface (thick dashed line) into the well; and (b) a rise in the elevation of the ocean combined with inundation of the coastline with saltwater causes both a rise in the freshwater table and landward movement of the saltwater interface (modified from Ferguson and Gleeson, 2012).

Methods

Observation Well Network

During the initial development of the water supply in 2008, four monitoring wells were drilled and installed near the production well (MW-2, MW-3, MW-5, and MW-6), and three shallow piezometers were driven, two of which were subsequently destroyed by construction of the septic field (Sevee & Maher Engineers, Inc., 2008b). The monitoring wells were installed with 5-ft screens at depths below ground surface between 23 and 44 ft (elevations between −14 and −33 ft NAVD88). In 2015, farther from the well field, MGS staff installed by hand 3 additional shallow piezometers, which are screened at the water table (PZ-4, PZ-5, and PZ-6) (Figure F2). Since 2015, MGS has been monitoring the water levels and specific conductivity of water in these wells and piezometers. Seven of the existing monitoring wells and piezometers are instrumented with water level loggers that record the hydraulic head every 15 minutes (Solinst Levelogger Edge and Schlumberger Mini-Diver), and one instrument that records head and specific conductivity (Solinst Levelogger LTC). In addition to the one well that continuously logs conductivity, MGS has periodically taken conductivity measurements from all the wells synoptically (at the same time).

Terrain Conductivity

As part of the field investigation, MGS also performed transects using a terrain conductivity meter (Geonics EM-34-3), an electromagnetic device that measures the apparent conductivity of the bulk subsurface. This geophysical technique works by inducing a current in the earth with an alternating current in a transmitter coil (Tx) that is placed on the ground surface. The magnetic field produced by the induced current is measured by a receiving coil (Rx) that is placed on the surface a set distance away from the transmitter (McNeill, 1980).

Because sand saturated with saltwater and sand saturated with freshwater have different bulk conductivities, the interface between saltwater and freshwater makes a good target for a terrain conductivity survey. By varying the spacing between transmitter and receiver, the effective depth of penetration of the measurement can be varied; it is therefore possible to use multiple measurements using different coil spacings to estimate the depth to the saltwater interface. The estimation is done by treating the earth as a two-layer model, in which the upper and lower layers have significantly different conductivities. Multiple measurements of apparent conductivity are then used to constrain the depth to the interface between the layers, as well as the conductivity of each layer (McNeill, 1980, 1983).

Numerical Groundwater Flow Modeling

A three-dimensional, steady-state groundwater flow model (USGS MODFLOW-2005; Harbaugh, 2005) was constructed of the State Park dune field and surrounding beaches, marshes and sea floor up to one mile from shore, and calibrated using the monitoring well data. The groundwater model simulates many of the processes occurring at Popham Beach, including recharge from precipitation, groundwater discharge to the wetlands and ocean, well pumping, septic system return flow, sea-level rise, and land-surface inundation. The model also uses the SWI2 package (Bakker et al., 2013) to simulate a sharp saltwater interface under a variety of well-pumping, recharge, and sea-level-rise scenarios.

The top surface of the model domain is a 100-ft grid of 190 columns and 200 rows, with elevations derived from a combination of lidar flights over both land and shallow water, plus several bathymetry data sources in deeper water. The top surface therefore represents the land surface and sea floor. General head boundaries on the sea floor and lake bottoms simulate the pressure of the overlying salt water, expressed as freshwater hydraulic head (Figure F6). A south-north cross section through the model (Figures F7 and F8), shows the topography of the model top, as well as the elevations of the six layers. The bottom of the model is a no-flow boundary at −300 ft NAVD88, which represents impermeable, unfractured bedrock.
The surfaces of the intertidal zone—marshes, mudflats, and beaches—are simulated as MODFLOW RIV boundaries (Figure F6). RIV boundaries are typically used to simulate flow through a river bottom controlled by a variable river stage elevation, but in this case they are used in order to alternate between subaerial conditions and inundation by the ocean from tides or

sea-level rise. In RIV cells that are inundated by ocean, the RIV stage elevation is set at sea level (actually the freshwater hydraulic head equivalent) and fresh recharge from precipitation is set as zero; if hydraulic head in the cell is lower than the sea-level equivalent, saltwater infiltrates the surface, and if it is higher, then groundwater discharges to the ocean. In RIV cells that are not inundated, fresh recharge is turned on and the RIV stage elevation is the same as the land surface elevation (the RIV bottom), which allows the marsh or beach to drain if head is higher than the land surface.

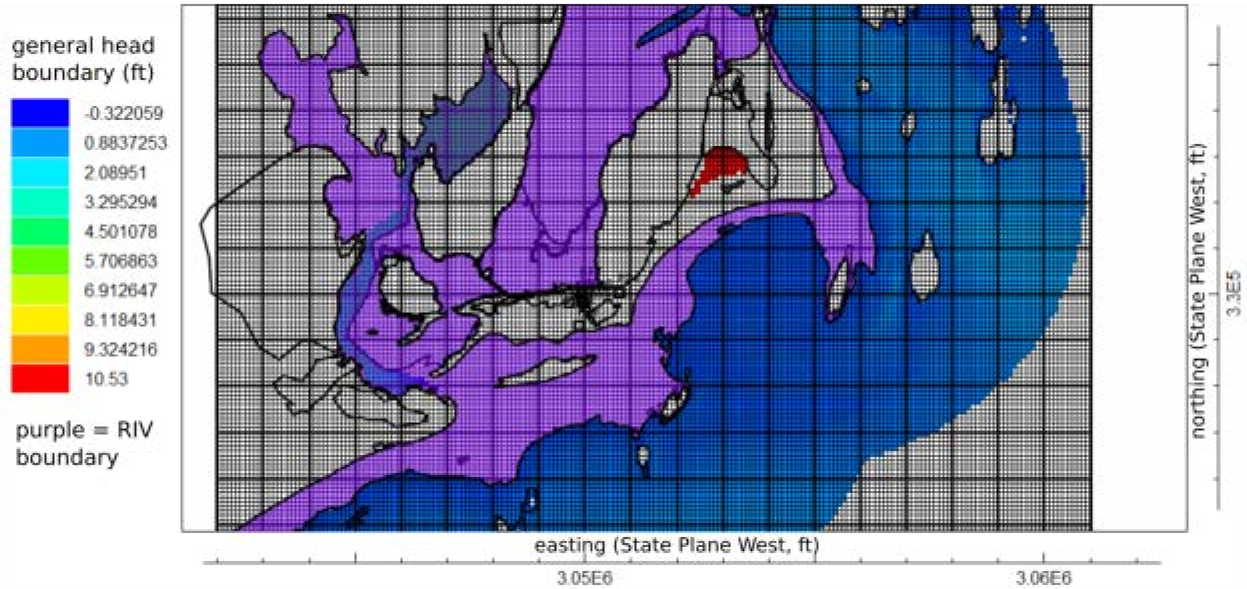


Figure F-6. A view of the top surface of the model domain, showing the 100-by-100-ft cells (fine grid mesh) and some of the model boundary conditions. Areas colored with the blue-to-red scale represent general head boundaries, with the color scale conveying the elevation of the boundary (freshwater head equivalent). Areas colored purple are RIV boundaries, where the elevation of the boundary stage is either the freshwater head (when inundated by ocean) or the land surface elevation (when not inundated). Land areas that are not inundated are also covered by recharge boundaries (not shown).

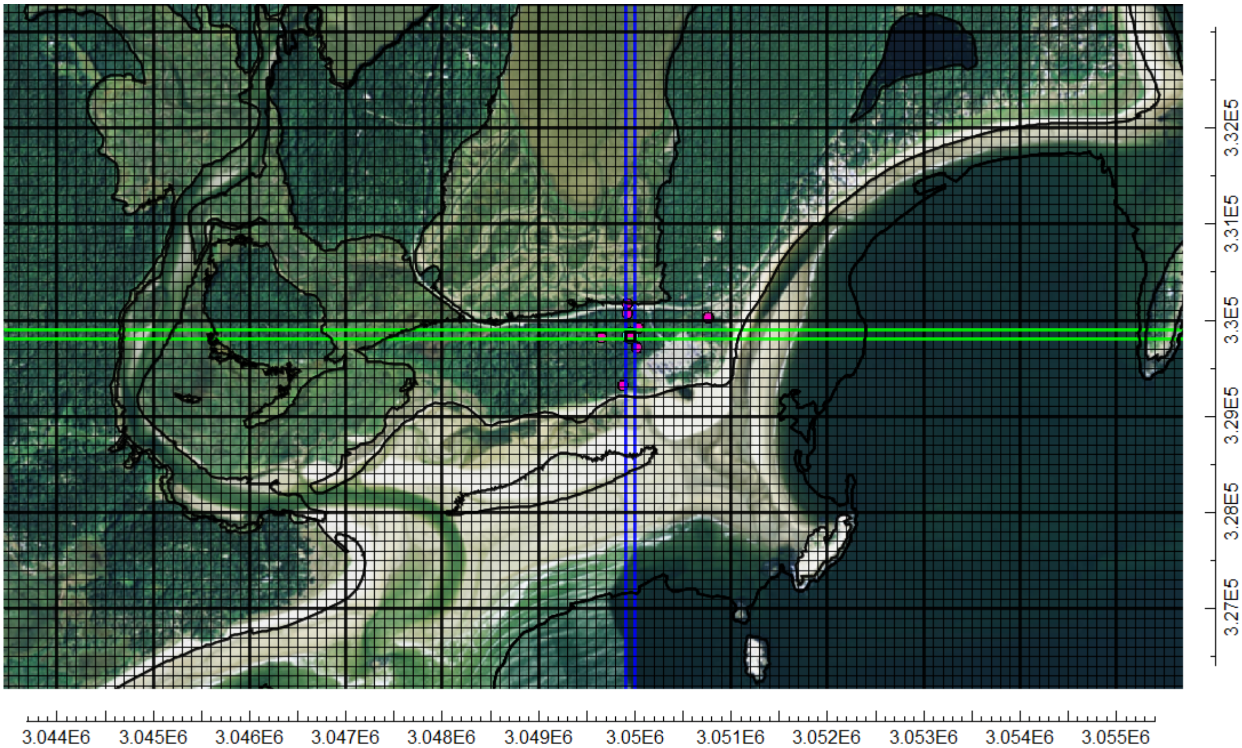


Figure F-7. A close up view of the top surface of the model grid, over an aerial photograph. The pumping well is at the center of the intersecting green row and blue column. The blue column represents the location of the cross sections shown in the following figures.

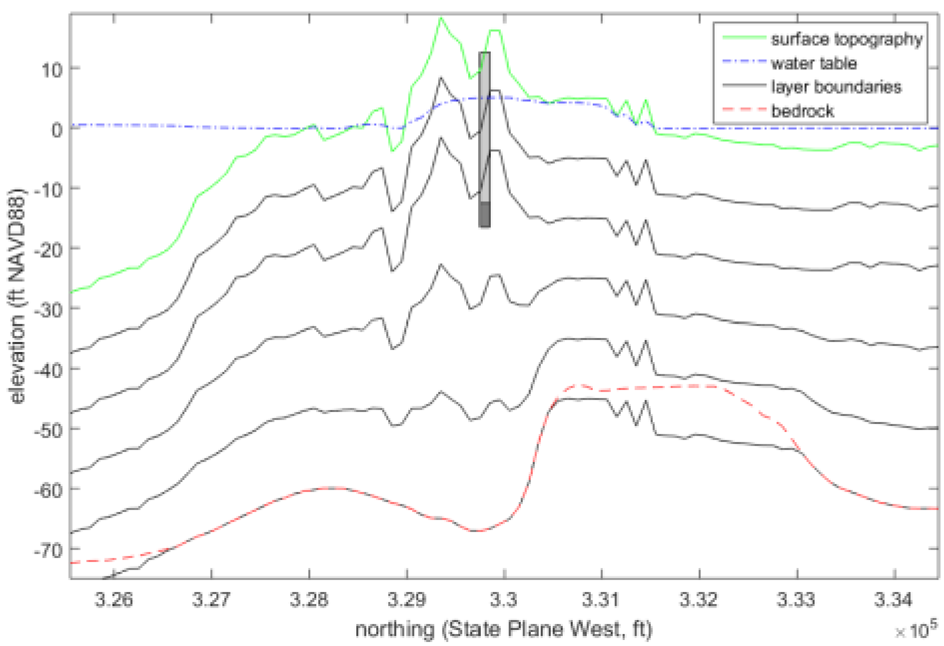


Figure F-8. A cross-section plot from south (left, Atlantic Ocean) to north (right, Atkins Bay) through the model at the location of the pumping well. The model row and appropriate elevations occupied by the well casing are symbolized as a grey bar, with dark grey for the well screen. Shown are the boundaries of the discretized model layers, as well as the bedrock surface and modeled water table (for 2015 conditions). The bottom of the model is at −300 ft (not shown).

In order to calculate steady-state head distributions and elevations of the saltwater interface, as well as for the purposes of model calibration, the model was initially run under steady state flow conditions, with a single stress period divided into 3000 time steps of 365 days each, or approximately 3000 years in total. The time length of 3000 years was chosen to approximate the age of the dune system, based on a single radiocarbon measurement (2,667+/-70 yBP) of a peat horizon near the Atkins Bay marsh, which yields a maximum calibrated deposition date for the overlying aeolian sands of between 845 and 815 BC (Buynevich, 2001). The purpose of the multiple time steps was to allow the SWI2 package to arrive at a quasi-steady-state solution for the saltwater interface position, since the simulation of movement of the saltwater interface is always transient (Baker et al., 2013). At the beginning of the 3000-year model simulation, groundwater was completely saline, and during the simulation, fresh recharge pushed the saltwater interface downwards until it reached a quasi-steady state, that is, it stopped moving appreciably relative to the temporal and spatial scales of the modeled system.

Model calibration was performed by adjusting the hydraulic conductivity of eight different material units, the recharge rate over six aerial units, and the conductance of three types of boundary condition (drain, RIV, and general head) (Table F1). Other aspects of the model that were adjusted to improve the model fit included horizontal anisotropy of bedrock (see Table F1), the vertical anisotropy of sedimentary units (final vertical conductivity is 1% of horizontal conductivity in all but bedrock), the thicknesses of model layers, and the extent and types of units and boundary conditions. Specific storage had a very small effect on the transient model results, and was set at 10^{-5} ft^{-1}. Additional model settings and parameters were needed to run the SWI2 saltwater intrusion package, primarily the effective porosity of the geologic units. While effective porosity does not affect the hydraulic head distribution, it does impact pore water velocities, and therefore the speed at which the saltwater interface moves through the aquifers. Effective porosity was ultimately set to 0.25 for unconsolidated units, and 0.01 for bedrock units.

unit or property	horizontal hydraulic conductivity (ft/day)	recharge (in/yr)	conductance per unit area (day^{-1})
sand	24	33	
aeolian (fine) sand	2.4	33	
coarse sand (buried)	120		
fines (silt, mud)	1	5	
marsh	1	3.5	
wetland	4	3	
shallow bedrock	0.35		
deep bedrock (east-west direction)	0.001		
deep bedrock (north-south direction)	0.01		
deep bedrock (vertical)	0.001		
bare ledge outcrop		1	
shallow drift over bedrock		4	
drain conductance (freshwater wetland)			1
RIV boundary conductance			1
general head boundary conductance			10

Table F-1. Calibrated parameters for the steady-state groundwater flow model.

The best model fit to measured conditions was achieved by minimizing the root mean square residual (RMSR) between simulated heads and measured head values at the screens of wells and piezometers. The simulated heads from the steady state model were compared to measurements taken in the monitoring wells in 2008, during the well investigation and construction. The model was then run in a transient simulation for 10 years, with the current estimated annual pumping rate of 4 gpm, and head results were compared to observations made in 2015. The RMSR metrics for both steady-state and transient models were used as targets during calibration.

After calibration, the model was run under a variety of transient scenarios that incorporated sea-level rise, varying levels of groundwater extraction, and increasing recharge rates. Discussed here are the details of three scenarios, referred to as scenarios A, B, and C. The initial conditions for the transient scenarios were taken from the final hydraulic head distribution and saltwater interface positions from the end of the steady state, 3000-year simulation. Each scenario involved a series of 13 stress periods, each with 100 time steps of 36.5 days each, or approximately 10 years for each period, which in total approximately simulated the years 2005 to 2135.

In each of the successive stress periods, the general head boundary and RIV stage elevations were increased to correspond to higher sea levels, the extents of the recharge boundaries were restricted to correspond with areas inundated by rising ocean, and optionally the pumping rates and recharge rates were altered (Table F2). The amount and rate of sea-level rise was calculated for the Portland tide gauge with the US Army Corps of Engineers Sea-Level Change Curve Calculator (USACE, 2015), using a sea-level rise curve that corresponds to the Intermediate-High scenario of the Third National Climate Assessment (NOAA, 2012) (Table F2 and Figure F9). In scenario A, the pumping rate was held constant at 4 gpm, the currently estimated annual rate of use, and the recharge rates were held at the calibrated values. In scenario B, the pumping rate was increased in the second and subsequent stress periods to 15 gpm, which is the annual equivalent of pumping at the maximum pump rate (60 gpm) for three entire months during the high-use season. In scenario C, the pumping rate was held at 4 gpm but the recharge rate was increased proportionally for all recharge areas by 1 percent in each stress period. This linear rate of increase is in line with forecasts for the Phippsburg area of a 4 percent increase in precipitation by around the year 2050 by Fernandez et al. (2015), but simulates a higher recharge rate than implied by the average forecast of a 6 percent increase in precipitation by around the year 2110 by Jacobson et al. (2009).

During the transient model runs, the positions of the water table and the saltwater interface at locations along the coastlines and beneath important infrastructure were recorded and plotted. Other transient model runs, not described in detail here, were used to simulate the effects of short-term pumping, daily tides, and coastal erosion on the elevation of the water table and the depth to salt water.

starting year	ending year	sea level (ft)	well pumping rate (gpm)			recharge multiplier (unitless)		
			A	B	C	A	B	C
2005	2015	-0.16	4	4	4	1	1	1
2015	2025	-0.06	4	15	4	1	1	1.01
2025	2035	0.19	4	15	4	1	1	1.02
2035	2045	0.50	4	15	4	1	1	1.03
2045	2055	0.86	4	15	4	1	1	1.04
2055	2065	1.28	4	15	4	1	1	1.05
2065	2075	1.76	4	15	4	1	1	1.06
2075	2085	2.29	4	15	4	1	1	1.07
2085	2095	2.88	4	15	4	1	1	1.08
2095	2105	3.53	4	15	4	1	1	1.09
2105	2115	4.23	4	15	4	1	1	1.1
2115	2125	4.92	4	15	4	1	1	1.11
2125	2135	6.04	4	15	4	1	1	1.12

Table F-2. Transient model timing and boundary condition changes for three scenarios discussed in the text, scenarios A (base conditions), B (high pumping), and C (increasing recharge).

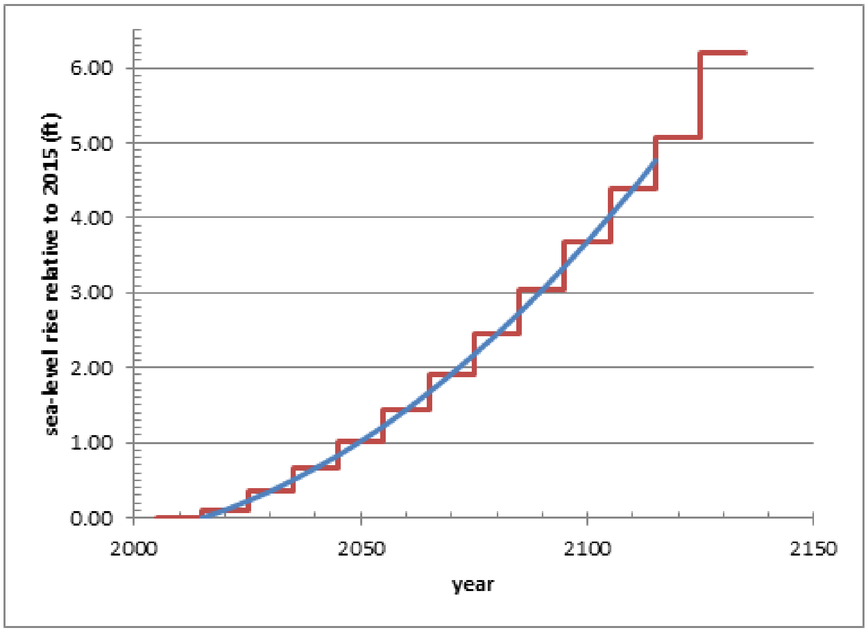


Figure F-9. Sea-level rise relative to the year 2015 (MSL = −0.16 ft) as estimated in the NOAA Intermediate-High scenario (blue line), and sea-level rise as simulated in the 10-year model stress periods (red line).

Results

Observation Well Network

Figure F10a shows an example of a groundwater level record from MW-2, in the middle of the dunes, screened at an elevation of −28 to −33 ft NAVD88. A general seasonal pattern can be seen, in which groundwater is at the lowest in September 2015, recovers through the fall and winter, and begins to drop again during the dry spring and summer of 2016. Periodic sharp increases in the water level are associated with precipitation events, and more gradual recessions follow each of these recharge events. A cycle of daily ups and downs may also be discernable, especially during the growing season in 2016. Figure F10b shows a shorter time interval from PZ-6, a shallow piezometer close to the frontal dune. In this record, both a daily cycle and a twice-daily cycle can be seen, slightly off-phase from one another. The daily cycle in both records is due to the daily cycle of plant transpiration; during the day trees and plants use water as they photosynthesize sugars, and much is lost through their leaves. The twice-daily cycle, which is more prominent in wells and piezometers closer to the beach or marsh, is caused by tidal fluctuations at the boundaries of the aquifer (the frequency is more accurately 1.93 cycles per day).

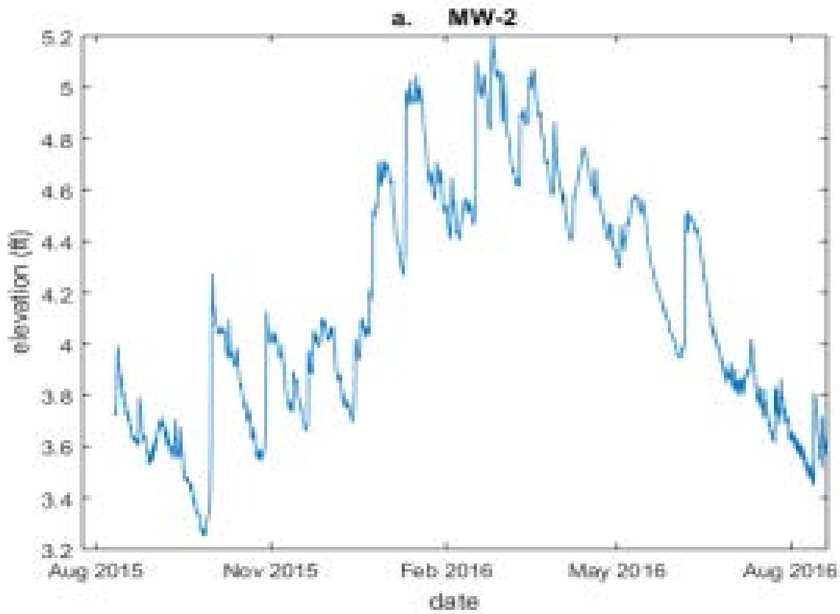


Figure F-10a. Groundwater levels in wells MW-2.

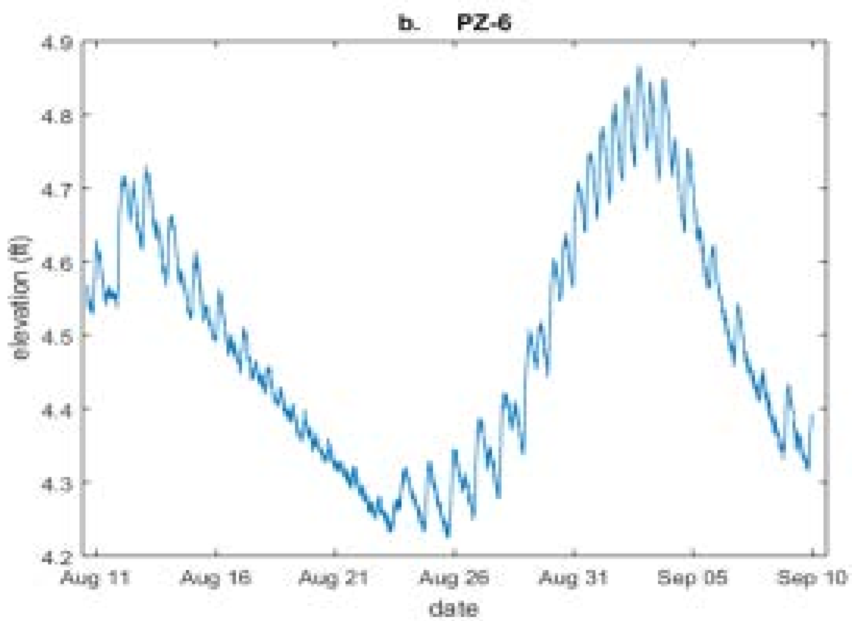


Figure F-10b. Groundwater levels in PZ-6.

In addition to one well that continuously logs conductivity, MGS has periodically measured conductivity manually in all the wells synoptically (at the same time). The highest observed value has been 275 μS/cm, recorded by the automatic logger in PZ-6 in January 2016. Because specific conductivity is proportional to the salinity of water, these measurements indicate that saltwater intrusion is not currently occurring in the parts of the aquifer where these wells are screened.

Terrain Conductivity

The solution of a two-layer-earth model of the terrain conductivity data (McNeill, 1980, 1983) indicated the presence of a conductivity contrast at a depth of 25-30 ft at the edge of the frontal dune on Center Beach, directly south of the pumping well, and 65-70 feet in the center of the dune field, about 200 ft to the west of the pumping well. These results are not consistent with the simulated position of the saltwater interface in the numerical groundwater flow model, which simulated the saltwater interface at depths of −86 ft and −101 ft in the same two locations, and may instead represent the depth to bedrock. In most of the subsurface beneath the Popham beach dune filed, the bedrock surface is shallower than the saltwater interface simulated by the model. See the next section, below, for a discussion of the uncertainty surrounding the relationship between the saltwater interface and the bedrock surface.

Numerical Groundwater Flow Modeling

The steady-state groundwater flow model, without groundwater pumping, achieved a good fit to well observations made in 2008 at the time of well installation (RMSR of 0.718). The first stress period of the transient model, simulating the water table under normal pumping conditions in 2015, also achieved a good fit to well observations made over that year (RMSR of 0.767 ft). During model calibration, the hydraulic head results were most sensitive to the conductivity, recharge, and anisotropy of the sand units, and least sensitive to specific storage and the conductances of boundary conditions. The saltwater interface results were sensitive to the effective porosity of bedrock, but not of sand. The water table in both models is generally as would be expected from the topography, highest (at just over 5 feet in 2015) in the center of the high dunes, and decreasing to the north and south as groundwater flows towards the ocean (Figures F11 and F12).

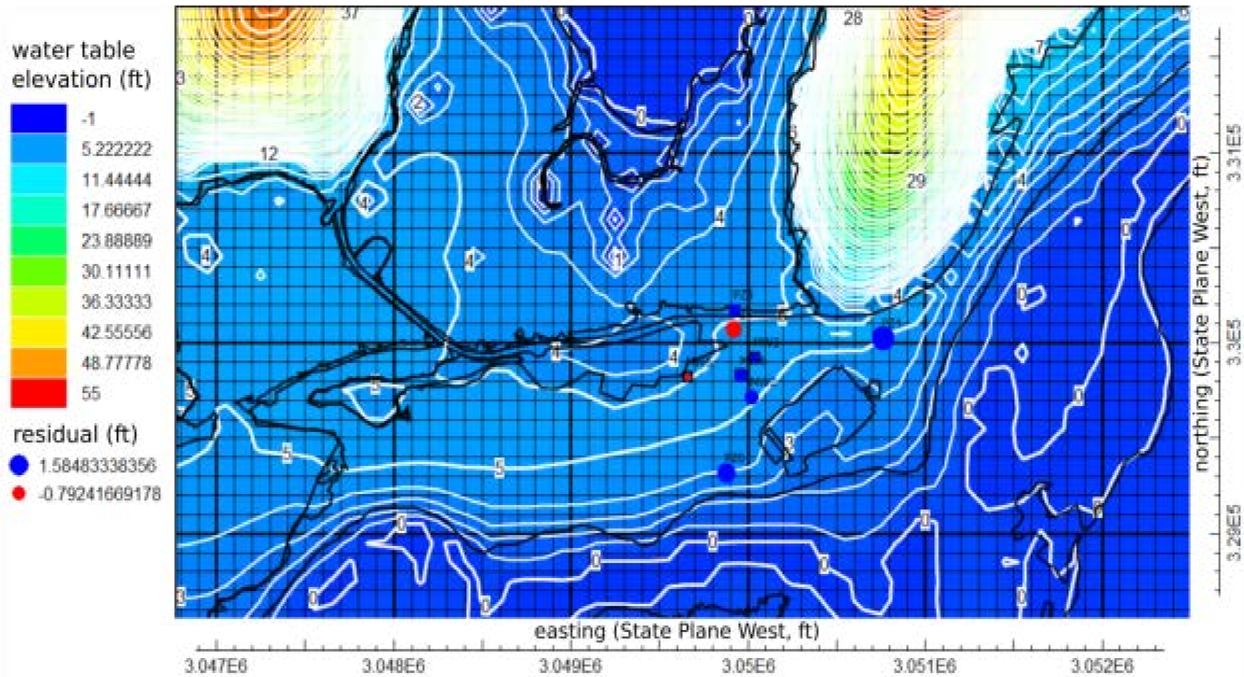


Figure F-11. The water table elevation distribution (colors and contours) across the top layer of the model, for the transient simulation representing 2015 conditions. The blue and red circles symbolize observation residuals at the seven monitoring wells and piezometers, with size proportional to the absolute value of the residual. Positive residuals (blue) indicate underestimation by the model, and negative (red) indicate overestimation.

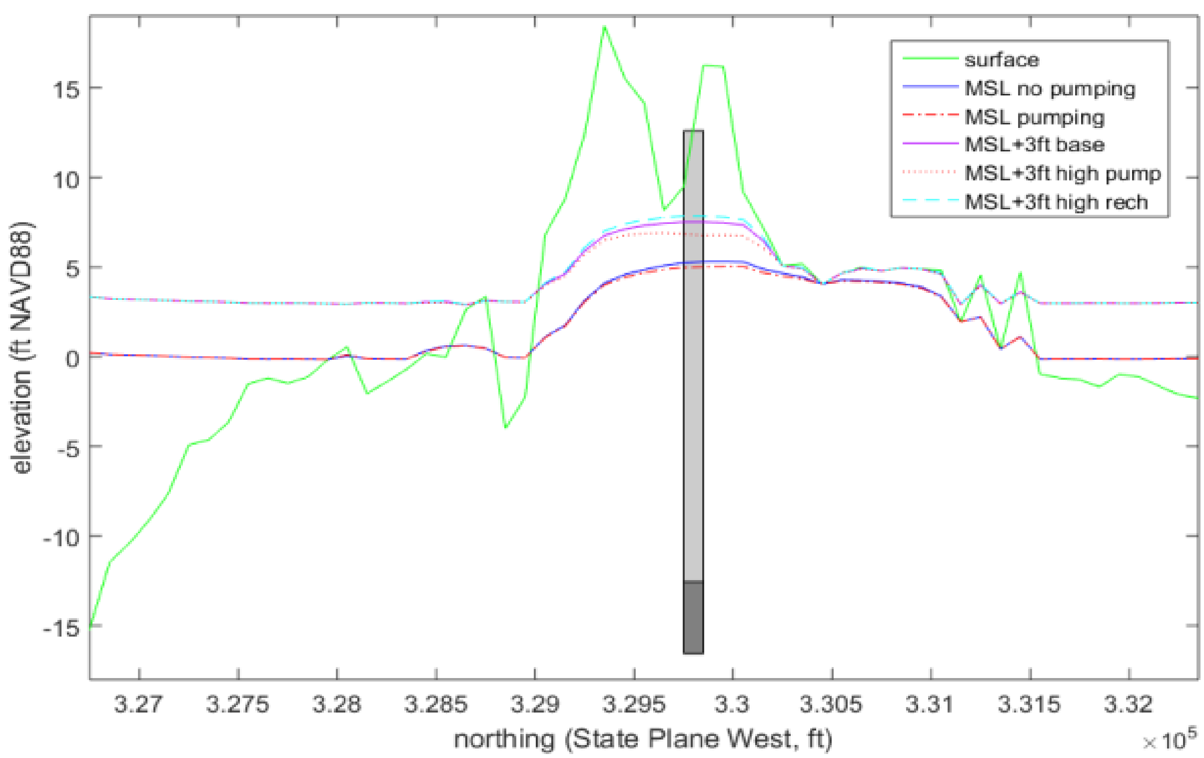


Figure F-12. A cross-section plot from south (left) to north (right) through the model at the location of the pumping well (grey bar). Shown are modeled water table elevations from five model runs: the steady-state model at MSL without pumping (blue line), the transient model at MSL with pumping (red dashed), and three versions of the transient model under 3.04 ft of sea-level rise—scenarios A (purple), B (red dotted), and C (cyan dashed).

Results of the saltwater intrusion model component are shown in Figure F13. The data as plotted here may be somewhat difficult to interpret visually, because the SWI2 package solves for the elevation of the saltwater interface (zeta) independently in every model layer. In each layer shown in the figure, the zeta is a cross-cutting line with freshwater above it and saltwater below. From layer to layer, it is possible to have saltwater on top of freshwater, as seen in layers 2 and 3 on the right side of Figure F13. In this case, the discharging freshwater in the lower layer, moving to the right, is partially trapped and pushed farther out beneath Atkins Bay by a lower-hydraulic-conductivity layer above it, which contains saltwater.

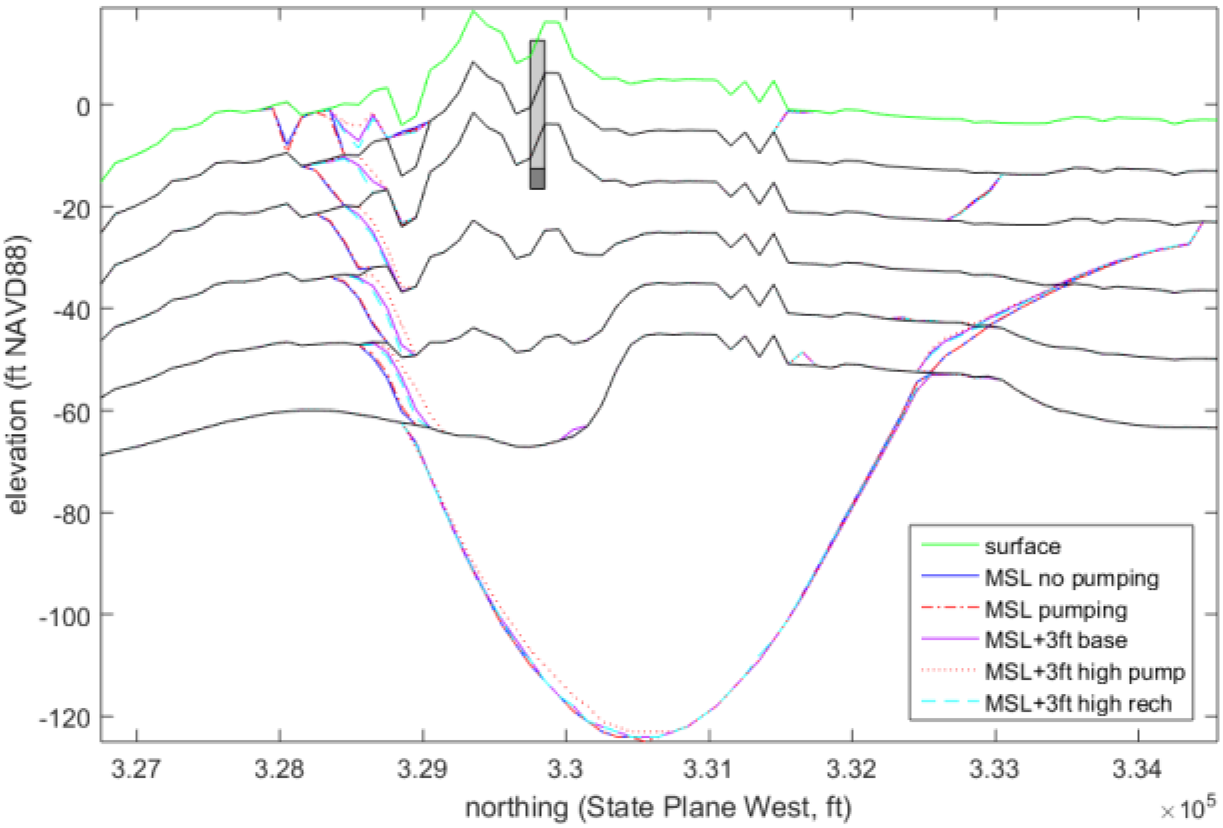


Figure F-13. A cross-section plot from south (left) to north (right) through the model at the location of the pumping well (grey bar). Shown are the elevations of the modeled sharp saltwater interface (zeta) under the same five model runs described in Figure F12.

All of the final models simulated saltwater interfaces that reached below the bedrock surface in the center of the dune field, meaning that the sandy aquifer beneath the high dunes was completely saturated with fresh water, and saltwater would only be found in fractures and pore spaces deep in the bedrock (Figure F13). The depth to saltwater was commonly over 100 feet below the ground surface over much of the dune system. Beneath the coastline and beach to the south and east of the park, the saltwater interface curved steadily upwards through the sandy aquifer to meet the surface slightly offshore of the mean tide line, as expected (similar to Figure F4 and the right side of Figure F3). Beneath the Atkins Bay marsh and mudflat, however, the subsurface in the middle layers remains fresh out some distance from shore (Figure F13). This extension of freshwater, as well as the relatively deep interface directly below the salt marsh, is due to several overlapping effects. First, the shallow bay without a steep shoreline makes for a weak vertical hydraulic gradient, and preserves a thin layer of saline groundwater on top of freshwater (similar to Figure F14), Second, at the same time the lower conductivity peat, muds and silts on the marsh and floor of Atkins Bay keep freshwater from upwelling, and drive it horizontally farther northward under the bay (similar to the left side of Figure F3). Finally, the narrow bay is affected by the proximity of the bedrock headlands to the east and west, so that the high hydraulic heads of nearby Sabino Hill have some influence on the depth to saltwater in the cross section of Figure F13, especially where the interface is in bedrock, making the interface deeper beneath the marsh than it otherwise would be.

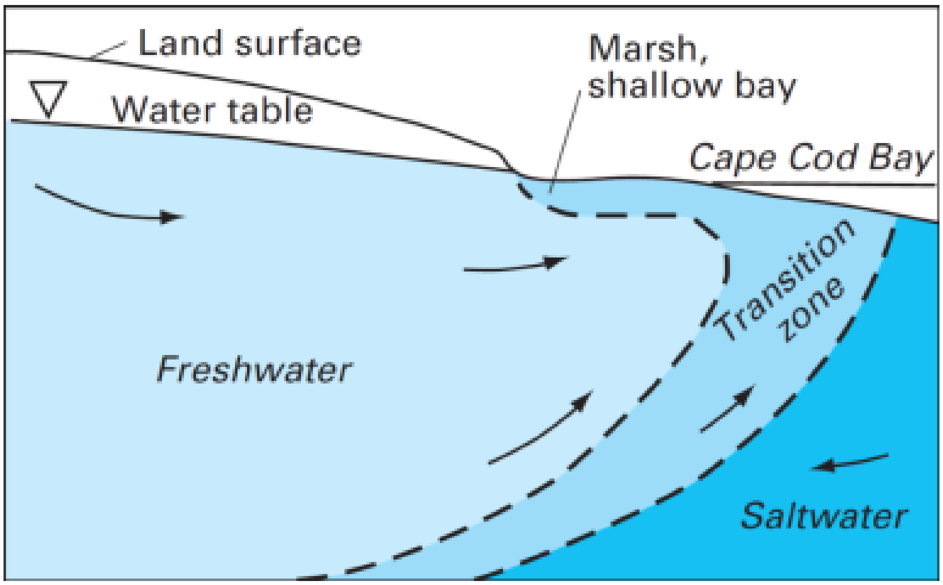


Figure F-14. A schematic example of the saltwater interface beneath a shallow marsh or bay, similar to the model results beneath Atkins Bay, observable in Figure F13 (from Barlow, 2003).

The time that it took for the saltwater interface to reach a quasi-steady state during the initial 3000-year simulation was highly dependent on the effective porosity of the bedrock, which can vary between 0 and 0.1 in fractured, crystalline metamorphic and igneous rocks (Freeze and Cherry, 1979). The interface moves downward through bedrock fastest at lower values of porosity and high values of hydraulic conductivity. Only in model runs that had unrealistic values of porosity approaching 0.5, while maintaining the low conductivity value of 0.01 ft/day, did the saltwater interface not move downward into bedrock within the simulation time. However, it is impossible without any direct measurements of the depth to saltwater to rule out the possibility that relict saltwater may exist in some fractures of the shallow bedrock, especially those that are very poorly connected to groundwater flow.

Discussed in the remainder of this section are results from the three transient model scenarios (A, base conditions; B, high pumping; and C, increasing recharge), with emphasis on time periods that simulate sea-level conditions of approximately 1, 3, or 6 feet above 2015 levels.

Simulated results show that the fresh water table rises considerably as sea level rises, but decreases only slightly due to pumping, even at a rate of 3.75 times the current estimate of use (Figure F12). Figure F15 shows the increase in the water table elevation as a function of sea-level rise at the pumping well (Figure F15a) and the septic system (Figure F15b), in all three scenarios. At the location of the septic system, which is the infrastructure most sensitive to rising water tables, 1.02 ft of sea-level rise leads to an increase in the water table of 0.76 ft (75% of the sea-level increase), and 3.04 ft of sea-level rise leads to an increase of 2.56 ft (84%), all in scenario A. The lowest chamber of the septic system is estimated to be within two feet of the water table at about 2.45 ft of sea-level rise, and to be completely flooded at less than 5 ft of sea-level rise. These thresholds occur at slightly lower values of sea-level rise in the high-recharge scenario C, and slightly higher values in the high-pumping scenario B. Furthermore, periods of wet weather, especially in the springtime, could easily raise the water table to above the modeled position.

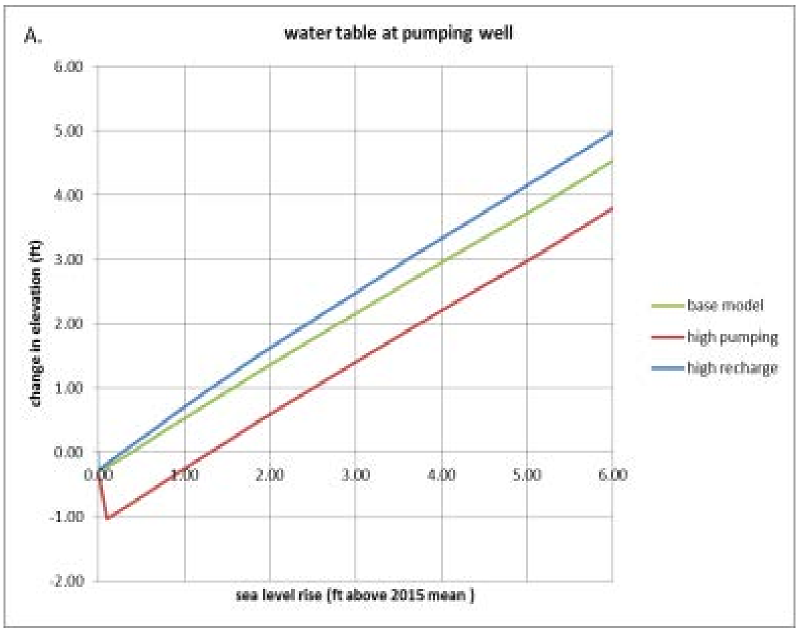


Figure F-15a. Relative changes in the elevations of the fresh water table at the pumping well (a) and the septic field (b), and relative changes in the elevation of the saltwater interface beneath the pumping well (c), all as a function of modeled sea-level rise. Results are included from three transient model scenarios: base model conditions (scenario A, green lines), high pumping (scenario B, red), and increasing recharge (scenario C, blue).

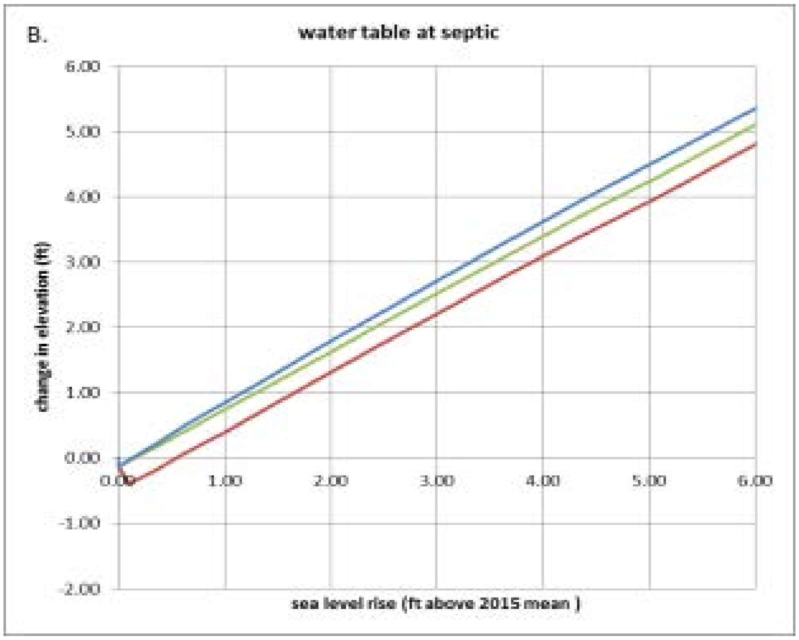


Figure F-15b.

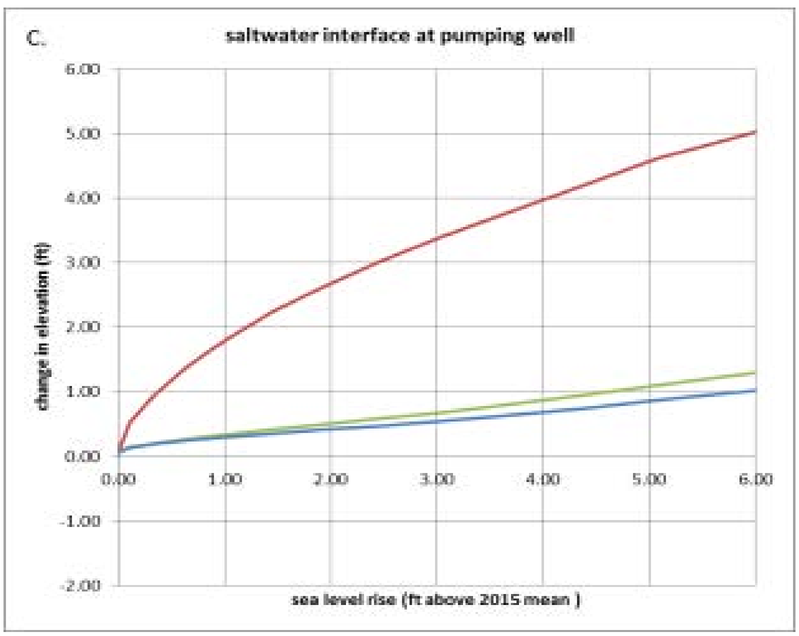


Figure F-15c.

In general, the results of the modeled saltwater interface lead to two main observations. First, notable saltwater intrusion to the north and south of the freshwater aquifer (beneath the Center Beach area and beneath the Atkins Bay marsh) was simulated by the model under approximately 3 ft of sea-level rise (Figure F13). Pumping at the current rate appears to have little impact on this lateral intrusion of saltwater (scenario A), although water extraction in the high-pumping scenario B does have a noticeable effect. These results, coupled with several heuristic models that incorporate shoreline erosion (not shown here), suggest that horizontal inundation of the land surface by saltwater is an important driver of lateral saltwater intrusion beneath the flooded coastline. Second, and somewhat in contrast to the first observation, the small amount of saltwater intrusion modeled directly beneath the pumping well is mainly controlled by the rate of pumping, and sea-level rise had little effect here (Figures F13 and F15c). Although Figure F15c does show a significantly larger increase in the saltwater elevation under the high-pumping scenario when compared with the other two scenarios, the increases are all very small in comparison to the total depth to saltwater of over 100 feet (the interface is modeled at approximately −113 ft NAVD88 beneath the pumping well). In what can only be good news for the water supply at Popham Beach, the amount of vertical intrusion of saltwater beneath the well was a maximum of 5 feet, even after 6 ft of sea-level rise combined with consistently high pumping at 3.75 times the current rate.

Implications of the Study

The ongoing monitoring of groundwater conductivity at Popham Beach demonstrates that saltwater intrusion is not currently occurring in any of the existing wells and piezometers at the State Park. Furthermore, the groundwater modeling study does not predict that saltwater intrusion should be a problem for the park's water supply under current conditions or in the near future. The saltwater interface below the pumping well is in bedrock at approximately −113 ft NAVD88, meaning that the entire thickness of the sand aquifer is saturated with fresh water at that location. The model suggests that groundwater pumping at the currently low rates will have little effect on the saltwater interface position, and only a small effect on the fresh water table elevation. Even pumping at 3.75 times the current rate (15 gpm versus 4 gpm) did not move the saltwater interface appreciably closer to the well screen.

Sea-level rise has the largest effects on saltwater intrusion on the margins of the freshwater aquifer below the beaches and coastline, due to inundation of the land surface and increasing pressure on the sea bed. The model showed that the largest shifts in the saltwater interface were mainly horizontal, and occurred in the top 40 feet of the subsurface beneath the southern and eastern beaches. Sea level rise does not dramatically affect the saltwater interface directly beneath the pumping well. Even under 6 ft of sea-level rise combined with consistently high pumping, the saltwater interface beneath the pumping well only rose from −113 ft to −108 ft NAVD88. The water supply well is not under direct threat of permanent saltwater intrusion under moderate levels of sea-level rise or anticipated shoreline erosion.

However, the implications for the State Park infrastructure of the groundwater flow modeling are not all positive. Due to increasing sea levels, the fresh water table under the septic field is predicted to rise by as much as 85% of the relative rise in sea-level, or up to 90% if recharge increases along with climate change. The septic system is at risk of failing to maintain necessary unsaturated conditions at 2.45 ft of sea-level rise (i.e., there will be less than 2 ft of unsaturated material beneath the lowest septic chamber), and is predicted to be flooded at least half of the year at less than 5 ft of sea-level rise.

This study did not directly address several potential issues related to water resources and sea-level rise, especially the risk to the water supply from storm surge and overtopping of the freshwater aquifer. Hurricane storm surges have the potential to push saltwater on top of the land surface significantly inland towards the pumping well, and the likelihood for quick infiltration of this saltwater into the top of the freshwater aquifer is high, especially given the high recharge ratio and permeability of the sandy dune sediments. Further modeling work that incorporates storm surge and unsaturated zone processes would help clarify this risk.

Acknowledgements

Thanks are due to Brian Murray, retired Popham Beach State Park manager, and the current manager Meagan Hennessey, for past and ongoing collaboration. Sevee & Maher Engineers, Inc., which performed the 2008 site investigation, well installation, and septic design, were very helpful and allowed us access to reports, figures, and digital site plans. Thanks also go to Robert Gerber, whose experience and advice with saltwater intrusion modeling were invaluable; Beverly Johnson at Bates College Department of Geology, who lent us important well monitoring equipment when ours was down; and Richard Winston of the US Geological Survey, for assistance with his ModelMuse software.

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A Natural Resource Inventory of Popham Beach State Park

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Prepared for the Maine Coastal Program and the Maine Bureau of Parks and Lands

2015

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Preface

This Natural Resource Inventory (NRI) for Popham Beach State Park was conducted for the Bureau of Parks and Lands (BPL) by the Maine Natural Areas Program (MNAP) as part of a larger effort to assess risks presented by climate change to state parks. Research relating to the natural history of Maine's state parks and to relevant climate change impacts was reviewed, and new data were collected for ecological communities and rare plant species when other field records were old or incomplete. No additional data was collected for animal species. Data for rare animals is based on the most recent information that was available from the Maine Department of Inland Fisheries and Wildlife at the time the report was written. The report includes an overview of the geology and soils and the land use history of the park. These elements are followed by descriptions of the natural communities and ecosystems along with their respective rare species. Potential impacts from sea level rise and climate change are included within the respective community and ecosystem descriptions. A table at the end of the report summarizes the potential impacts from sea level rise and climate change and provides management considerations.

Acknowledgements

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Introduction

The ~600 acre Popham Beach State Park in Phippsburg is one of Maine's most visited state park and receives over 100,000 visitors each year (Morris, Roper and Allen 2006). Popham Beach is well known for its undeveloped setting, its extensive complex of beaches and rivers, and for the sand bar exposed at low tide that provides access to Fox Island. Popular activities include swimming, surfing, fishing (surf casting), and other beach-based recreation.

Summer recreation at Popham Beach State Park. [Photo from City of Bath]

Popham Beach is Maine's most dynamic beach system, with sand deposition and erosion caused by currents in the Kennebec and Morse Rivers and with exposure to waves refracting around islands and shoals during major storm events. The extreme dune erosion between 2007 and 2012, especially along the western side of Popham Beach, has raised the public's concern over beach dynamics and the possible influence of climate change.

The biological systems at Popham Beach are diverse, and include many rare and threatened species. Undisturbed **Beach Strand** and **Dune Grassland** provide nesting habitat for the state endangered Least Tern (*Sternula antillarum*) and the state endangered / federally threatened Piping Plover (*Charadrius melodus*). Roughly 1/3 of the park is **Spartina Saltmarsh**, which provides important habitat for many plant and animal species, including the state endangered purple foxglove (*Agalinis purpurea*), rare saltmarsh tuber bulrush (*Bolboschoenus robustus*), and rare saltmarsh false-foxglove (*Agalinis maritima*), Saltmarsh Sparrow (*Ammodramus caudacutus*, special concern), and the salt marsh tiger beetle (*Cicindela marginata,* special concern). The state's largest occurrence of **Pitch Pine Dune Woodland**, a rare forest type occurring on stable back dunes, also occurs within the park. An increase in major storms and higher sea levels as a result of climate change could put many of these habitats and natural systems at risk.

In this natural resource inventory, we examine the various factors influencing natural systems at Popham Beach State Park, and evaluate the adaptability of each of these systems to climate change.

Regional Overview

Popham Beach State Park is within the 'Casco Bay Coast' bioregion, an area of the coast characterized by long peninsulas that were buried beneath the ocean (or 'drowned') as the glaciers receded. Bedrock in this region is mostly highly metamorphosed sandstones and pelites, although granitic plutons occur throughout. Harder, folded layers of bedrock were more resistant to glacial scour and are found on the many narrow upland ridges, while softer bedrock was eroded and now underlies the regions many valleys (McMahon 1990). Along the many peninsulas, this bedrock was covered in a thin layer of unsorted glacial drift (till) that in many areas was washed away thousands of years ago by wave action.

The climate of the Casco Bay Coast bioregion is moderated by the Gulf of Maine and is cooler in the summer than the interior. Mean maximum July temperature is 78.8° F and the mean January minimum temperature is 13.1° F (McMahon 1990). This bioregion is a melting pot for habitat types which are characteristic of other parts of the coast. This includes pitch pine woodlands, which are common along the southern coast, and coastal spruce fir forests which are emblematic of the Downeast region.

In this region, there are 109 beaches, encompassing ~530 acres. The largest of these beaches are Popham Beach and Small Point Beach in Phippsburg (178 and 116 acres, respectively). Other beaches include Mile Beach (Reid State Park, Georgetown), Head Beach (Phippsburg), and Andrews Beach (Long Island) (Maine Geological Survey 1976).

Geology and Soils

Bedrock:

Though the bedrock at Popham Beach State Park is mostly covered by surficial deposits, areas of exposed bedrock occur in upland areas. Bedrock becomes exposed along the Maine coast as a result of coastal storms, which cause large swells that come well above the high tide line and erode surficial materials. Immediately after the Laurentide ice sheet receded from coastal Maine (~14,000 years ago), sea levels were as much as 70 meters higher than they are today (Barnhardt, Belknap and Kelley 1997, Belknap, Kelley and Gonz 2002, Kelley, Dickson and Belknap 1992), and all of Popham Beach State Park was under water. As the present day coast began to emerge from the ocean in the process of isostatic (postglacial) rebound, the ocean surf washed away any marine clay that covered now-exposed bedrock ledges. In more recent times, fire and other disturbance events that remove vegetation, such as clearing for pasture, have led to further erosion of thin soils during major storms. Phippsburg has a rich fire history (Barton 2012), and as a result, upland bedrock ledges have remained exposed.

Most of the property is underlain by Devonian Granite, an unmetamorphosed igneous rock type that weathers to form acidic soils. Within the park, granite influences vegetation cover on ledges dominated by conifers and heath shrubs. The remainder of the property is underlain by rock within the 'Ordovician – Precambrian Z Cape Elizabeth Formation.' This formation is primarily comprised of slate, with lesser amounts of schist, quartzite, and phyllite. Most of the area in Popham Beach State Park underlain by this bedrock type is covered by surficial deposits.

Surficial:

Four major surficial deposit types occur at Popham Beach State Park: beach, till, thin drift, and organic deposits. Soils that weather from each sediment type are described in each section. A map of surficial deposits is found in Appendix 2.

Beach Deposits

The beach system at Popham Beach is one of the most dynamic in the state. Over the last five years, this beach has undergone some dramatic changes, including extreme erosion of dune systems. These recent changes highlight a ~15 year cycle of sand bar and tidal channel movement at the mouth of the Morse River (Goldshmidt and Fitzgerald 1991) (Figure 1). The Maine Geological Survey has been tracking recent changes and providing management recommendations (Dickson 2012, Dickson 2009, Dickson 2008).

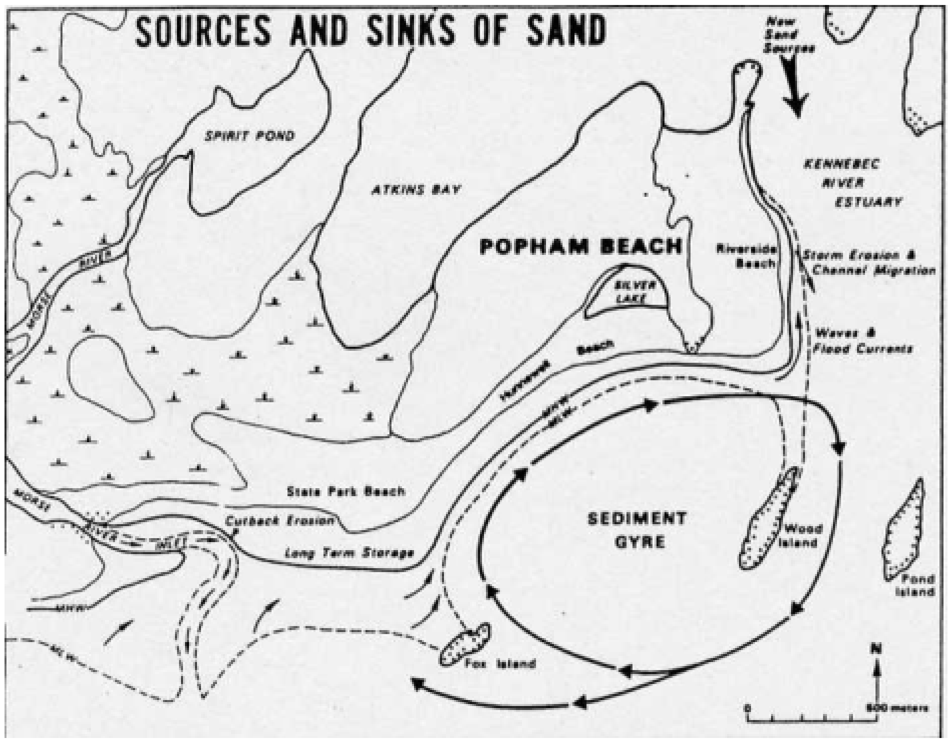

Figure 1. Diagram showing currents at the mouth of the Kennebec and Morse Rivers leading to the formation of the Fox Island Tombolo. (Goldshmidt and Fitzgerald 1991)

Deposition and erosion at most sand beaches in Maine is largely a result of wave action. At Popham Beach, current from the Morse River and Kennebec River interact with offshore islands to create complex erosion and deposition scenarios. Over the last 50 years, large areas of beach and sand dunes have been created and washed away by tidal currents (Dickson 2008), with the most recent dune erosion events mirroring those that occurred in the 1950s . The opposing currents of the Morse and Kennebec Rivers are also resposible for creating the Fox Island tombolo, the sand bar that connects Fox Island to the mainland (Goldshmidt and Fitzgerald 1991).

Over the course of ~15 years, the main channel of the Morse River migrates from Morse Hill Point eastward until it finds easier passage back in its original position. When the Morse River is adjacent to Morse Hill Point, Popham Beach will be in an accretion cycle, with over 100,000 m^3 of sand added to the beach (FitzGerald, et al. 2000). However, when the Morse River moves further east, sand is eroded away from Popham

Beach and deposited on the eastern flank of Seawall Beach or on offshore sand banks (Goldshmidt and Fitzgerald 1991).

Exceptional erosion events that impact park grounds and infrastructure are of greatest concern to park management. These extreme erosion events typically occur when the Morse River is at its easternmost point in the described cycle, and when tidal currents are running parallel to the shoreline. Between 2007 and 2012, Popham Beach experienced erosion unprecedented in the previous 100 years. The current of the Morse River eroded roughly 20 acres of sand dune within the park, and threatened to undermine a newly constructed bath house. Even following the breach of Sewall Beach, the Morse River continued to threaten the bath house. To protect park infrastructure, ~10,000m^3 of sand was scraped into the eastern mouth of the Morse River. This succeeded in alleviating the erosion threat to the bathhouse (J. T. Kelley 2013). In the past 100 years, there was only one other event (in 1953 and not as severe) where the dune woodland was reduced by erosion (see Figure 2).

Currently, Popham Beach is in an accretion cycle. The beach and sand dunes will likely recover over the next 10-15 years, and may not see such extreme erosion events for 50 years. However, climate change and predicted sea level rise (Gehrels, Belknap and Black 2002) may increase the frequency of these more extreme erosional events, causing more damage to dunes, dune woodlands and park infrastructure. Already, the rate of sea level rise at many of Maine's beaches may be too great for the landward transgression of dunes, and much of the sand budget at many beaches is moving offshore (Stephen Dickson, personal communication).

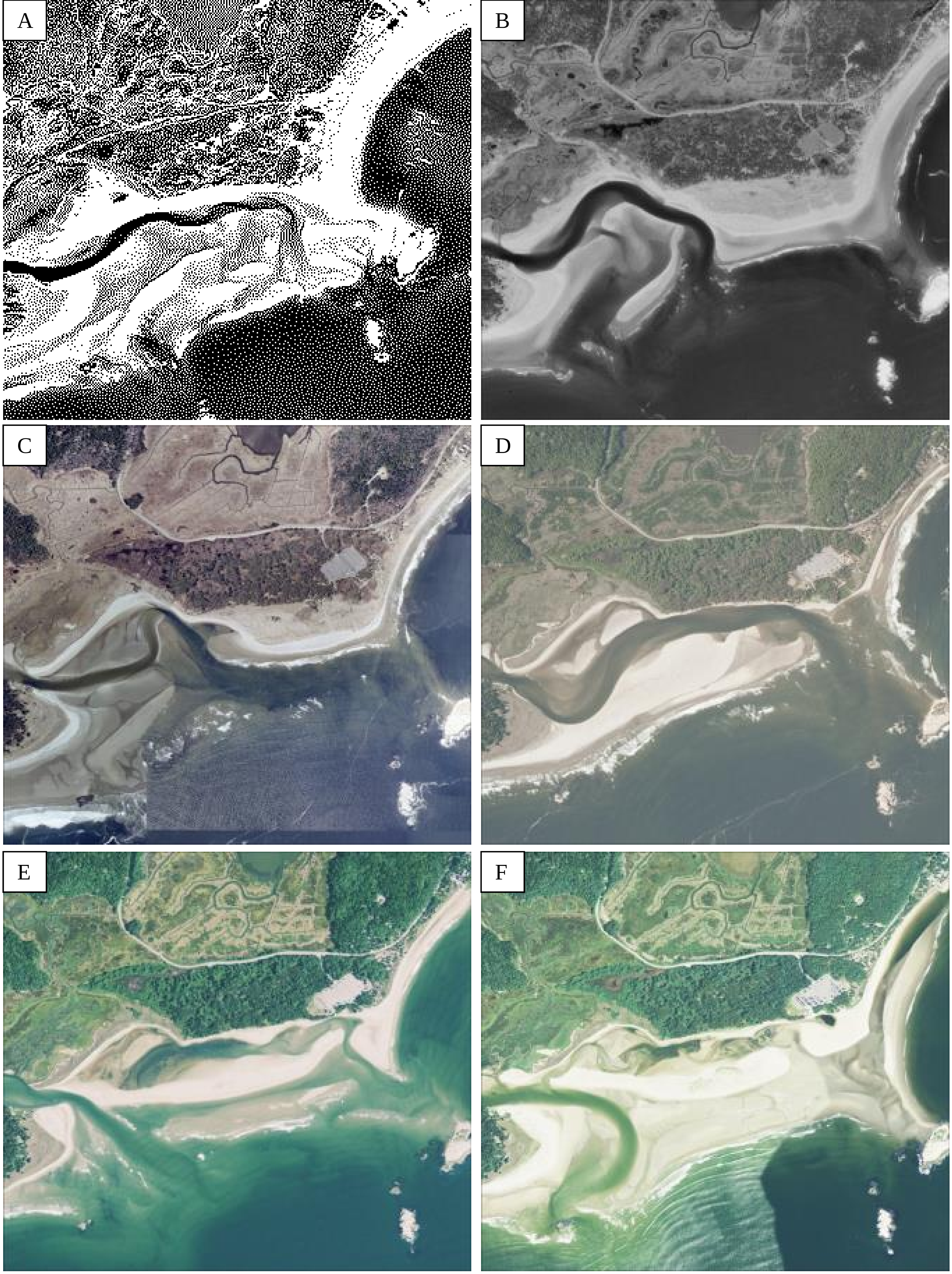

Figure 2. Chronology of Morse River migration at inlet. A: Image from 1953 showing the last severe erosion cycle, where dune systems were completely eroded away (image from Maine Geological Survey). B: Image from 1996, dune systems have recovered from previous erosion cycles. C: Image from 2003, when eastward channel begins to form. D: Image from 2009, Patriot's Day storm of 2007 causes the course of the Morse River to run parallel to the shoreline initiating extreme dune erosion. Bathhouse is constructed in the Spring of 2009. E: Image from 2011, showing breach of Seawall Beach by Morse River that occurred in March 2010. Tidal currents in eastern mouth of Morse River continue to erode area in front of parking lot and bathhouse, toppling trees and threatening structures. F: Image from 2013. Beach scraping performed in December 2011 has closed off east mouth of the Morse River. Risk to park infrastructure is greatly lowered until the next erosion cycle.

Till Deposits

Till, an unsorted glacial material deposited by receding glaciers, is the predominant surficial deposit in upland sites. Till is not sorted by the movement of water and includes rock and sediment of all sizes. Soils that form from till tend to be very stony and are rarely prime for farmland, but are sometimes pastured. At Popham Beach State Park, till mostly weathers to form soils in the Hollis series, a soil type low in iron sulfides that includes gneiss, schist, and granite, and which is typically shallow to bedrock (Soil Survey Staff 2013). A small area north of Spirit Pond contains soils in the Sutton series. These soils are typically deeper and occur in flat depressions, where hydraulic (groundwater) connectivity is relatively high throughout (Soil Survey Staff 2013). Vegetation on Hollis and Sutton soils is not markedly different within Popham Beach State Park.

Thin Drift

Areas delineated as having thin drift deposits contain considerable exposed bedrock. These areas are relatively steep and ledgy and are typically dominated by conifers in the overstory. Many trees are often stunted due to poor growing conditions.

Organic Deposits

At Popham Beach, the primary areas containing organic (or peat) deposits are within saltmarshes. Roughly 11,000 years ago, post-glacial land-mass rebound was at its peak, and sea level in Maine was nearly 60 meters below the current sea level (J. T. Kelley 2013, Barnhardt, Belknap and Kelley 1997). For several thousand years, areas now occupied by saltwater marshes were uplands or freshwater wetlands, and formed freshwater peat. As the land mass began to settle, and these areas were again flooded by salt water, saltmarshes replaced freshwater wetlands. While freshwater peat is often composed of purely organic material, salt peat is usually composed of a mix of fine inorganic sediments and organic material. Combined, the freshwater peat and salt peat in saltmarshes is often several meters thick (Orson, Warren and Niering 1987, Buynevich and FitzGerald 2002). Due to the dynamic nature of beach deposits, organic sediments may be buried by sand but visible as a layer within the beach. Like submerged organic deposits, organic material buried under sand decomposes only very slowly due to saturation and anaerobic conditions. These organic layers are less prone to erosion than beach deposits, and at Popham Beach have played a role in shaping the Morse River (Dickson 2012).

Land Use History

Phippsburg has been the site of intensive human habitation for thousands of years. Numerous shell heaps (or 'middens') and shards of ancient pottery have been found around Phippsburg, including at a site within the grounds of what was later to become Fort Baldwin. Evidence suggests that Abenaki peoples may have used what is now Popham Beach State Park seasonally as a base for fishing activities (Phippsburg Observer 2010). It is possible that native peoples would have used fire to manage upland forests for wild game, given that there is considerable historic evidence of fire along the Phippsburg peninsula (Barton, The Dynamics of Pitch Pine Stands in the TNC Basin Preserve, Phippsburg, Maine 2012).

In 1607, a group of ~100 colonists arrived and established Fort Baldwin, the first colony in New England. This colony was established in an area adjacent to what is now Popham Beach State Park, led by George Popham, nephew of Sir John Popham, financier and namesake to the colony and beach. These early colonists likely cleared some of the forest to create pasture, built structures, and constructed Maine's first ship: the Virginia. The colony only lasted one year and its lasting impact on the natural areas of Sabino Head are unknown. However, a steady stream of new colonists were arriving to the Maine coast by the late 1600s, including Phippsburg, and much of the upland area was cleared for pasture and for timber resources over the subsequent ~200 years (Brand n.d.). Pastures were abandoned en masse statewide in the late 1800s as wool from richer pastureland in the Midwest and west found eastern markets via the Erie Canal (Wessels 2006). This is a scenario that likely played out at what is now Popham Beach State Park.

In the early 1700s, the saltmarshes in Phippsburg were divided into lots to access the valuable salt hay (Brand n.d.). Trenches were dug to drain the marshes, and these are still visible in aerial photography. Salt hay was harvested initially by hand and later using horse-drawn mowing machines. Horses would wear large wooden horseshoes to keep from sinking in the mud. Hay was stacked on platforms known as 'staddles' to keep it from floating away while it dried and was often collected in the winter once the marsh had frozen (Hussey n.d., Packham 1997). Salt hay harvesting came to an end in the early 20th century, although ditching may have continued into the mid-20th century in a failed attempt to control mosquito populations. The road which eventually became Route 209 was constructed to cross the marsh to connect Sabino Head to the mainland sometime in the late 1700s- early 1800s, based on an examination of old topographic maps and charts.

Park Vulnerability to Projected Sea Level Rise

Because of the uncertainty of future glacial melt rates in the Greenland and Antarctic Ice Sheets, climate scientists predict a wide range of possible sea level rise outcomes. However, most models predict a minimum of 0.6-1' of sea level rise by 2100 (based on continuation of current rates of sea level rise), and some models incorporating increased glacial melt and other complex factors predict as much as 6.5' of sea level rise (National Research Council 2010). Using 2 meter resolution LIDAR digital elevation model data, the Maine Geological Survey has spatially projected sea level scenarios for 1', 2', 3.3' and 6' of sea level rise. These scenarios as they apply to Popham Beach State Park are shown in Appendix 2.

Currently, 230 acres or 35% of park area is flooded during the highest annual tide. This includes most areas of intertidal beach and beach strand as well as saltmarsh. The remaining 422 acres (GIS, not surveyed acreage) of non-tidal lands, primarily uplands, including areas dominated by sand deposits, till and organic deposits, will become increasingly flooded as sea level rise increases. As much as 8% of the non-tidal area of the park will be inundated with 1' of rise, and 25% of the non-tidal area of the park will be inundated at 6' of rise (Table 1). It is important to note that the effects of sea level rise are complex, with many variables. The impacts may be greater or lesser than projected high tide lines may suggest, depending on sedimentation rates of coastal wetlands and the fluidity of sandy environments. As recent history shows, the erosion of dunes above the mean high tide line is likely.

Table 1. Acreage and percentage of current non-tidal wetlands and upland area flooded at Popham Beach State Park during the highest annual tide with four different sea level rise scenarios.

Sea level rise, in feet	Acres	% of current non-tidal area
1	35	8%
2	57	13%
3.3	77	18%
6	104	25%

Ecological Features and Potential Effects from Sea Level Rise and Climate Change

Characteristic ecological processes of the rare and exemplary natural communities, as well as other dominant habitat types, are addressed in this section. Rare plants, rare animals, Significant Wildlife Habitats, and Essential Wildlife Habitats are discussed in the context of the natural communities in which they occur. The potential impacts from sea level rise and climate change on the natural resource features is discussed under each natural community or dominant habitat type.

Natural communities present at Popham Beach State Park can be divided into three general categories: sandy habitats, wetlands, and uplands. A complete vegetation map can be found in Appendix 2.

Sandy Habitats

Sandy habitats develop as a result of sediment deposition through wave action, current and wind. Species living here are well adapted to a constantly changing environment, including both erosion and deposition of sand. These species are also tolerant of salt spray and exposure. Many coastal sandy habitats statewide are especially vulnerable to sea level rise because adjacent uplands and back dunes are developed, a rigid boundary that will prevent landward sand movement. Natural communities in sandy habitats include Sandy Bottom, Beach Strand, Dune Grassland, Rose - Bayberry Maritime Shrubland, and Pitch Pine Dune Woodland.

Sandy Bottom

These low tidal areas constitute sandy parts of the beach that are largely submerged, as well as areas of the beach that regularly are exposed to wave action (surf zone). Due to the constantly shifting substrate and wave disturbance these areas are un-vegetated, but provide important habitat for mollusks, arthropods and fish species. These, in turn, are important food sources for shorebirds.

Animals have adapted in a number of ways to this environment. A number of species bury themselves in the sand in sub-tidal areas to hide from predators or wait for prey including moon snails (*Naticidae*), whelks (various families), sand dollars (*Echinarachnius parma*), lady crab (*Ovalipes ocellatus*), and American lance (*Ammodytes spp.*). Mole crabs (*Emerita spp.*), razor clams (*Ensis directus*), and coquina clams (*Donax spp.*) inhabit the surf zone and are important prey species for shorebirds (Tyrell 2005). Shorebirds using this habitat during the summer months include Piping Plovers (see 'Beach Strand' section for more information about this species), Sanderling (*Calidris alba*), Semipalmated Plover (*Calidris semipalmatus*), Semipalmated Sandpiper (*Calidris pusilla*), Willet (*Tringa semipalmata*), Whimbrel (*Numenius phaeopus*), Black-bellied Plover (*Pluvialis squatarola*), and others. In the winter months, shorebird composition shifts and includes northern migrants including Surf Scoters (*Melanitta perspicillata*), White-winged Scoters (*M. fusca*), and Eiders (*Somateria spp.*) (Maine Department of Inland Fisheries and Wildlife 1982-2013). Purple Sandpipers (*Calidris maritima*), a species of special concern in Maine, also frequent the shoreline at Popham Beach during the winter months. Purple Sandpipers are a circumboreal species that breeds in the arctic and migrates to the east coast during the winter, mostly occupying rocky coastline and offshore islands. Maine has a 'high responsibility' for this species because a large portion of the North American population winters off Maine's coast (Mittelhauser, Tudor and Connery 2013). Purple Sandpipers are considered vulnerable to sea level rise and climate change; however, sandy habitats are somewhat marginal for Purple Sandpipers, and changes to wave exposed rocky shorelines are likely to have a greater impact to this species than changes to sandy habitats.

Because they lack vegetation or other organisms providing biogenic habitat, such as eelgrass, kelp, or mussel beds, sandy bottoms are some of the most resilient marine environments to human activities such as scouring from fishing nets or trampling by recreation (Tyrell 2005). It is unlikely that climate change will impact the *extent* of these communities at Popham Beach. However, rising temperatures and ocean acidification may have profound effects on mollusk communities and the species dependent upon them.

Beach Strand

Beach Strand communities constitute sparsely vegetated upper beaches and foredune areas only flooded at especially high tides. Many areas accumulate debris including driftwood, rotting kelp, and eelgrass, which provide cover and constitute a seed bed for recruitment of several plant species. Plants occurring in this community are halophytes, species highly adapted to salt spray, periodic flooding, and sand deposition, and are specialized to the various micro-environments present on the Beach Strand. Plant adaptations to tolerate saltwater conditions include regulation of roots to salt uptake, extrusion of salt from salt glands and salt bladders, succulence to dilute the concentration of salt within the plant and provide other molecular-level benefits, and waxy leaves and stems protect the plants from salt absorption (Packham 1997). Vegetation in Beach Strands is often considered 'early successional' because it traps sand allowing more densely vegetated Dune Grasslands to develop.

The most common pioneer species along the Beach Strand at Popham include sea rocket (*Cakile edentula*) and saltwort (*Salsola kali*, non-native). Both species are annuals with high salt tolerance and with heavily branching stems that capture sand during summer months. Depending on erosion and accretion cycles of the beach sand, these species may capture and stabilize sand above high tide line allowing American beachgrass (*Ammophila breviligulata*) to colonize. Other dune species, including beach pea (*Lathyrus japonicus*) and beach wormwood (*Artemesia stelleriana*), will also

Sparseley vegetated Beach Strand a Popham Beach State Park.

colonize once sand has been stabilized. These species are highly tolerant to being buried by sand and during accretion periods the sparsely vegetated Beach Strand will succeed to more densely vegetated Dune Grasslands. Other common Beach Strand / foredune species at Popham include sea-kale (*Atriplex patula*), seabeach sandwort (*Arenaria peploides*) and rough cocklebur (*Xanthium echinatum*) (Trudeau, Godfrey and Timson 1977).

The recent erosion and subsequent relocation (avulsion) of the Morse River channel through Seawall Beach has led to an unusual circumstance where beach vegetation is migrating from one beach to another. Prior to the avulsion, accreting sand along the eastern end of Seawall Beach was being colonized by the foredune species American beachgrass and beach pea. Following the avulsion, this beach spit became an island and has stayed sufficiently above mean high tide to continue to support scattered beach vegetation. Natural processes are pushing this sandbar island onto Popham Beach (see Figure 1), and the first colonists of the new dunes and foredune areas may be 'immigrant' vegetation from Seawall Beach.

While Beach Strand communities are relatively common in Maine and throughout New England, undisturbed examples of this community are rare. Coastline development including the construction of jetties, seawalls, and piers, as well as residential development, has led to the reduction of Beach Strands by over 75% throughout the northeast (Maine Department of Inland Fisheries and Wildlife 2014). This has had dire effects on the viability of a pair of bird species that depend on Beach Strand areas for nesting habitat: Piping Plover and Least Tern. Piping Plovers and Least Terns have been impacted across their range, and they are listed as endangered under the Maine Endangered Species Act. Piping Plovers are also federally listed as a threatened species. The Maine Department of Inland Fisheries and Wildlife has designated Essential Habitat for Piping Plovers and Least Terns for the entirety of the beach and foredune area at Popham Beach State Park (Appendix 2).

Piping Plovers and Least Terns make their nests in foredune sand troughs in the spring and are highly vulnerable to disturbance from recreational activities.

Piping Plover (*Charadrius melodus*). Photo: Doug Suitor.

These species are threatened by numerous native and non-native predators within the coastal zone. Dogs, cats, foxes, raccoons and other predators account for nearly all Piping Plover mortalities during nesting season. The Audubon Society, U.S. Fish and Wildlife Service, and Maine Department of Inland Fisheries and Wildlife have worked in partnership to protect Piping Plover and Least Tern nests in Maine since 1981. Due to their efforts, which include roping off nesting areas, fenced exclosures around nesting sites, public outreach, and predator and pet control, nesting pairs of Least Terns and Piping Plovers have been increasing. In 2012, 13 young Piping Plovers fledged from 6 nesting pairs, the most since 1997. Additionally, a new colony of Least Terns formed in 2012 at Popham Beach State Park (Least Terns had not nested at Popham Beach for many years prior). In 2013, predation by foxes prevented Least Terns from fledging young, and reduced the number of fledgling Piping Plovers. Despite episodes of predation, Popham Beach's relatively undeveloped setting has maintained high-quality habitat for Least Terns and Piping Plovers. In contrast, the adjacent and more developed Hunnewell Beach has not been used by Piping Plovers for many years (Maine Audubon Society 2012, Maine Audubon Society 2013). Other wildlife species that use this habitat include Common Terns (*Sterna hirundo*) and other more common migratory shorebirds (Gawler and Cutko 2010).

Statewide, Beach Strand communities are highly vulnerable to climate change. As sea level rises, Beach Strands will likely migrate landward. If there is ample room to accommodate such migration (i.e. undeveloped backdune areas), there is a good chance that these habitats will continue in the future. However, in areas where Beach Strand communities are backed by developed dunes (i.e. seawalls or coastal development), it is likely these areas will be lost, with dire implications for the species that depend on these habitats. Fortunately, the relatively undeveloped areas of Popham Beach State Park may be large enough to accommodate the migration of Beach Strand habitat under some projections of sea level rise.

Dune Grassland

Dune Grasslands typically occur well above the mean high tide line and are formed through combined effects of sand accretion (as a result of wind, current and wave action) and the effects of dune vegetation, which collects and stabilizes sand.

Like the Beach Strand, the Dune Grassland environment is especially harsh. Dunes are extremely dry and windswept, often well above the water table, and well developed soil structure is completely absent. Because of this harsh environment, only a few species thrive here. American beachgrass (*Ammophila breviligulata*) is dominant in near-shore areas. Well adapted to being buried by sand and forming deep root networks, this species is primarily responsible for the stabilization of dune sand. Species that co-occur include beach pea (*Lathyrus japonicus*), which is codominant in some areas, raspberry (*Rubus idaeus*), gooseberry (*Ribes hirtellum*), and sea-beach sedge (*Carex silicea*). Dry backdunes will generally contain the above species, beach-heather (*Hudsonia tomentosa*), *Cladonia* lichens, beach pinweed (*Lechea maritima*), flax-leaved stiff aster (*Lonactis linariifolia*), and bayberry (*Morella caroliniensis*) (Trudeau, Godfrey and Timson 1977, Hoffman and Buonopane 1996).

Dune Grasslands have been drastically reduced from their historic extent by development and are considered rare (S2) in Maine. Existing Dune Grasslands on private and public ownership are highly sensitive to degradation from recreational use. Even light foot traffic can cause unintended consequences that have long lasting impacts to dune systems (Gawler and Cutko 2010).

Beach grass (*Ammophila breviligulata*) colonizing new dune area at Popham Beach State Park.

Prior to 2007, the Dune Grasslands at Popham Beach State Park were some of the largest and most intact in the state. Following the Patriot's Day Storm of that year and the subsequent erosion events (see Figure 2), roughly 20 acres of Dune Grasslands were washed away, leaving only ~11 acres remaining within park boundaries. While the erosion events between 2007 and 2012 were far more severe than any that have occurred in the previous 100 years, the catastrophic dune erosion that occurred was not completely without precedent. In 1953, the Morse River initiated an extreme erosion cycle that completely eliminated nearly the same area of Dune Grassland. In less than 25 years, these 20 acres of dunes had recovered, as is evident from reports and aerial imagery (see Fig. 1). It is largely *because* of these erosion and accretion events that such large Dune Grasslands develop at Popham Beach, for without regular natural disturbance events, these areas would likely become forested.

Like Beach Strand communities, Dune Grasslands are important habitat for Least Terns and Piping Plovers. Many other common ground nesting shorebird species utilize dunes for nesting habitat including some of the most common denizens of beaches such as the Herring Gull (*Larus smithsonianus*), Ring-billed Gull (*L. delawarensis*), Spotted Sandpiper (*Actitis macularius*), and Great Black-backed Gull (*L. marinus*). Other ground nesting bird species that may utilize Popham Beach include the Common Tern and the Short-eared Owl (*Asio flammeus*).

Dune Grasslands are equally if not more vulnerable to climate change than Beach Strand communities. Evidence at some Maine beaches indicates that the current rate of sea level rise paired with cross-shore currents may be too great to develop new landward dunes, due to sand being moved offshore (Stephen Dickson, personal communication). With moderate rates of sea level rise, Dune Grasslands will likely move landward. Where dunes or backdune areas are developed, there will be little room for these systems and they may be lost. In the near term, Popham Beach is in an accretion cycle. It is likely that the dunes that eroded in the last few years will re-form. However, projections for sea level rise indicate that erosion periods will likely be more extreme in the future, causing cycles of landward dune migration. Forested backdunes at Popham likely provide adequate buffers. However, it is possible that the parking lot and bath houses are in the path of landward dune movement.

Rose - Bayberry Maritime Shrubland

Rose - Bayberry Maritime Shrubland is a common coastal natural community that occurs on a variety of substrates along the coast. This natural community is often well above mean high tide line, but may be flooded during storm tides. Other stressors include salt spray and wind and weather exposure. Rose - Bayberry Maritime Shrublands are among the least impacted coastal communities by recreation, due to their dense, inhospitable shrub cover. However, few 'natural' examples of this habitat are known, as much of the area now occupied by this shrubland was historically used for agriculture or other land use.

At Popham Beach, dominant species include bayberry (*Morella caroliniensis*), Virginia rose (*Rosa virginiana*), meadowsweet (*Spiraea alba*), raspberry (*Rubus idaeus*), and poison ivy (*Toxidendron* sp.). Also found are the invasive Morrow's honeysuckle (*Lonicera morrowii*), rugosa rose (*Rosa rugosa*), and Japanese barberry (*Berberis thunbergii*). Despite the somewhat early-successional appearance of this natural community, this shrubland may be very stable. The roughly 8 acres of shrubland at Popham Beach delineated by Trudeau et al. 1977 are still extant today and have not succeeded to forest.

The extent to which these shrublands are used by wildlife is not fully known. In southern Maine, shrublands provide important habitat for the State Endangered New England cottontail, a species not found in the Midcoast. It is suspected that in the appropriate setting, these shrublands may provide nesting habitat for Common Eider, Black Duck (*Anas rubripes*), and Herring and Great Black-backed Gulls (Gawler and Cutko 2010).

Rose - Bayberry Maritime Shrublands may be pushed further inland by rising sea levels, but this community type is generally considered to be at low risk. At Popham Beach, current sea level rise projections indicate that current areas of shrubland may be exposed to more regular dune erosion and accretion processes.

Pitch Pine Dune Woodland

Pitch Pine Dune Woodlands are stable backdune communities with open (~ 35% closure) canopies. Eolian (windblown) sand continues to be deposited in these areas and restricts the vegetation that occurs here. These woodlands are largely south-coastal in distribution and reach their greatest extent on Cape Cod. Because of their limited range and development pressure, these communities are considered globally rare (G2G3). These natural communities are considered very rare in Maine as well (S1), and many of the historic examples are now developed.

Pitch pine came to Maine, along with the state's other fire adapted pines, 7-8 thousand years ago during a climactically dryer period, where natural (and possibly human caused) fires were more common (Barton, White and Cogbill 2012). As the climate cooled, the extent of fire adapted species became increasingly restricted to a collection of isolated sites where xeric environments and/or continued fire regimes allowed them to persist. For pitch pine, this includes sandy outwash plains in southern Maine where regular fire intervals allow pitch pine recruitment, dry bedrock outcrops, coastal bogs, and backdunes. Phippsburg has had a rich fire history, the most recent a ~6,000 acre fire in 1926 (Barton 2012). While Pitch Pine Dune Woodlands may not require fire disturbance to persist, the fire adapted species that occur in these communities were likely able to spread here as a result of landscape-scale fires.

Pitch pine dune woodland at the eastern end of the park.

Pitch Pine Dune Woodland occupies ~45 acres of Popham Beach State Park, and this example is the largest of this community type in Maine. Pitch pine is dominant in the canopy, but scattered red maple, red oak, and paper birch are very occasional. Some areas are densely wooded, while others are glade-like, with beach heather and cladonia lichens growing in openings. Trees range in age from 90-150 years old, are somewhat stunted at 25-40 feet tall, and have an average diameter of 8 inches. Understory species include beach heather, American beach grass, wavy hair grass (*Deschampsia flexuosa*), shaved sedge (*Carex tonsa*), Canada-mayflower (*Maianthemum canadense*), bayberry (*Morella caroliniensis*), wild sarsaparilla (*Aralia nudicaulis*), starflower (*Trientalis borealis*), bunchberry (*Cornus canadensis*), and trailing blackberry (*Rubus hispidus*).

Extensive wildlife surveys have not been performed for Pitch Pine Dune Woodlands at Popham Beach State Park. However, it is likely that songbirds including

Prairie Warbler and Pine Warbler may utilize this open habitat. Additionally, a number of rare moths that specialize on pitch pine, including the oblique zale (*Zale obliqua*), pine pinion (*Lithophane lipida lipida*), and the southern pine sphinx (*Lapara coniferarum*) may occur at this site.

Pitch Pine Dune Woodland is extremely vulnerable to climate change, especially at Popham Beach State Park. There is no mechanism for Pitch Pine Dune Woodlands to migrate landward. Eolian deposition rates are not great enough to counterbalance sea level rise; pitch pine dune woodlands are comprised of land based vegetation that colonizes sand dunes after they have been stable for many years. Climate change and sea level rise are likely to bring about a period of extreme instability to beach and dune systems, and will likely lead to loss of many of our dune forests. During the erosion cycle of 2007-2012, 1.7 acres of pitch pine dune woodland were washed away, including trees over 100 years old. While this event cannot be definitively linked to climate change, it illustrates how this natural community will be impacted by extreme weather events and rising seawater. At Popham Beach the existing Pitch Pine Dune Woodland already occurs at a high-point between two saltmarshes and has no area to which it can migrate. Loss of Pitch Pine Dune Woodland area by 2100 as a result of tidal flooding is predicted to be 8 acres (18%), 14 acres (31%), 18 acres (40%) and 26 acres (58%) for 1', 2', 3.3' and 6' of sea level rise, respectively. This analysis does not take erosion resulting from severe storms into account, so loss is likely to be greater.

Estuarine Wetlands

Although part of the same wetland system, the tidal marshes at Popham Beach State Park are part of two separate watersheds. The tidal marshes to the west of Route 209 drain to the Morse River, while those to the east empty into Atkins Bay, part of the Lower Kennebec. Though Route 209 largely represents the height of land between the two tidal marshes, a 2.5 acre area nested within the backdune may have been impounded by the road or other human activity, and is currently supporting a brackish pool and cattail marsh. Tidal marshes provide critical habitat for many wildlife species, including migratory birds and fish. It is estimated that 2/3 of commercial fish and bait species landed in the Gulf of Maine depend on estuarine wetlands at some point in their life cycle (Dinne, Bonebakker and Whiting-Grant 2011).

Spartina Saltmarsh

Spartina Saltmarsh, dominated by *Spartina* grasses.

There are approximately 190 acres of Spartina Saltmarsh within Popham Beach State Park, which represents a significant portion of the 350 acre Morse River- Atkins Bay Spartina Saltmarsh. Spartina Saltmarshes (S3) are estuarine wetlands dominated by a suite of halophytic plants occurring in zones defined by their degree of tolerance for saltwater and inundation. Narrow fringing tidal marshes occur in places where coarse sediments, surf, or high tidal gradients prevent accumulation of sediment and peat into large flats, and are smaller and less diverse than Spartina Saltmarshes. Spartina Saltmarshes are found in places protected from wave and current action, such as behind barrier beaches. Spartina Saltmarshes are typically more diverse, and develop salt pannes, marsh border communities and numerous tidal inlets or channels.

Low areas of the Spartina Saltmarsh including river channels and low flats that are flooded twice daily are dominated by saltwater cord-grass (*Spartina alterniflora*), a perennial deciduous grass that often occurs in monoculture. High marsh flats are dominated by salt-meadow grass (*Spartina patens*), with scattered rushes (*Juncus balticus, Juncus gerardii*), sea-milkwort (*Glaux maritima*), sea lavender (*Limmonium nashii*), saltmarsh arrow grass (*Triglochin maritima*), seaside goldenrod (*Solidago sempervirens*), saltmarsh tuber-bulrush (*Bolboschoenus maritimus*), and others. Non-native alkali grass (*Puccinellia maritima*) was introduced to North America in ships' ballast (Haines 2011) and is occasionally co-dominant with salt-meadow grass (Trudeau, Godfrey and Timson 1977).

Several rare plants occur within the Spartina Saltmarsh, including saltmarsh false foxglove (*Agalinis maritima*, S3), sea-coast tuber-bulrush (*Bolboschoenus robustus*, S2) and the state's only occurrence of purple false-foxglove (*Agalinis purpurea*, S1). Purple false foxglove occurs between the sandy road shoulder north of Route 209 and the saltmarsh. Because of its location, it is possible that purple false foxglove may have been introduced here during road construction and is therefore not a natural occurrence of the species. Saltmarsh false foxglove and sea-coast tuber-bulrush both occur in high-marsh areas, and the greatest concentrations of these species (>1000 plants) are within areas of marsh adjacent to Campbell Island (a marsh-bound island in the west of the park).

The rare sea-coast tuber-bulrush (*Bolboschoenus robustus,* S2) occurring within high marsh at Popham Beach State Park.

Areas within the Morse River-Atkins Bay saltmarsh have been highly disturbed by ditching for salt hay and mosquito control. Saltmarsh ditching greatly impacts the hydrology of the marsh by vastly reducing the overall area of salt pannes and making the saltmarsh a more uniform, homogenous environment. Salt pannes are typically sparsely vegetated, with widgeongrass (*Ruppia maritima*) and algal associates comprising the most common cover. Other areas of the marsh likely to be impacted by ditching include low areas of the high marsh dominated by glasswort (*Salicornia maritima*), seaside plantain (*Plantago maritima*), blue green algae, and others.

Spartina Saltmarshes are highly productive and critical feeding and nesting habitat for many coastal wildlife species. Dead plant material forms the base of the food web, feeding invertebrates including insects, snails, crabs, amphipods, shrimp and worms. Two species of mosquitos (*Aedes cantator* and *A. sollicitans*) exclusively breed in fishless (very small) saltmarsh pools (Maine Forest Service, Insect and Disease Labaritory n.d.). Small fish species including mummichogs (*Fundulus heteroclitus*) and

Atlantic silversides (*Menidia menidia*) lay their eggs in saltmarshes, which adhere to saltmarsh cordgrass stems, and feed on invertebrates. These small fish, in turn are prey to commercial fish species, including striped bass and winter flounder, which will come to saltmarshes to feed (Packham 1997, Taylor 2008).

Popham Beach State Park has one of the northernmost occurrences of the rare salt marsh tiger beetle (*Cicindela marginata*) in Maine. The salt marsh tiger beetle is found at the park within a sparsely vegetated Beach Strand at the convergence between the backdune and the Spartina Saltmarsh, and is considered a species of special concern in Maine. In 2010, 40 adults were observed at Popham Beach. Larval habitat for salt marsh tiger beetles mirrors adult beetle habitat, and consists of sand burrows near the high tide line on protected backdunes, adjacent to tidal marsh. The salt marsh tiger beetle preys on other invertebrates in and adjacent to saltmarshes (Ward and Mays 2011).

Backdune – saltmarsh interface, important habitat for the rare salt marsh tiger beetle (*Cicindela marginata*).

Many migratory, shore and seabirds depend on saltmarshes both for nesting and feeding habitat. One of the northernmost populations of Saltmarsh Sparrow (*Ammodramus caudacutus*) in North America is at Popham Beach. Saltmarsh Sparrows nest on the ground within the high marsh area and are a species of special concern in Maine. Saltmarsh Sparrow nests are often flooded during high tide, which is not necessarily lethal to young. However, a recent study indicates that the number of flooding events is directly related to the success of the nest in fledging young, and that an increase in flooding events in the high marsh could have a negative impact on the viability of Saltmarsh Sparrows (Bayard and Elphick 2011).

Saltmarshes are complex systems that change in size depending on sediment accretion rates and sea level. Human influences have long played a role in the shaping of saltmarshes; sediment accretion rates rose significantly following European settlement and deforestation due to increased runoff, causing dramatic increase in saltmarsh area in many places (Kirwan and Murray 2007). Evidence indicating a dramatic expansion in saltmarsh cordgrass (low marsh) and a decrease in high marsh (Donnelly and Bertness 2001) over the last 150 years may be more related to a decrease in sedimentation rates (as a result of reforestation) than to rising sea level.

Spartina Saltmarshes are considered highly vulnerable to climate change. These systems exist in equilibrium by balancing sediment accretion rates with sea level rise, and rapid changes to either part of the equation could have major consequences for the viability of coastal marshes. Models examining the relationship between sea level rise and sediment accretion indicate that over the next 100 years, saltmarshes will likely expand along their landward edge where topography allows, and will increasingly be eroded away along stream channels, although rapid rates of sea level rise could potentially lead to catastrophic marsh loss (Kirwan and Murray 2007).

These effects may be compounded by historical land-use of saltmarshes. Ditches dug for the production of salt hay or mosquito control may make marshes more vulnerable to erosion. Unfortunately, the now widely used restoration technique of ditch-plugging in saltmarshes is now known to increase erosion and die-off of *Spartina* grasses (Vincent, Burdick and Dionne 2012).

Expansion of stream channels as a result of sea level rise, including the Morse River, could potentially increase erosion of adjacent dunes. Because these dune systems largely protect the Spartina Saltmarsh from wave action and storm surges, sea level rise could ultimately lead to a negative feedback loop where both marshes and dunes are rapidly eroded. While it is difficult to predict specific outcomes from sea level rise, it is likely that overall marsh area will be reduced, especially high marsh, with adverse consequences for plants and wildlife that depend on this habitat.

Cattail Marsh

Cattail Marsh within Popham Beach State Park likely occurs as a result of impoundment by Route 209. Prior to the road construction in the early 1800s, this area may have included high-marsh species. This cattail marsh does include some high marsh species (*Bolboschoenus maritimus, Spartina pectinata*), but it is dominated by narrow-leaf cattail (*Typha angustifolia*), a species now thought to be non-native to New England (Haines 2011). It is likely that this area does receive some tidewater during very high tides. This Cattail Marsh is not of high conservation concern.

Upland Forest

246 acres of upland forest are within the park boundary. Upland forest communities at Popham Beach State Park include Mixed Forest, Oak-Pine Woodland, Oak- Northern Hardwoods Forest and Spruce-Fir Forest.

At Popham Beach, upland forest is important for buffering adjacent wetlands from sedimentation. Intact, mature examples of upland forest are rare due to southern Maine's land use history. Similarly, sufficiently large examples are under-represented in conserved lands in central and southern Maine (Schlawin and Cutko 2014).

Upland forest areas are unlikely to be impacted greatly by sea level rise at Popham Beach State Park. However, other impacts of climate change, including increased frequency of severe storm events, increased activity of non-native tree pests and other invasive species, and changing microclimates could affect upland forests. Hemlock woolly adelgid, an invasive tree pest, has already been detected in Phippsburg. Hemlock woolly adelgid has rapidly spread from a handful of occurrences in southern Maine only a few years ago to the entire coastline. The hemlock woolly adelgid stresses trees, ultimately killing them, and is likely to further expand its range as mean annual temperatures rise. Other invasive insect pests that could potentially impact Popham Beach State Park include winter moth and emerald ash borer.

Currently, invasive plant species are not out-competing native plants. Invasive plants have been found in several locations along dunes or in shrublands, and in formerly settled areas where invasive earthworms (*Lumbricus terrestris*) were found in the soil. Morrow's honeysuckle and Japanese barberry are present but uncommon, and other species have not yet been detected. As the surrounding landscape continues to become more fragmented by development, an increase in invasive plants introduced through soil disturbance, landscaping, or other vectors is possible. Early detection and removal of invasive plant species will keep natural areas intact.

Mixed Forest

Mixed forest was mapped where generic, unexceptional upland forest natural communities could not be distinguished from one another. At Popham Beach State Park, this includes oak-pine forest, hemlock forest, upland cedar forest, aspen-birch forest, or spruce-northern hardwoods forest. While these generic upland forests are not primary habitats for coastal plant and animal species (nesting/breeding), they provide essential secondary upland habitat for many species of greatest conservation need (Maine State Wildlife Action Plan, work in progress).

Spruce-Fir Forest

Spruce-fir forest is one of the most common forest types in Maine, and it is well adapted to the cool, moist, sub-boreal climate of the Downeast coast, western mountains, and northern regions. However, in central and southern Maine, this forest type is relatively uncommon, and occurs only in patches right along the coast and in isolated locations.

Within Popham Beach State Park, Spruce-fir forest is dominated by red spruce (50% cover), with lesser amounts of white pine, red maple, hemlock, and balsam fir. Mature trees are ~ 80 years old. Most of the spruce-fir forest at Popham Beach State Park occurs on thin soils. The understory is dominated by tree regeneration, largely spruce and fir, but also includes intermediate wood fern (*Dryopteris intermedia*), Canada mayflower (*Maianthemum canadense*), starflower (*Trientalis borealis*), bracken fern (*Pteridium aquilinum*), wavy hair-grass (*Deschampsia flexuosa*), and others. Three-lobed bazzania (*Bazzania trilobata*), a liverwort, is common in the understory.

Coastal spruce-fir forests provide valuable nesting habitat for conifer forest specialists including the Yellow-bellied Flycatcher (*Empidonax flaviventris*), Cape May Warbler (*Setophaga tigrina*), Blackpoll Warbler (*Setophaga striata*), Bay-breasted Warbler (*Setophaga castanea*), Northern Parula (*Setophaga americana*), Swainson's Thrush (*Catharus ustulatus*), and others. These forests also provide shelter for many animal species during winter months when other areas are inhospitable because of wind, sea spray, deep snow, and other variables. A warming climate could lead to decreased viability of spruce and fir in southern Maine.

Oak - Pine Woodland

Small patches of Oak - Pine Woodland occur within the park on south-facing, rocky slopes. Red oak is dominant with white or pitch pines occasional. The sparse understory contains mainly dry-site species including huckleberry (*Gaylusaccia baccata*), wavy hair-grass (*Deschampsia flexuosa*), and bracken fern (*Pteridium aquilinum*). In some locations, these habitats are known to support populations of rare invertebrates that feed on oak trees.

Oak-pine woodland, found on south facing slopes.

Pitch Pine Woodland

Several small patches of Pitch Pine Woodland occur within the upland forest portion of the park on the north side of Rt. 209 at Sabino Hill. Pitch Pine Woodland is a rare natural community type in Maine (S3) and typically occurs on rocky uplands near the coast. Pitch Pine Woodland was originally mapped for 35 acres on Sabino Hill in 1989. The early mapping was generalized, and during the NRI surveys in 2014 the area was found to be far smaller (~ 3 ac) and comprised of even smaller patches within the matrix forest. It's possible that some previously mapped area was lost due to increases in other tree species, but it's more likely that the original mapping was overly inclusive. The occurrence is too small to be considered significant for this type and is no longer tracked by MNAP.

Where the Pitch Pine Woodland does occur, the tees are on average 8 inches in diameter and are 130-150 years old. The understory is dominated by ericaceous shrubs including huckleberry, highbush blueberry (*Vaccinium corymbosum*), wintergreen (*Gaultheria procumbens*), and wavy hairgrass. At Popham Beach State Park, these habitats also contain scattered broom crowberry (*Corema conradii*). Soils are generally very thin and rocky. More extensive examples of this community occur elsewhere in Phippsburg and at Reid State Park.

Management Considerations

Popham Beach State Park has one of the highest visitation rates of all of Maine's state parks and contains some of the largest examples of important and threatened coastal habitats for plants and animals. Under current conditions, a number of the significant natural features at the Popham State Park require active management, much of which is already taking place. Dune Grassland and the nesting habitats of Least Tern and Piping Plover are vulnerable to trampling. The current approach of using signage and judicially placed fencing helps keep visitors from trampling sensitive dune vegetation and from disturbing the nesting birds.

The seaward side of the Pitch Pine Dune Woodland along with a significant area of the Dune Grassland has been heavily eroded in recent years due to the realignment of the Morse River channel. The heavy erosion has been the subject of much attention due to the increased vulnerability of the park's bath house. Fortunately, river channel has moved away from the shore and the threat of additional erosion has abated for the time being. Unfortuanately, it is probable that there will be future oscillations in the location of the Morse River channel and more erosion events. Therefore, it would be prudent to use this interval of decreased threat to consider how to limit future damage to important park features, both natural and manmade.

Other near term activities or considerations that could benefit significant natural features at the park include:

- Periodic monitoring for pests and invasive species, particularly in the Pitch Pine Dune Woodlands, Dune Grasslands, and Spartina Saltmarsh. These natural communities currently have little to no colonization of invasive species, and will benefit from being kept free of these pests.
- Periodic monitoring of sensitive areas for impacts from recreational activity, particularly the Dune Grasslands and the Pitch Pine Dune Woodlands. These communities currently receive very little visitor use. If usage patterns change to the detriment of the communities they should be addressed.
- Allowing natural succession and disturbance processes to occur unimpeded in unmanaged areas with exceptions for public safety.

- Incorporation of information on vulnerable rare plant and animal species into park planning. The salt marsh tiger beetle lives in the interface of the back dune and the saltmarsh at the west end of the park, an area that is occasionally explored by beach visitors. If use of these areas increases, the beetle habitat could be jeopardized. Consultation with an IFW biologist on the needs of the species is recommended. Two rare plant species, saltmarsh bulrush and large purple false-foxglove, occur within the park in an area very close to Rt. 209. This is the only site in the state where large purple false-foxglove is known to occur. The park may need to advocate on behalf of the protection of these rare species populations if any substantial improvements are proposed for Rt. 209 in this area.

In regards to climate change, most of the significant natural features within the park are vulnerable to impacts from sea level rise and increased storm intensity and frequency due to a warming climate. The Bureau of Parks and lands has a high responsibility for several features within the park because of their extreme rarity within the state, and their disproportionate occurrence on state park lands. Those features include Dune Grasslands, Pitch Pine Dune Woodlands, Piping Plover (E) - Least Tern (E) Essential Habitat, Saltmarsh Sparrow, Saltmarsh Tiger Beetle, and large purple false-foxglove.

While the habitats unable to adapt to sea level rise such as Pitch Pine Dune Woodland may decrease in size, other habitats such as Beach Strands, Dune Grasslands, and Spartina Saltmarsh may be able to adapt to sea level rise by migrating inland. The mechanics allowing each coastal habitat to move inland are different. At Popham Beach State Park the Spartina Saltmarsh on the west side will provide room for the landward movement of the dune formation and the associated Dune Grassland. There is relatively less room for the Spartina Saltmarshes themselves to migrate landward as sea level rises, and if some or all of the existing marsh cannot keep up with the continued tidal elevation increases, areas of marsh will be lost. As sea level rises and tidal marshes migrate onto adjacent low elevation areas, they will colonize the area currently supporting the Maritime Shrubland, as well as a portion of the Pitch Pine Dune Woodland.

Looking at the whole Morse River estuary (~262 acres), the only area with any significant potential to accommodate marsh migration are these areas within the park, though even they are relatively small in comparison to the whole marsh (~10%). The Spartina Saltmarsh on the north side of Rt. 209 adjoining Atkins Bay is bordered and the by sloping land and the road, and has negligible potential for marsh migration.

The future of the Pitch Pine Dune Woodland at Popham Beach State Park is somewhat uncertain as it cannot gradually migrate like a beach or dune as it becomes inundated by rising sea levels. However, only about a third (37%) of the community will become tidal at 3.3' of sea level rise, and the remainder will likely persist unless other erosional forces destabilize it. If a significant portion is retained, it will provide a seed source for the eventual colonization of any adjacent, newly developed, persistent dunes.

Coastal dune and wetland systems provide important buffers against storm surges for coastal development. When coastal dune and wetland systems are compromised or lost, the adjacent upland areas and associated development become increasing vulnerable to damage from storms. To reduce the potential for damage and the related costs of repairs, and to allow landward transgression of sensitive dune and marsh environments, new park infrastructure should be designed to be adaptable or moveable, or placed in areas where it won't be affected by sea level rise and other climate change impacts. During the next major erosion cycle, there may be pressure to protect park infrastructure with new seawalls. This type of adaptation could have negative consequences for Popham's iconic dunes, saltmarshes, and beach, and while only providing marginal protection for structures.

A summary table listing the projected impacts and respective management considerations for each rare or exemplary feature are listed starting on the next page.

Summary of Potential Impacts to Significant Natural Features

Dune Grassland (S2/G4?) **Size:** 11-33 acres[1]

Associated special features:

State Priority: Very high priority, the second best examples in the state (B[1] rank), there are less than 250 acres of this type statewide, feature is also a priority site for Salt Marsh Tiger Beetle because of minimal disturbance and location at the edge of its range.

3.3' Sea Level Rise inundation acreage: Without movement of the dune 14 acres will be inundated when sea level has increased by 3.3'.

Projected Change: possible migration, the feature has the potential for landward movement in areas where there are low-lying wetlands on its landward side, but not where there are higher elevation uplands or development.

Vulnerability to one-time events (storms): This feature is vulnerable to storms but has recovery potential. Frequent, heavily eroding storms could prevent its reestablishment.

Management considerations: State Parks have a high responsibility for this type due to their disproportionate occurrence on state park lands. Allowing the Dune Grassland to migrate unimpeded in response to sea level rise may aid in its persistence in the park. Other considerations; 1) monitor for impacts from human use, 2) periodically monitor for invasive plants and consider management for invasive plants if practical and if there is a high likelihood of habitat improvement, and 3) learn from outcomes in other affected east coast locations with Dune Grasslands.

[1] Dune Grassland within Popham Beach State Park is undisturbed, but adjacent disturbed area on Hunnewell Beach is considered part of the same system depressing the EO rank. Acreage reflects only Dune Grassland found on Popham Beach State Park, and reflects the acreage range anticipated given natural cycles of erosion and accretion.

Pitch Pine Dune Woodland (S1/G2) **Size:** 49 acres

State Priority: This example is a high priority, it is the most extensive and intact example of this extremely rare type in the state (A rank) and is highly vulnerable to loss due to sea level rise and erosion from intense storm events. It is also vulnerable to periodic oscillations in the channel of the Morse River which can lead to significant erosion.

3.3' Sea Level Rise inundation acreage: More than one third of the feature, 18 acres, will be inundated by the highest annual tide when sea level rise increases by 3.3'.

Projected Change: At least a third of the feature will be inundated by tidal flow, primarily entering from the west and northwest from the adjacent marshes. It is likely these newly inundated areas will be colonized with tidal marsh vegetation. The remainder of the feature will be likely be even more vulnerable to erosion, especially along the seaward side where increased sea level will bring surf into and over existing protective dunes. However, due to the extremely dynamic nature of sand deposition, changing currents, and dune formation at this site, it is difficult to predict with any certainly what will happen on the seaward side of the feature.

Vulnerability to one-time events (storms): Pitch pine has moderate tolerance to salt water spray, but low numbers of trees within this community make it more vulnerable to storm damage or impacts from pathogens. A catastrophic storm with significant storm surge and heavy surf could severely damage this and other sand based features at the park.

Management considerations: A portion of this feature will most likely be lost at some point in the future, though how soon depends on the rate of sea level rise. Prior to the eventual impacts from sea level rise, it is recommended to avoid impacts from human uses so as to retain the good condition of what will remain. Also note, pitch pines along some areas of Maine's coast are vulnerable to pitch pine shoot tip damage caused by two pests, the European pine tip moth (*Rhyacionia buoliana*) and Diplodia tip blight (*Diplodia pinea*). Both pests can affect the growth rate of affected trees, and cause them to appear stressed. Heavy damage can result in mortality, as bark beetles commonly attack severely weakened trees. Another potential pest is the southern pine beetle (*Dendroctonus frontalis*). The recent destruction of pitch pine woodlands on Long Island from the southern pine beetle is one indication of the vulnerability of this type to expanding ranges of forest pests.

Spartina Saltmarsh (S3/G5) **Size:** 350

Associated special features:

- Saltmarsh Sparrow (SC/S3B/G4)
- Salt Marsh Tiger Beetle (SC/G5)
- Tidal Waterfowl and Wading Bird Habitat
- Shorebird Roosting Area
- Large Purple False Foxglove (E/S1/G5)
- Saltmarsh Bulrush (SC/S2/G5)
- Saltmarsh False Foxglove (SC/S3/G5)

State Priority: High priority, the type is widespread on Maine's coast, but like other tidal marshes, it is vulnerable to loss if sea level rise rates exceed sedimentation rates, and or marsh migration rates onto adjacent low lying landscapes. Based on the species composition, disturbance history, landscape context, and full size of the community (including areas both in and outside of the park), this Spartina Saltmarsh is a considered to be a good quality example when compared to other examples within the state. Also note that this Spartina Saltmarsh is one of the best sites in the state for Saltmarsh Sparrow.

3.3' Sea Level Rise inundation acreage: 35 acres inundated on adjacent park lands.

Projected Change: The potential for marsh migration for the Morse River portion of the park's marshes is modest at best, with 18 acres of the Pitch Pine Woodland likely becoming marsh, along with an adjoining area of five acres in and around the patch of Maritime Shrubland. Other areas adjacent to the marsh are too elevated to accommodate anything more than a narrow band of potential new marsh area. The potential for marsh migration for the Atkins Bay portion of the park's marshes is negligible with only a narrow band in most areas, and no potential at all in a few others. If sea level rise exceeds accretion rates, areas of marsh will be lost, most likely after sea level rise exceeds 3.3'. Sea level rise will negatively impact Saltmarsh Sparrow, as their nests are vulnerable to subtle increases above normal tidal elevations.

It is also important to consider that once sea level has risen by 3.3 feet above current highest annual tide, Rt. 209, if not previously elevated, will be inundated, allowing tidal flow to cross between the Atkins Bay and Morse River portions of the marshes. If Rt. 209 were not currently obstructing the movement of tide waters, the marshes would be joined, as they probably were prior to the road's construction. If the marshes join as a result of seas level rise, it's possible a channel would develop connecting Atkins Bay to the Morse River. If significant tidal flow passed through the new channel it would exacerbate the erosion of the existing marshes. Therefore, it's possible that by elevating the road and preventing the marshes from joining, it would help the marshes persist in these locations for a longer period of time.

Vulnerability to one-time events (storms): Not for vegetation, but Saltmarsh Sparrow nests (and likely salt marsh tiger beetles) are vulnerable to unusually high flooding across the marsh surface.

Management considerations: Assess merits of action if any, learn from others already experimenting with management (i.e., southern New England and mid-Atlantic states). There are currently no proven adaptive strategies for saving tidal marshes that cannot keep up with sea level rise other than allowing them to migrate where local topography allows. If the existing tidal marshes are overwhelmed by sea level rise, and available migration areas are limited, tidal marsh area will be lost with no opportunity to mitigate for it. Additionally, marsh migration into available adjacent areas may be affected by existing soils in those areas, with organic soils being more readily colonized than inorganic soils.

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Piping Plover (E) - Least Tern (E) Essential Habitat **Size:** N/A

State Priority: Top priority for both species, considered excellent habitat.

3.3' Sea Level Rise inundation acreage: N/A

Projected Change: Follows fate of dune system, but could be lost due to other variables.

Vulnerability to one-time events (storms): Nesting is routinely vulnerable to unusually high water events. More events would lead to poor nesting success.

Management considerations: State Parks have high responsibility for this type. Monitor potential for human use impacts.

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Appendix 1: Table of Exemplary Features

Exemplary Natural Communities

Feature Name	**Scientific Name**	**State Rank**	**EO Rank**	**Size (ac)**
Dune Grassland	Dune Grassland	S1	AB[1]	11-33[1]
Pitch Pine Dune Woodland	Pitch Pine Dune Woodland	S1	A	45
Spartina Saltmarsh	Spartina Saltmarsh	S3	B	350
Coastal Dune-Marsh Ecosystem	Coastal Dune-Marsh Ecosystem	S3	A	1480

Rare Plants

Feature Name	**Scientific Name**	**State Rank**	EO Rank	Size (ac)
Sea-coast tuber bulrush	*Bolboschoenus robustus*	S2	E	-
Purple false-foxglove	*Agalinis purpurea*	S1	E	-
Saltmarsh false-foxglove	*Agalinis maritima*	S3	SC	-

Rare Animals

Feature Name		Protection Rank	EO Rank	Size (ac)
Piping Plover	*Charadrius melodus*	E	-	-
Least Tern	*Sternula antillarum*	E	-	-
Saltmarsh Sparrow	*Ammodramus caudacutus*	SC	-	-
Purple Sandpiper	*Calidris maritima*	SC	-	-
Salt Marsh Tiger Beetle	*Cicindela marginata*	SC	-	-

[1] Dune Grassland within Popham Beach State Park is undisturbed, but adjacent disturbed area on Hunnewell Beach is considered part of the same system depressing the EO rank. Acreage reflects only Dune Grassland found on Popham Beach State Park, and reflects the acreage range anticipated given natural cycles of erosion and accretion.

Appendix 2: Maps

Map 1: Bedrock Geology at Popham Beach State Park

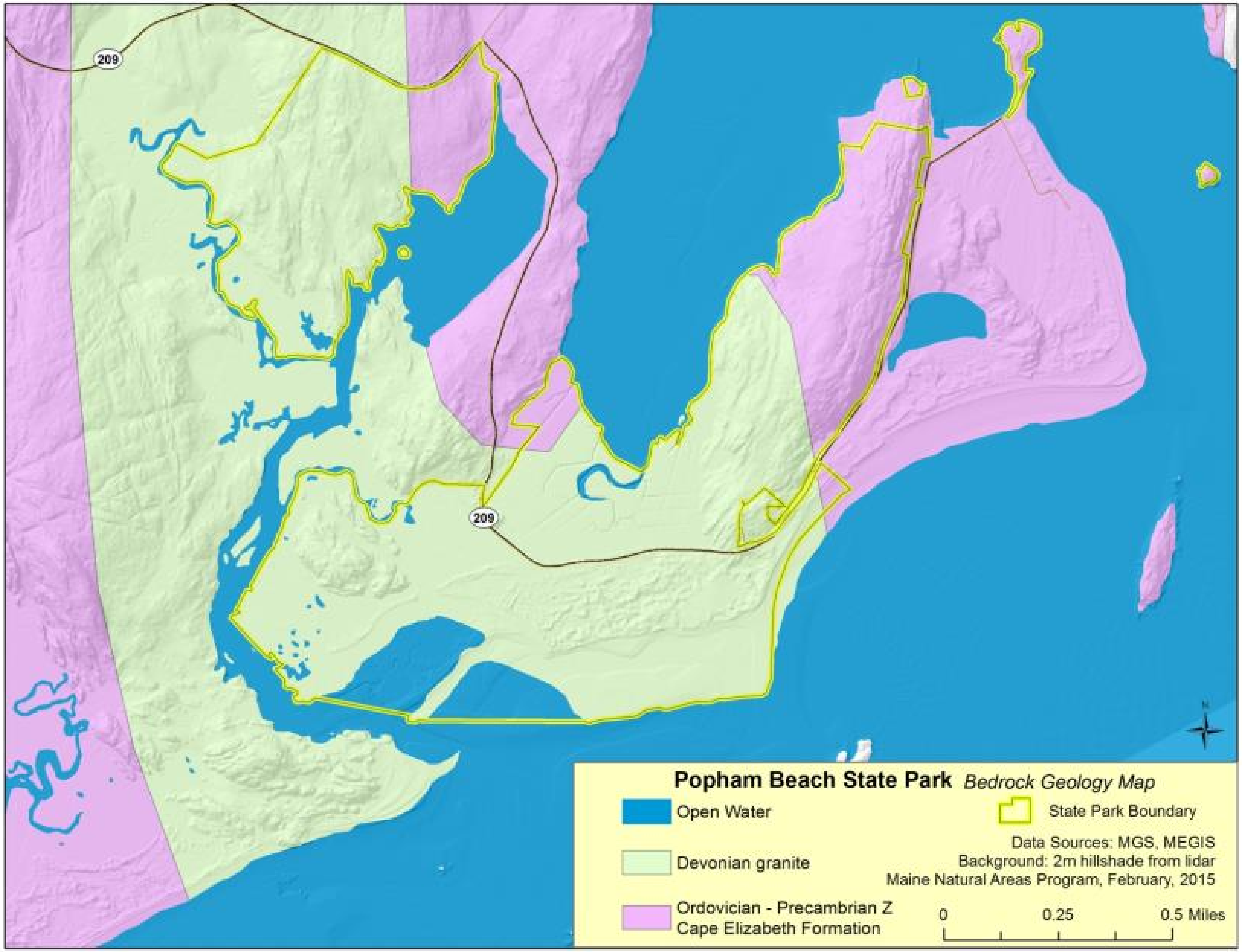
Map 2: Surficial Geology at Popham Beach State Park

Map 3: Natural Communities at Popham Beach State Park

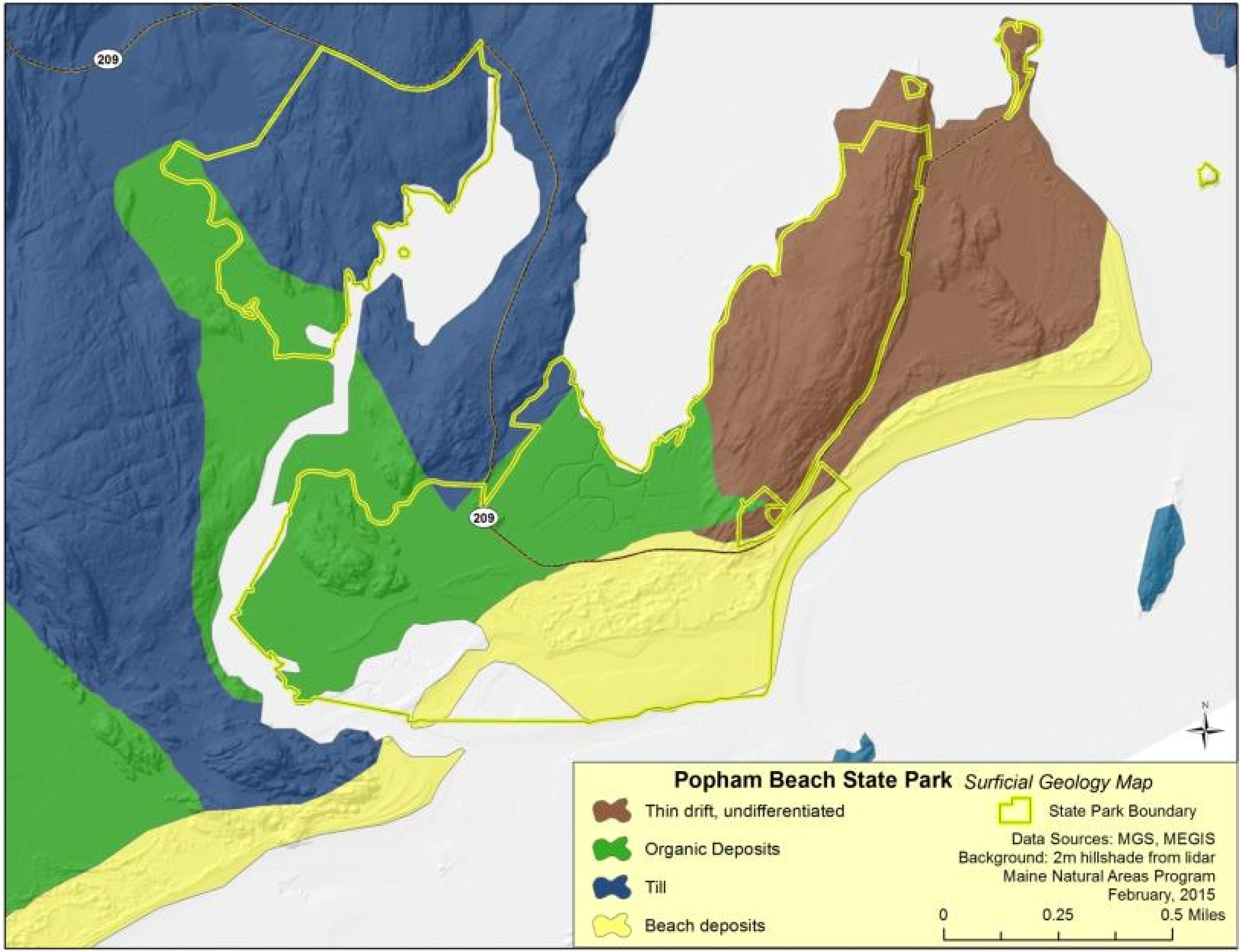
Map 4: Rare Plants and Animals at Popham Beach State Park

Map 5: 1’, 2’, 3.3’ and 6’ Sea Level Rise Scenarios at Popham Beach State Park

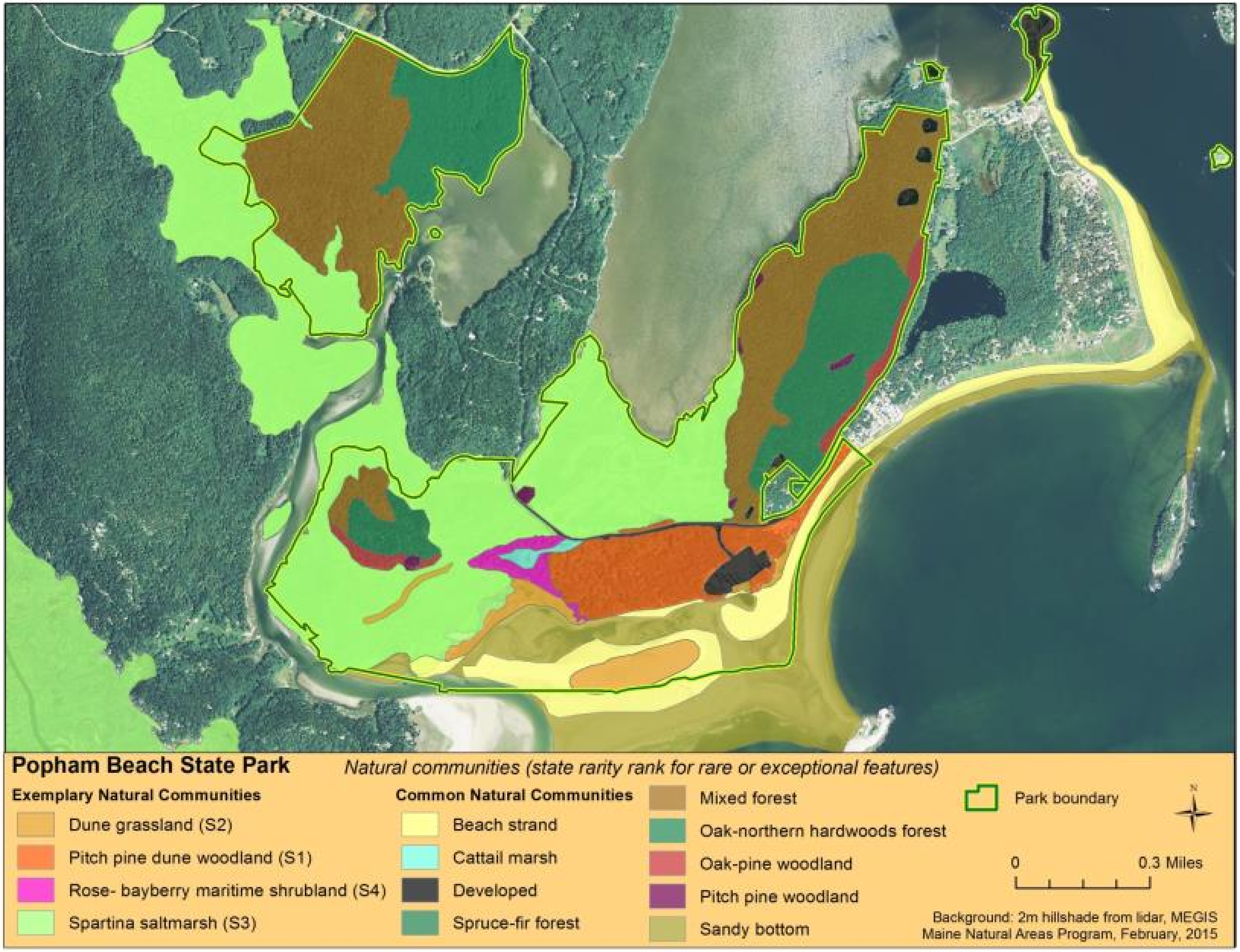
Map 1: Bedrock Geology at Popham Beach State Park



Map 2: Surficial Geology at Popham Beach State Park

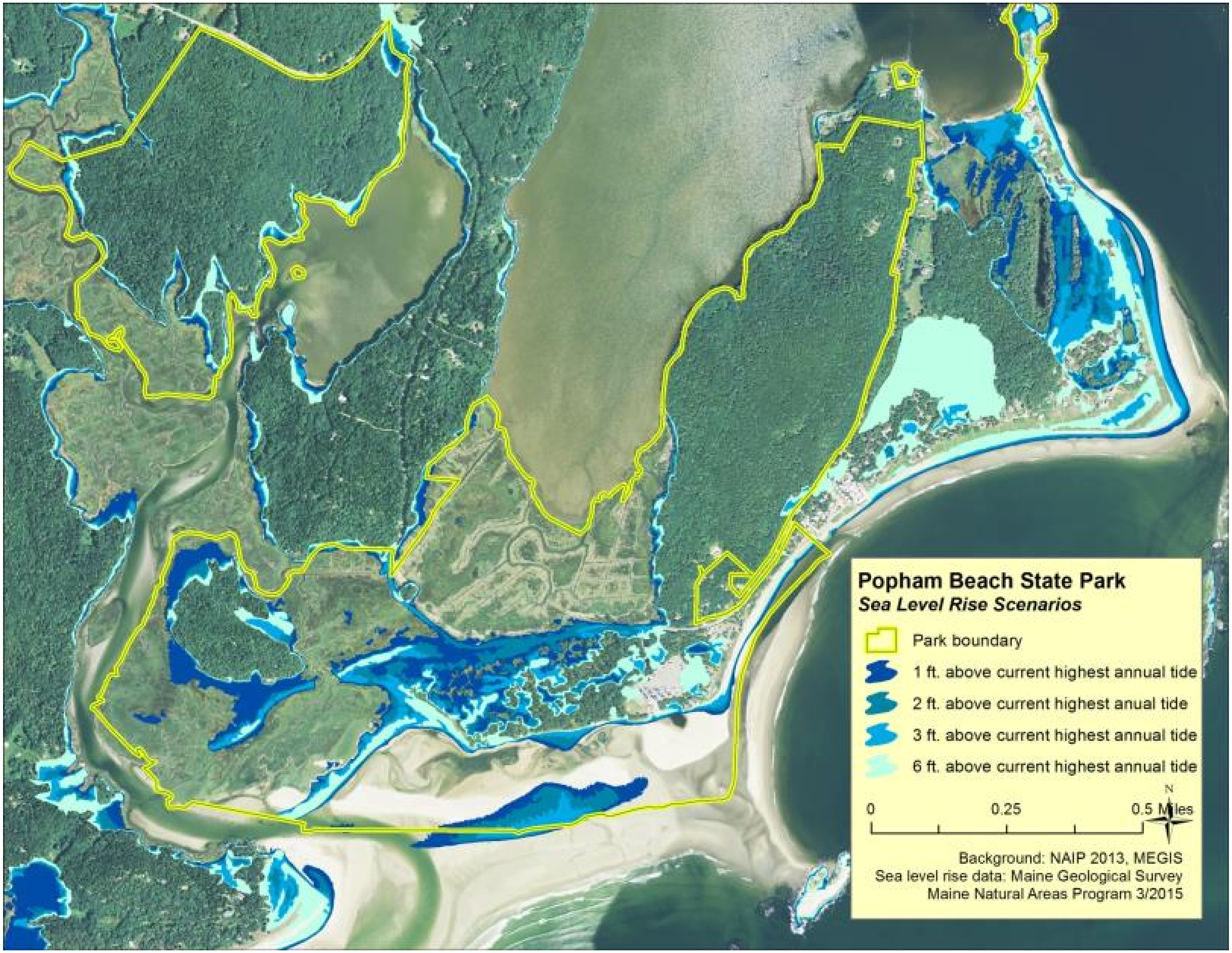


Map 3: Natural Communities at Popham Beach State Park



Map 4: Rare Plants and Animals at Popham Beach State Park

Map 5: 1’, 2’, 3.3’ and 6’ Sea Level Rise Scenarios at Popham Beach State Park



Appendix 3: Rare Plant and Animal Fact Sheets

Maine Department of Agriculture, Conservation and Forestry
Natural Areas Program

Agalinis maritima (Raf.) Raf.

Saltmarsh False-foxglove

Habitat: Saltmarshes. [Tidal wetland (non-forested, wetland)]

Range: Confined to saltmarshes of the Atlantic coast from Maine southward to Florida

Phenology: Flowers in late summer.

Family: Orobanchaceae

Aids to Identification: Like its more common relative purple gerardia (*A. paupercula*), the plant has five-petaled, bell-shaped flowers borne erect at the tips of the branched stems. Saltmarsh false-foxglove may be distinguished by its distinct preference for saltmarshes and by its leaves, which are thick and succulent, linear in shape and about 2-3 cm long. As it grows less than 40 cm high, it is often almost concealed by the surrounding vegetation.

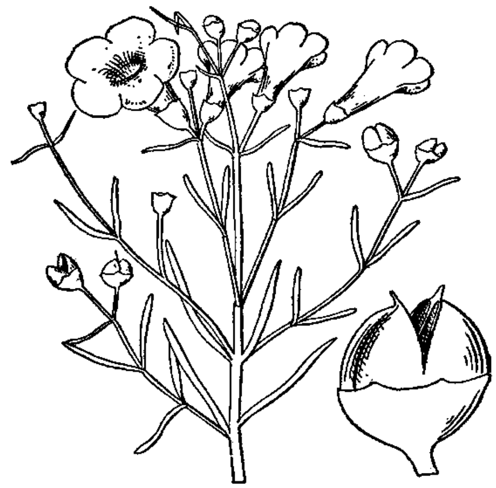


Illustration from Britton & Brown's Illustrated Flora of the Northern United States and Canada, 2nd ed.

Ecological characteristics: Can occur in large populations in intact saltmarshes. Maine populations are represented by *A. maritima* var. *maritima*.

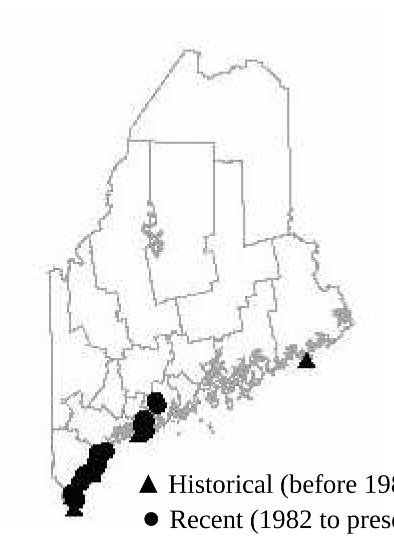
Synonyms: Formerly known as *Gerardia maritima* Raf.

Rarity of *Agalinis maritima*

State Rank:	S3	Rare in Maine
New England Rank:	None	
Global Rank:	G5	Species demonstrably widespread, abundant, and apparently secure globally.

Status of *Agalinis maritima*

Federal Status:	None	No Federal Status.
State Status:	Special Concern	Rare in Maine based on available information, but not sufficiently rare to be considered Threatened or Endangered.



Known Distribution in Maine:

This rare plant has been documented from a total of 17 towns in the following counties: Cumberland, Lincoln, Sagadahoc, Washington, York.

Reasons for rarity:
Reaches its northern range limit in southern Maine.

Conservation considerations:
This plant persists well as long as the natural hydrology of its saltmarsh habitat is maintained.

Plant rarity and status is based on 2015 data. Nomenclature follows *Flora Novae Angliae: A Manual for the Identification of Native and Naturalized Higher Vascular Plants of New England* (Haines 2011). The Natural Areas Program, within the Department of Agriculture, Conservation and Forestry, maintains the most comprehensive source of information on Maine's rare, threatened, and endangered plants and natural communities, and is a member of the Association of Biodiversity Information.

If you know of locations for this plant or would like more information on this species,
Please contact the Natural Areas Program.
State House Station 93, Augusta Maine 04333; telephone (207) 287-8044

STATE ENDANGERED

FEDERALLY THREATENED

George Matula

Piping Plover

(*Charadrius melodus*)

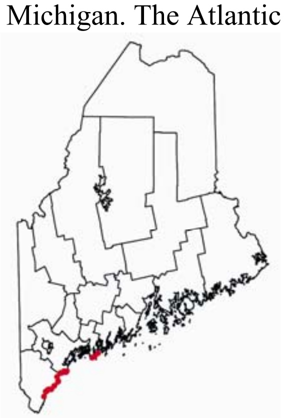
Description

The piping plover is a small, handsome shorebird (about seven inches long) found on sandy beaches and dunes in southern Maine. Its back is a uniform sandy brown color. The underside is white, and is interrupted by a single narrow black band around the neck. The bill is short and orange with a black tip. The legs are orange. The semipalmated plover, a common migrant on beaches in late summer, is similar in appearance, but has a darker brown head and back and a wide brown or black collar.

Summer visitors to southern Maine beaches have a good opportunity to see piping plovers. Signs, fenced sections of beach, and nest exclosures identify areas of the beach that are being managed for nesting piping plovers. By giving the birds space and following a few rules of beach etiquette, we can share the beach with this endangered species.

Range and Habitat

The piping plover breeds in three distinct populations in North America. About 2,000 pairs nest in alkali wetlands and along large rivers in the northern Great Plains of the U.S. and Canada. A tiny population of only about 60 pairs nests on beaches along Lakes Superior and Michigan. The Atlantic coast population of about 2,000 pairs nests on ocean beaches from Newfoundland to South Carolina. Wintering areas include the southeast Atlantic coast from North Carolina south to Mexico and into the Bahamas and the West Indies.



Habitat for the piping plover includes beaches, mudflats, sandflats, tidal ponds, and salt marshes. On the Atlantic coast, gravel, or shell-covered beaches above the high tide line. Sand spits, barrier islands, blowout areas in dunes, and dredge spoil are preferred nesting areas.

Life History and Ecology

After returning to breeding beaches in Maine in April, males establish and defend a territory by elaborate aerial displays. The breeding territory includes both feeding and nesting habitat. When the male has attracted a mate, one of several scrapes is selected as the nest site and is lined with pieces of shell and tiny pebbles. Over a period of six days the female lays a clutch of four eggs. Incubation begins after the laying of the last egg and lasts for about 28 days. Both sexes share with incubation and feeding young. If the first nest is destroyed, females may re-nest.

Within hours of hatching, the precocial chicks leave the nest but stay close to be brooded by the parents. Parents lead the chicks away from the nest scrape a day or two after hatching, but usually remain within the established territory. Chicks remain close to parents and alternate between feeding and being brooded. Adult females may desert broods within 5-10 days after hatching. Fledging occurs in 28-32 days.

After fledging, adults and young congregate on feeding areas prior to migration. Piping plovers feed primarily on marine worms and small crustaceans found in the "splash zone," although they also feed extensively in piles of wrack (seaweed) that accumulates at the high tide line. Intertidal flats and back dune ponds are also used for feeding. Plovers can live to be 14 years of age.

Threats

Habitat loss and degradation, human disturbance, and predation threaten the recovery of this species. Over two-thirds of Maine's 30 miles of beaches have been lost as nesting habitat for piping plovers because of construction

nest sites include open sand,
beaches are used by tens of thousands of visitors annually during the plover nesting season. Beach users can crush nests and chicks and disturb feeding birds. Pets (dogs and cats) destroy nests and harass plovers. Vehicles required for beach maintenance activities, especially beach sweeping and garbage collection, can crush eggs and chicks and alter habitat. Beach sweeping and removal of the wrack line also eliminates valuable feeding habitat. Garbage left on beaches attracts predators, including foxes, skunks, raccoons, crows, and gulls, all of which readily prey on plover eggs and chicks. Beach restoration and "nourishment" activities can have a net benefit for plovers if done in the off-season, but also may attract birds to high human use areas. Without intensive management, the aforementioned threats would rapidly reduce Maine's plover population to near-extinction.

Conservation and Management

Piping plover populations declined in the 1800s because of unlimited harvesting for subsistence and the millinery trade (ladies' hat decorations). Numbers increased and peaked in the 1940s following the passage of the Migratory Bird Treaty Act. After WWII, many Maine beaches were rapidly developed for summer homes, and populations of plovers and other beach nesting birds plummeted. By 1981, only seven pairs could be found in the state.

Atlantic coast piping plovers are federally threatened, and they were listed as endangered in Maine in 1986. Goals and objectives for managing piping plovers in Maine were established through recommendations by a public working group in 2001. A state management plan was developed in 2007. Piping plover nesting, feeding, and brood-rearing habitats were given legal protection by Essential Habitat designation in 1995. Essential Habitat designation requires that all projects funded, permitted, and carried out by municipalities and state agencies in mapped areas be reviewed by MDIFW.

Piping plover management begins in April when plover territories on beaches are fenced and signed. These areas offer refuge from human disturbance for nesting birds and recently fledged chicks. Wire mesh exclosures are placed around nests as soon as they are found to prevent predation by birds and mammals. Biologists and wardens patrol nesting areas several times weekly to deter dogs, educate the public, and monitor nests and chicks. In some instances, programs to deter or remove nest predators have been initiated. Population and productivity data are collected each year to monitor population health and recovery status. Plovers share their beach environment with nesting least terns (endangered).

of jetties, seawalls, and high density housing. Maine's

In some communities, municipalities help with monitoring and management activities. Intensive management has enhanced productivity and survival of young, and numbers have steadily increased to 55-60 pairs at about 20 sites in 2002.

Recommendations:

- Avoid further residential development of beach and dune habitats. Review Essential Habitat maps and guidelines prior to development near plover and tern beaches and adjacent dunes, intertidal areas, and salt marshes. Consult with a biologist from MDIFW and the U.S. Fish and Wildlife Service prior to any project that alters beaches or dunes.
- Municipalities should strive to maintain important beach and dune systems identified by MDIFW as open space, identify these areas in comprehensive plans, and conserve accordingly.
- Use voluntary agreements, conservation easements, conservation tax abatements and incentives, and acquisition to protect important habitat for threatened and endangered species.
- Follow the state and federal laws and regulations pertaining to sand dunes.
- To preserve water quality and wetland functions, maintain contiguous, forested riparian habitats at least 250 feet from salt marshes adjacent to plover and tern nesting areas. Follow Shoreland Zoning standards.
- Avoid major projects and activities on plover and tern beaches during the nesting season (April 1 to August 31).
- Do not approach plovers or terns or their nests. Respect fenced or posted areas to protect endangered species and other wildlife.
- Keep pets off the beach during the nesting season (April 1 to August 31).
- Remove trash from the beach. Carry in/carry out is the best trash collection policy.
- Avoid flying kites or placing beach volleyball areas within 150 years of plover or tern nesting areas.
- Avoid fireworks within one mile of nesting areas.
- Avoid use of vehicles on the beach during the nesting season. If vehicles are used, employ a "spotter" to walk in front of the vehicle to search for eggs and chicks.
- When feasible, remove jetties and seawalls that adversely affect plover and tern habitat.

STATE ENDANGERED

Least Tern

(*Sterna antillarum*)

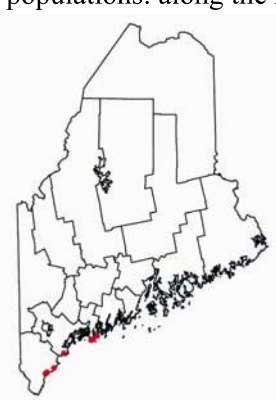
S. Maslowski

Description

Feisty and acrobatic, the least tern is the smallest of Maine's five species of nesting terns. It is about nine inches long and has a 20-inch wingspan. The least tern is white with pale gray feathers on the back and upper surfaces of the wings, except for a narrow black stripe along the leading edge of the upper wing feathers. Its cap is black with a small patch of white on the forehead. In summer, the adult has a yellow bill with a black tip, and yellow to orange feet and legs. The juvenile has a black bill and yellow legs, and the feathers on the back are darker than those of the adult, with a distinctly "scaled" appearance. The least tern's small size, white forehead, and yellow bill distinguish it from Maine's other resident terns.

Range and Habitat

Least terns breed in three North American populations: along the Atlantic coast from Maine to Texas, the Pacific Coast from California to Mexico, and the major rivers in the Mississippi watershed. The Atlantic Coast population is the largest at about 10,000 pairs. Least terns migrate to the eastern coast of Central and South America and northeast Brazil for the winter.



Least tern nesting habitat includes open sand, gravel, or shell-covered beaches above the high tide line. The birds are particularly attracted to the dynamic sand spits at the ends of beaches. They feed on small fish over shallow open water areas, stream and river outlets, tidal ponds, and salt marshes adjacent to nesting areas.

Life History and Ecology

Least terns arrive in New England between late April and early May. Most do not return from wintering areas to breed until they are 2-3 years old. Males establish and defend territories where they display to prospective mates, either to reestablish old pair bonds or to find a new mate. During courtship the male feeds fish to a female. Both sexes make scrapes in sandy areas with sparse vegetation above the high tide line, although the female selects the scrape that becomes the nest.

First clutches of two eggs are laid about 2-3 weeks after arrival on the breeding grounds. Incubation begins after laying the first egg and lasts 19-25 days. Both sexes incubate, brood, and feed chicks. Renesting occurs if the eggs or chicks are destroyed early in the breeding period. Both sexes defend their territory, eggs, and chicks. Birds from a colony often band together to drive away potential predators, including humans, by diving and defecating on intruders.

Chicks depart the nest shortly after hatching and may wander as far as 200 yards from the nest. Fledging occurs after 20 days. After the young have fledged, adults and young from several nests associate with each other for feeding, loafing, and roosting. Fledglings follow parents to feeding areas, where they are fed by parents and eventually begin to forage for themselves. Young birds disperse from colony sites about three weeks after fledging. Before migrating, adults with fledglings may remain for 6-8 weeks within the coastal breeding habitat. Adults and juveniles congregate at prime fishing areas beginning in late July and early August. They forage in bays, estuaries, rivers, creek mouths, and tidal marshes, usually within 1½ miles from colonies. They hover up to 30 feet above the water, then plunge into the water and grasp small marine fish with their beaks. The species of forage fish documented in Maine include Hake, Herring, and Sand Lance.

Immatures remain on wintering areas for their first year. Wintering areas of the Atlantic coast populations are largely unknown, although some banded birds have been resighted on the northern coast of South America. Least terns can live to 24 years of age.

Threats

Habitat loss from development and climate change, human disturbance, and predation threaten the recovery of this species. Natural phenomena (storm tide flooding, excessive rainfall) can also cause egg and chick loss. Over 2/3 of Maine's 30 miles of beaches have been lost as nesting habitat for least terns because of construction of jetties, seawalls, and high-density housing. Maine's beaches are used by tens of thousands of visitors annually during the least tern nesting season. Beach users can crush nests and chicks. Pets (dogs and cats) destroy nests and harass terns. Beach maintenance activities, especially vehicles associated with beach sweeping and garbage collection, can crush chicks and alter habitat. Garbage left on beaches attracts predators, including foxes, skunks, raccoons, crows, and gulls, all of which readily prey on tern eggs and chicks. Beach restoration and "nourishment" activities can have a net benefit for least terns if completed outside the nesting season, but also may attract birds to high human use areas. Without intensive management, the aforementioned threats would rapidly reduce Maine's least tern population to extinction.

Conservation and Management

There are no records of least terns nesting in Maine during early European settlement. They were likely present, but were quickly extirpated by subsistence hunting. The species was nearly extirpated from the entire East Coast during the 1870s by overharvest for the millinery trade (decorating ladies' hats). Least terns were first recorded nesting in Maine in 1961. Since that time, nesting colonies have been documented at 13 sites. Populations have been monitored since 1977 and have fluctuated between 39 pairs (in 1982) and 212 pairs (in 2010).

Pacific and interior populations of least terns are federally endangered. Least terns are listed as a Species of Management Concern on the East Coast by the U.S. Fish & Wildlife Service. They were listed as Maine's first endangered species in 1982. A state management plan was written for least terns in Maine in 1993 and revised in 2007. Least tern nesting, feeding, and brood-rearing habitats were given legal protection in Maine by designating these areas as Essential Habitats in 1995. Least tern numbers have not increased substantially despite two decades of intensive management.

Least tern management begins in May when nesting areas on beaches are fenced and signed. These protected areas offer refuge from human disturbance for nesting terns and recently fledged chicks. Chronic predation and human disturbance are major factors limiting populations, and entire colonies can be lost in a single night from these causes. In many years, only a handful of young are fledged. Electric fencing and large wire mesh fences have been employed to deter predators, with mixed results. Predator control (especially removal of resident pairs of foxes) has not been effective because of social and political limitations that reduce the effectiveness of trappers. Nightly monitoring of colonies has recently proven to be successful in deterring predators. Biologists and wardens patrol nesting areas several times weekly to deter dogs, educate the public, and monitor nests and chicks. Population and productivity data are collected each year to monitor population health and recovery status.

Because of Essential Habitat designation, all projects or activities funded and carried out by municipalities and state agencies are reviewed by MDIFW. In some communities, municipalities help with monitoring and management activities. Least terns nest in the same beach environment as piping plovers (endangered).

Recommendations:

- Avoid further residential development of beach and dune habitats. Review Essential Habitat maps and guidelines prior to development near plover and tern beaches and adjacent dunes, intertidal areas, and salt marshes. Consult with a biologist from MDIFW and the U.S. Fish and Wildlife Service prior to any project that alters beaches or dunes.
- Municipalities should strive to maintain important beach and dune systems identified by MDIFW as open space, identify these areas in comprehensive plans, and conserve accordingly.
- Use voluntary agreements, conservation easements, conservation tax abatements and incentives, and acquisition to protect important habitat for threatened and endangered species.
- Follow the state and federal laws and regulations pertaining to sand dunes.
- To preserve water quality and wetland functions, maintain contiguous, forested riparian habitats at least 250 feet from salt marshes adjacent to plover and tern nesting areas. Follow Shoreland Zoning standards.
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- Keep pets off the beach during the nesting season (April 1 to August 31).
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- Avoid flying kites or placing beach volleyball areas within 150 yards of plover or tern nesting areas.
- Avoid fireworks within one mile of nesting areas.
- Avoid use of vehicles on the beach during the nesting season. If vehicles are used, employ a "spotter" to walk in front of the vehicle to search for eggs and chicks.
- When feasible, remove jetties and seawalls that adversely affect plover and tern habitat.

A Natural Resource Inventory of Reid State Park

Prepared by
Donald Cameron and Justin Schlawin
of the
Maine Natural Areas Program

For the
Maine Bureau of Parks and Lands

2015

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Award # NA13NOS4190138.**

Preface

This Natural Resource Inventory (NRI) for Reid State Park was conducted for the Bureau of Parks and Lands (BPL) by the Maine Natural Areas Program (MNAP) as part of a larger effort to assess risks presented by climate change to state parks. Research relating to the natural history of Maine's state parks and to relevant climate change impacts was reviewed, and new data were collected for ecological communities and rare plant species when other field records were old or incomplete. No additional data was collected for animal species. Data for rare animals is based on the most recent information that was available from the Maine Department of Inland Fisheries and Wildlife at the time the report was written. The report includes an overview of the geology and soils and the land use history of the park. These elements are followed by descriptions of the natural communities and ecosystems along with their respective rare species. Potential impacts from sea level rise and climate change are included within the respective community and ecosystem descriptions. A table at the end of the report summarizes the potential impacts from sea level rise and climate change and provides management considerations.

Acknowledgements

We would like to thank Phillip de Maynadier, Lindsay Tudor, and Tom Hodgman (Wildlife Biologists at the Maine Department of Inland Fisheries and Wildlife), Stephen Dickson and Pete Slovinsky (Coastal Geologists at the Maine Geological Survey), and Wade Simmons, Tristan Cole, and Abigail Urban (Interns at the Maine Natural Areas Program) for their help with this Natural Resource Inventory. We would also like to thank the Maine Coastal Program and the Maine Outdoor Heritage Fund for their financial support of this project.

Introduction

Reid State Park was donated to the State of Maine in 1946, becoming the first State-owned saltwater beach. Today, the park, located in Georgetown, attracts over 100,000 visitors per year and is one of Maine's most visited state parks (Morris, Roper and Allen 2006). Wide sandy beaches, rocky headlands and a unique bedrock lagoon make Reid State Park a popular summer destination, and the mix of upland forests, marshes, and sand dunes attracts visitors year round. Popular activities include hiking, swimming, surfing, fishing (surf casting) and other beach-based recreation.

Summer recreation at Mile Beach at Reid State Park

The biological systems at Reid State Park are diverse and include a number of rare plant and animal species, along with some of the state's best examples of rare coastal natural communities. Beach Strand and Dune Grassland provide nesting habitat for the state endangered / federally threatened Piping Plover (*Charadrius melodus*) and the state endangered Least Tern (*Sterna antillarum*). The special concern species, saltmarsh false-foxglove (*Agalinis maritima*) grows in the extensive Spartina Saltmarshes, which also provide habitat for the two Special Concern species, Saltmarsh Sparrow (*Ammodramus caudacutus*) and saltmarsh tiger beetle (*Cicindela marginata*). Pitch Pine Woodlands, an uncommon natural community type in Maine, occur on low ridges and exposed bedrock within the park. An increase in major storms and higher sea levels as a result of climate change could put many of these habitats and natural systems at risk.

In this natural resource inventory, we examine the various factors influencing natural systems at Reid State Park, and evaluate the adaptability of each of these systems to climate change.

Regional Overview

Reid State Park is within the 'Casco Bay Coast' bioregion, an area of the coast characterized by long peninsulas that were buried beneath the ocean (or 'drowned') as the glaciers receded. Bedrock in this region is mostly highly metamorphosed sandstones and pelites, although granitic plutons occur throughout. Harder, folded layers of bedrock more resistant to glacial scour are found on the many narrow upland ridges, while softer bedrock was eroded away and now underlies the region's many valleys (McMahon 1990). Bedrock was covered in a thin layer of unsorted glacial drift (till) that in many areas was washed away thousands of years ago by wave action.

The climate of the Casco Bay Coast bioregion is moderated by the Gulf of Maine, and is cooler in the summer than interior regions. Mean maximum July temperature is 78.8° F and the mean January minimum temperature is 13.1° F (McMahon 1990). This bioregion contains a mosaic of habitat types that occur on other portions of the Atlantic Coast, including pitch pine woodlands, which are more common in southern New England south to the Mid-Atlantic region, and coastal spruce - fir forests which are emblematic of the Downeast region of Maine.

There are 109 beaches in the Casco Bay Coast bioregion, encompassing ~530 acres. Two of the largest of these beaches, Mile Beach and Half-Mile Beach, are within Reid State Park. Other beaches include Popham Beach, Small Point Beach and Head Beach in Phippsburg, and Andrews Beach in Long Island (Maine Geological Survey 1976).

Geology and Soils

Bedrock:

Two types of bedrock underlie Reid State Park. Though mostly covered by surficial deposits, bedrock is exposed in some upland areas and on the coastal headlands. Bedrock becomes exposed along the Maine coast as a result of coastal storms, which cause large swells that come well above the high tide line and erode surficial materials. Immediately after the Laurentide ice sheet receded from coastal Maine (~14,000 years ago), sea levels were as much as 70 meters higher than they are today (Barnhardt, Belknap and Kelley 1997, Belknap, Kelley and Gonz 2002, Kelley, Dickson and Belknap 1992), and all of Reid State Park was under water. As the present day coast emerged from the ocean in the process of isostatic (postglacial) rebound, the ocean surf washed away any marine clay that covered now-exposed bedrock ledges. In more recent times, fire and other disturbance events that remove vegetation, such as clearing for pasture, have led to further erosion of thin soils during major storms. Georgetown Island has a rich fire history (Barton 2012) and as a result, upland bedrock ledges have remained exposed.

Most of the park property is underlain by rock within the 'Ordovician – Precambrian Z Cape Elizabeth' Formation. This formation is primarily comprised of slate, with lesser amounts of schist, quartzite, and phyllite, and is exposed in places along an elevated ridge in the western half of that park that separates the two tidal wetland basins. The exposed bedrock in this area creates conditions favorable for pitch-pine dominated communities. The remainder of the property is underlain by rock in the 'Ordovician Precambrian Z Spring Point Formation,' an unmetamorphosed igneous rock type that weathers to form acidic soils. This bedrock type is concentrated in the southern half of the park, and constitutes a majority of the areas beneath the park's wetlands. In these areas, the substantial surficial, beach, and organic deposits are more important in influencing vegetative cover than the underlying bedrock. It is interesting to note that the park's southern headland is composed of rock in the Spring Point Formation, while the northern rocky headland and the islands off the coast consist of Cape Elizabeth Formation.

Surficial:

Three major surficial deposit types occur at Reid State Park: beach, till, organic deposits. Soils that weather from each sediment type are described in the following section. A map of surficial deposits is found in Appendix 2.

Beach Deposits

Reid State Park has two linear, southeast facing beaches that receive large surf. Mile-beach is the more northern beach (length ~ 0.7 miles). It is delimited by two rocky headlands, and contains a high natural frontal dune that protects a saltmarsh and estuarine channel. Half-mile beach, further south (actual length ~ 0.5 miles), is the smaller of the two and forms a true beach spit barrier that influences and constricts the mouth of the Little River. Both beaches have coarse sand, a relative abundance of feldspar minerals, and classic seasonal profile changes.

Unlike many coastal barrier beaches and dunes in Maine, Reid State Park's beaches are not actively supplied with sand from nearby rivers, such as the Kennebec or the Sheepscot. Instead, the source of the sand is likely from offshore sands deposited by the Kennebec River during a time of much lower sea levels. Wave action, currents, and tides have been reshaping and redistributing this historic sand delta, and are responsible for the beaches at Reid State Park.

Soil cores taken at Mile and Half-Mile Beaches document layers of sand overlying saltmarsh peat. Radiocarbon dating of the peat and organic matter have found them to be roughly 3500 years old, suggesting that the beaches and dunes have been in existence for over 3000 years and have migrated inland considerably over that time period ((Buynevich and FitzGerald 2002).

Till Deposits

Till, an unsorted material deposited by receding glaciers, is the predominant surficial deposit in upland sites. Till is not sorted by the movement of water, and includes rock and sediment of all sizes. Soils that form from till tend to be very stony and are rarely prime for agricultural cultivation, but can be used for pasture. At Reid State Park, till mostly weathers to form soils in the Hollis series, a soil type low in iron sulfides and including gneiss, schist and granite and which is typically shallow to bedrock

(Soil Survey Staff 2013). A secondary soil series that forms from till deposits and is located in Reid State Park is the Biddeford Series. These soils formed in glaciomarine deposits, are typically very deep and very poorly drained, and often occur in coastal lowlands and river valleys. In the Park, these soils are located on the west side of Ice Pond and in low-lying areas adjacent to the saltmarshes.

Organic Deposits

At Reid State Park, the primary area containing organic (or peat) deposits are in the western part of the park, along the Little River wetland basin. Roughly 11,000 years ago, post-glacial land-mass rebound was at its peak, and sea level in Maine was nearly 60 meters below the current sea level (J. T. Kelley 2013, Barnhardt, Belknap and Kelley 1997). For several thousand years, areas now occupied by saltwater marshes were uplands or freshwater wetlands, forming freshwater peat. As the land mass began to settle, and these areas were again flooded by salt water, saltmarshes replaced freshwater wetlands. While freshwater peat is often composed of purely organic material, saltmarsh peat is usually composed of a mix of fine inorganic sediments and organic material. Peat in saltmarshes may be as much as several meters thick (Orson, Warren and Niering 1987, Buynevich and FitzGerald 2002). Due to the dynamic nature of beach deposits, organic sediments may be buried by sand, but visible as a layer within the beach. As noted above, peat underlines the sand deposits at Reid State Park. Like submerged organic deposits, organic material buried under sand decomposes only very slowly due to saturation and anaerobic conditions. These organic layers are less prone to erosion than beach deposits, and at Reid have played a role in shaping the Little River.

Land Use History

Around 1650, an Englishman named John Parker acquired Georgetown Island from the Abenaki tribes and settled in the southern portion of the island. Prior to that exchange, the Abenaki people are thought to have only been transient visitors of the island, which they referred to as *Erascohegan*. John Parker built the first known permanent structure, and the island became known as Parker's Island to European colonists. Colonization of the area proceeded slowly and unevenly over the next decades due to war and turmoil in the region, but gradually accelerated after a truce was signed in 1759.

It is estimated that about half of the island was once converted to pasture (G. J. Varney 1886). Land was also cleared for the timber industry, which thrived on the island and fueled maritime trade and shipbuilding, another important island industry. But the trend of clearing land reversed in the late 1800s as wool from richer pastureland in the Midwest and west found eastern markets via the Erie Canal. Abandonment of pasture led to the re-establishment of forests in much of the island. This is a scenario that likely played out at what is now Georgetown Island (Wessels 2006).

Park Vulnerability to Projected Sea Level Rise

Climate scientists predict a wide range of possible sea level rise outcomes due to the uncertainty of future glacial melt rates in the Greenland and Antarctic Ice Sheets. However, most models predict a minimum of 0.6-1' of sea level rise by 2100 (based on continuation of current rates of sea level rise), and some models incorporating increased glacial melt and other complex factors predict as much as 6.5' of sea level rise (National Research Council 2010). Using 2 meter resolution LIDAR digital elevation model data, the Maine Geological Survey has spatially projected sea level scenarios for 1', 2', 3.3' and 6' of sea level rise. These scenarios as they apply to Reid State Park are shown in Appendix 4.

Currently, 178 acres or 26% of park area consists of tidal land. This includes most areas of intertidal beach and beach strand as well as saltmarsh. The remaining 519 acres (GIS, not surveyed acreage) of non-tidal lands, primarily uplands, including areas dominated by sand deposits, till and organic deposits, will be encroached upon as sea level increases. As much as 2% of the non-tidal area of the park will be inundated with a 1' increase in sea level, and 10% of the non-tidal area of the park will be inundated with a 6' increase (Table 1). It is important to note that the effects of sea level rise are complex, with many variables. The impacts may be greater or lesser than projected high tide lines may suggest, depending on sedimentation rates of coastal wetlands and the fluidity of sandy environments.

Table 1. Acreage and percentage of current non-tidal park area projected to be flooded during the highest annual tide with four different sea level rise scenarios.

Sea level rise	Acres	% of current non--tidal area
1'	11	2%
2'	19	4%
3.3'	28	5%
6'	52	10%

Ecological Features and Potential Effects from Sea Level Rise and Climate Change

Characteristic ecological processes of the rare and exemplary natural communities, as well as other dominant habitat types, are addressed in this section. Rare plants, rare animals, Significant Wildlife Habitats, and Essential Wildlife Habitats are discussed in the context of the natural communities in which they occur. The potential impacts from sea level rise and climate change on the natural resource features are discussed under each natural community or dominant habitat type.

Most of the natural communities within Reid State Park are part of a larger Coastal Dune Marsh Ecosystem, which is characterized by low-lying coastal areas with sand beaches, dunes, and saltmarshes behind the dunes, usually bounded on the landward side by forests (Gawler and Cutko 2010). Natural communities present at Reid State Park can be divided into three categories: sandy habitats, wetlands, and uplands. A complete vegetation map can be found in Appendix 2.

Sandy Habitats

Sandy habitats develop as a result of sediment deposition through wave action, current, and wind. Species living here are well adapted to a constantly changing environment, including both erosion and deposition of sand. These species are also tolerant of salt spray and exposure. Many coastal sandy habitats statewide are especially vulnerable to sea level rise because adjacent uplands and backdunes are developed, a rigid boundary that will prevent landward sand movement. Natural communities in sandy habitats include Sandy Bottom, Beach Strand, and Dune Grassland.

Sandy Bottom

These low tidal areas constitute sandy parts of the beach that are largely submerged, as well as areas of the beach that regularly are exposed to wave action (surf zone). Due to the constantly shifting substrate and wave disturbance these areas are un-vegetated, but provide important habitat for mollusks, crustaceans, and fish species. These, in turn, are important food sources for shorebirds.

Animals have adapted in a number of ways to this environment. A number of species bury themselves in the sand in sub-tidal areas to hide from predators or wait for prey including moon snails (Family *Naticidae*), whelks (various families), sand dollars (*Echinarachnius parma*), lady crab (*Ovalipes ocellatus*), and American lance (*Ammodytes* spp.). Mole crabs (*Emerita* spp.), razor clams (*Ensis directus*), and coquina clams (*Donax* spp.) inhabit the surf zone and are important prey species for shorebirds (Tyrell 2005). Shorebirds using this habitat during the summer months include the state endangered / federally threatened Piping Plover (see 'Beach Strand' section for more information about this species), Sanderling (*Calidris alba*), Semipalmated Plover (*Charadrius semipalmatus*), Semipalmated Sandpiper (*Calidris pusilla*), Willet (*Tringa semipalmata*), Whimbrel (*Numenius phaeopus*), Black-bellied Plover (*Pluvialis squatarola*) and others. In the winter months, shorebird composition shifts and includes northern migrants including Surf Scoter (*Melanitta perspicillata*), White-winged Scoter (*M. fusca)* and Eiders (*Somateria* spp.) (Maine Department of Inland Fisheries and Wildlife 1982-2013). Purple Sandpipers (*Calidris maritima*), a species of special concern in Maine, also frequent the shoreline at Reid State Park during the winter months. Purple Sandpipers are a circumboreal species that breeds in the arctic and migrates to the east coast during the winter, mostly occupying rocky coastline and offshore islands. Maine has a 'high responsibility' for this species because a large portion of the population winters off Maine's coast (Mittelhauser, Tudor and Connery 2013). Purple Sandpipers are considered vulnerable to sea level rise and climate change; however, sandy habitats are somewhat marginal for Purple Sandpipers, and changes to wave exposed rocky shorelines are likely to have a greater impact to this species than changes to sandy habitats.


Purple Sandpipers winter on rocky headlands and island shores in Maine – photo by Glen Mittelhauser

Because they lack vegetation or other organisms providing organic habitat, such as in eelgrass (*Zostera marina*), kelp, or mussel beds, sandy bottoms are some of the most resilient marine environments to human activities such as scouring from fishing nets or trampling by recreation (Tyrell 2005). It is unlikely that climate change will have an impact on these communities at Mile and Half Mile Beaches of Reid State Park, as the few constituent species are highly mobile and adaptable, and because there is considerable habitat connectivity.

Beach Strand

Beach Strands communities are comprised of the sparsely vegetated upper beaches along with fore-dune areas. These areas are flooded only at seasonally high tides, and when there is significant storm generated wave action. Many areas accumulate debris including driftwood, rotting kelp and eelgrass, which provide cover and constitute a seed bed for recruitment of several plant species. Plants occurring in this community are halophytes, highly adapted to salt spray, periodic flooding and sand deposition, and are specialized to the various micro-environments present on the Beach Strand. Plant adaptations to tolerate saltwater conditions include regulation of roots to salt uptake, extrusion of salt from salt glands and salt bladders, succulence to dilute the concentration of salt within the plant and provide other molecular-level benefits, and waxy leaves and stems that guard against salt absorption (Packham 1997). Vegetation on Beach Strands is often considered 'early successional' because it traps sand, creating conditions conducive to the eventual colonization of American beachgrass (*Ammophila breviligulata*).

Beach Strand at Reid State Park

The most common pioneer species along the Beach Strand at Reid State Park include sea rocket (*Cakile edentula*) and saltwort (*Salsola kali*, non-native). Both species are annuals with high salt tolerance and with heavily branching stems that capture sand during summer months. Depending on erosion and accretion cycles of the beach sand, these species may capture and stabilize sand above high tide line aiding future colonization of American beachgrass. Other dune species including beach pea (*Lathyrus japonicus*) and beach wormwood (*Artemesia stelleriana*) will also colonize once sand has been stabilized. These species are highly tolerant to being buried by sand; and during accretion periods, Beach Strands will succeed to dune grasslands. Other common Beach

Strand / foredune species at Reid State Park include sea-kale (*Atriplex patula*), seabeach sandwort (*Honckenya peploides*), and rough cocklebur (*Xanthium echinatum*) (Trudeau, Godfrey and Timson 1977).

While Beach Strand communities are relatively common in Maine and throughout New England, un-disturbed examples of this community are rare. Due to coastline development including the construction of jetties, seawalls and piers, as well as residential development, undisturbed Beach Strands have been reduced by over 75% throughout the northeast (Maine Department of Inland Fisheries and Wildlife 2014). This has had dire effects on the viability of a pair of rare bird species that depend on Beach Strand areas for nesting habitat: the Piping Plover and the Least Tern. Piping Plovers and Least Terns have been impacted across their range, and are listed as endangered under the Maine Endangered Species Act. Piping Plovers are also federally listed as a threatened species.

Piping Plovers and Least Terns make their nests in troughs in the sand in the spring, and are highly vulnerable to recreational activities occurring within their preferred nesting areas. Both native and non-native predators are more numerous in coastal zones than ever before. Predators including dogs, cats, foxes, raccoons, and others account for nearly all Piping Plover mortalities during nesting season. The Audubon Society, U.S. Fish and Wildlife Service, and Maine Department of Inland Fisheries and Wildlife have worked in partnership to protect Piping Plover and Least Tern nests in Maine since 1981. Due to their efforts, which include roping off nesting areas, fenced exclosures around nesting sites, public outreach, and predator and pet control, nesting pairs of Least Terns and Piping Plovers have been increasing. In 2013, Reid State Park supported two nesting pairs and six Piping Plover fledglings. Other wildlife species that use this habitat include Common Terns and other more common migratory shorebirds (Gawler and Cutko 2010).


Least tern

Statewide, Beach Strand communities are highly vulnerable to climate change. In response to sea level rise, Beach Strands will likely migrate landward. If there is ample room to accommodate such migration (i.e. undeveloped, low-lying back dune areas), there is a good chance that these habitats will continue in the future. However, in areas where Beach Strand communities are backed by developed dunes (i.e. seawalls or coastal development) or elevated uplands, it is likely these areas will be lost, with dire implications for the species that depend them. Currently, it is unclear how successful landward migration of Beach Strands in Reid State Park will be. Behind Mile Beach, an artificially high dune was built in 1940, which may delay and complicate the landward migration. Likewise, the shifting channel of the Little River behind Half-Mile Beach may eventually erode away the land that could support shifting Beach Strand communities.

Dune Grassland

Dune Grasslands typically occur well above the mean high tide line, and are formed through combined effects of sand accretion (as a result of wind, current, and wave action) and the sand trapping effects of dune vegetation. Reid State Park contains two

Dune grassland behind Mile Beach

Hudsonia with yellow flowers in the dune grassland

areas of Dune Grassland communities, with the larger being associated with Mile Beach, and the smaller associated with Half Mile Beach.

Similar to the Beach Strand, the dune environment is especially harsh. Dunes are extremely dry and windswept, often well above the water table, and developed soils are completely absent. Because of this harsh environment, only a handful of species thrive. American beachgrass (*Ammophila breviligulata*) is typically the dominant plant species in near-shore areas, and actively re-colonizes disturbed areas on the fore dune where erosion has exposed plant roots. Well adapted to being buried by sand and forming deep root networks, this species is primarily responsible for the stabilization of dune sand. Species that co-occur on the dunes behind Mile and Half Mile beaches include beach pea (*Lathyrus japonicus*), red raspberry (*Rubus idaeus*), gooseberry (*Ribes hirtellum*), poison ivy (*Toxicodendron radicans*), and false heather (*Hudsonia tomentosa*). The non-native beach rose (*Rosa rugosa*) forms a large patch at the northeast edge of the dune. Dry back dunes, while still classified as dune grasslands, contain small dense patches of bayberry (*Morella caroliniensis*), as well as many of the above listed species.

During the latter part of World War II, just prior to the establishment of the park, Navy fighter pilots from Brunswick Naval Air Station used the area for training, firing rockets at floating targets moored offshore of Mile Beach as they flew landward from over the ocean. A section of the existing dune toward the south end of the beach was built up at that time to provide a 'back-stop' for stray ordinance (S. M. Dickson 2002). The artificially tall dune still persists today, and is largely covered with a dense mix of shrubby vegetation.

Dune Grasslands have been drastically reduced from their historic extent by development and are considered rare (S2) in Maine with less than 250 acres currently documented. Existing dune grasslands on private and public ownership are still highly sensitive to degradation from recreational use. Even light foot traffic can cause unintended consequences that have long lasting impacts to dune systems (Gawler and Cutko 2010). Fortunately, the Dune Grasslands at Reid State Park have been minimally disturbed and remain largely intact, though some erosion has occurred on the transition from the beach strand. Park management practices discouraging public access of the dune grasslands have been very effective.

Foreground: Area of dune historically built up for W.W. II aerial target practice. Background: Mile Beach.

Like Beach Strand communities, Dunes Grasslands are important habitat for Least Terns and Piping Plovers. Many other common shorebird species utilize dunes for nesting habitat including some of the most common denizens of beaches such as the Herring Gull (*Larus smithsonianus*), Ring Billed Gull (*Larus delawarensis*), Spotted Sandpiper (*Actitis macularius*), and Greater Black Backed Gull (*Larus marinus*) (all ground nesters). Other ground nesting bird species that may utilize the sandy habitats at Reid State Park include the Common Tern (*Sterna hirundo*), and Short Eared Owl (*Asio flammeus*).

Dune Grasslands are equally if not more vulnerable to climate change than Beach Strand communities. Evidence at some Maine beaches indicates that the current rate of sea level rise paired with cross-shore currents may be too great to develop new landward dunes, with sand being moved offshore (Stephen Dickson, personal communication). With moderate rates of sea level rise, dune grasslands will likely move landward. Where dunes or back dune areas are developed, there will be little room for these systems and they may be lost. Adequate space is available for limited landward migration of Dune Grasslands in Reid State Park, although the Little River and lagoon system confine the area of possible dune establishment. The artificially tall fore dune behind the west end of Mile Beach may delay the impacts of sea level rise on the Dune Grassland.

Undisturbed Spartina Saltmarsh along the Little River on the west sdie of the Reid State Park

Estuarine Wetlands

Two estuarine systems occur within the boundaries of Reid State Park (Appendix 2, Map 3). The larger of the two (~160 ac in the park) is a back-barrier saltmarsh, associated with the Little River and forms the western boundary of the park. This saltmarsh is particularly significant in that it is one of the largest saltmarshes in Maine that has never been ditched or intersected by roads. It provides valuable resources for wildlife as well as being an excellent reference for estuarine research. The smaller of the two estuarine systems (~ 88 ac) is also a back-barrier saltmarsh, and occurs in the broad, tidally drained basin behind Mile Beach. This area is protected from storm surge by the dune. Saltmarshes provide critical habitat for many wildlife species, including migratory birds and fish. It is estimated that 2/3 of commercial fish and bait species landed in the Gulf of Maine depend on estuarine wetlands at some point in their life cycle (Dinne, Bonebakker and Whiting-Grant 2011).

Spartina Saltmarsh

Spartina Saltmarsh is the dominant natural community type in Reid State Park's tidal wetland systems, occupying approximately 248 acres and occurring extensively in both the Little River and Mile Beach Lagoon wetland complexes. Spartina Saltmarshes (S3) are estuarine wetlands dominated by a suite of halophytic plants occurring in zones defined by their degree of tolerance for saltwater and inundation. Narrow fringing marshes occur in places where coarse sediments and surf, or high tidal gradients prevent accumulation of sediment and peat into large flats, and are smaller and less diverse. Spartina Saltmarshes are found in places protected from wave and current action, such as behind barrier beaches, along river channels, and in sheltered coves. These marshes are typically more diverse and often develop salt pannes. Tidal wetlands within Reid State Park are primarily Spartina Saltmarshes that have formed behind barrier beaches.

Spartina Saltmarsh behind Mile Beach

Salt pannes and pools near Todd's Point access road

Lower elevation areas of Spartina Saltmarshes, referred to as 'low marsh', include river channel margins and low flats that are regularly flooded by the tides. Low marsh is typically dominated by smooth cordgrass (*Spartina alterniflora*), a perennial grass that often occurs in monocultures. Slightly higher areas, referred to as 'high marsh', occupy the extensive, broad flat surface of the marsh, and are dominated by saltmeadow cordgrass (*Spartina patens*). This species may also grow as a monoculture but is often mixed with a stunted variety of smooth cordgrass. A third, slightly more elevated zone (also part of the high marsh) is often dominated by black grass (*Juncus gerardii*) which is mixed with other halophytic species including sea-milkwort (*Lysimachia maritima*), seaside goldenrod (*Solidago sempervirens*), sea lavender (*Limonium carolinianum*), common glasswort (*Salicornia depressa*), and others.

The margins of saltmarshes at the upland interface often support species tolerant of brackish conditions such as three-square bulrush (*Schoenoplectus pungens*), Baltic rush (*Juncus balticus*), and smooth saw-sedge (*Cladium mariscoides*). The Spartina saltmarsh behind Mile Beach is bisected by a causeway that provides vehicular and pedestrian access to Todd's Point. The natural hydrology of the saltmarsh on the upstream side of the causeway may be impacted by an undersized culvert. Scoured pools on either side of the culvert, along with a high ratio of tidal channel width to culvert width are strong indicators of a tidal restriction (Justus 2001). Brackish marsh conditions are well developed along the outer edges of the saltmarsh here suggesting the full extent of tidal flow is not routinely reaching the entirety of the marsh area, and subsequently ground water flow is seeping well out into the marsh.

Tidal restriction at culvert under Todd's Point access road

Spartina Saltmarshes are highly productive and provide critical feeding and nesting habitat for many coastal wildlife species. Dead plant material forms the base of the food web, feeding invertebrates including insects, snails, crabs, amphipods, shrimp, and worms. Two species of mosquitos (*Aedes cantator* and *A. sollicitans*) exclusively breed in very small, fishless saltmarsh pools (Maine Forest Service, Insect and Disease Labaritory n.d.). Small fish species including mummichogs (*Fundulus heteroclitus*) and Atlantic silversides (*Menidia menidia*) lay their eggs in saltmarshes, which adhere to saltmarsh cordgrass stems, and produce fry that feed on invertebrates. These small fish in turn are prey to commercial fish species including striped bass (*Morone saxatilis*) and winter flounder (*Pseudopleuronectes americanus*), which will come to saltmarshes to feed (Packham 1997, Taylor 2008).

Many migratory shore and seabird species depend on saltmarshes both for nesting and feeding habitat. The tidal marshes of Reid State Park support one of the northernmost populations of Saltmarsh Sparrow in North America. Saltmarsh Sparrows are a species of special concern in Maine, and nest on the ground within the high marsh area. Saltmarsh Sparrow nests are often flooded during high tide, which is not necessarily lethal to young. However, a recent study indicates that the number of flooding events is directly related to the success of the nest in fledging young and that an increase in flooding events in the high marsh could have a negative impact on the viability of Saltmarsh Sparrows (Bayard and Elphick 2011).

Spartina Saltmarshes are complex systems that change in size depending on sediment accretion rates and sea level. Human influences have long played a role in the shaping of saltmarshes; sediment accretion rates rose significantly following European settlement and deforestation due to increased sediment laden runoff, causing dramatic increase in saltmarshes area in many places (Kirwan and Murray 2007). Evidence indicating a dramatic expansion in saltmarsh cordgrass (low marsh) and decrease in high marsh (Donnelly and Bertness 2001) over the last 150 years may be more related to a decrease in sedimentation rates (as a result of reforestation) than to rising sea level.

Spartina Saltmarshes are considered highly vulnerable to climate change. These systems exist in equilibrium balancing sediment accretion rates with sea level rise, and rapid changes to either part of the equation could have major consequences for the viability of Spartina Saltmarshes. Models examining the relationship between sea level rise and sediment accretion indicate that over the next 100 years, Spartina Saltmarshes will likely expand along their landward edge where topography allows, and will increasingly be eroded away along stream channels, although rapid rates of sea level rise could potentially lead to more extensive or catastrophic marsh loss (Kirwan and Murray 2007).

Expansion of stream channels as a result of sea level rise, including the Little River, could potentially increase erosion of adjacent dunes. Because these dune systems largely protect the marsh from wave action and storm surges, sea level rise could ultimately lead to a negative feedback loop where both marshes and dunes are rapidly eroded. The early effects of sea level rise may be a net gain in marsh area as the existing marsh will be maintained, and newly inundated non-tidal lands will be added to it. However, if sea level continues to increase, and the rate exceeds the accretion of sediments in the marsh, at some point between 3' and 6' in rise it is possible that there will be significant loss to the existing marsh (Bird 2015). A significant decrease in marsh areas would have adverse consequences for plants and wildlife that depend on this habitat.

Freshwater Pond and Wetlands

Ice Pond

Ice Pond is a relatively small, freshwater pond located in the northern most part of the park adjacent to Seguinland Road. The pond is dammed with large quarry stones near where it drains toward the road, and subsequently is deeper and probably greater in area than it was prior to impoundment. The open water area of the pond is approximately five acres, and there is an adjacent grassy marsh of about 14 acres that is likely also influenced by the artificial water level caused by the dam. Beaver use the pond and likely have also influenced water levels, causing mortality of some trees on the pond margins. A narrow band

Ice Pond with quarry stone dam in foreground of leather leaf (*Chamaedaphne calyculata*), cattail (*Typha latifolia*), bluejoint (*Calamagrostis canadensis*) and various sedge species occur along the broad southern border of the pond. White water-lily (*Nymphaea odorata*), yellow pond-lily (*Nuphar variegata*), water-shield (*Brasenia schreberi*), and small pondweed (*Potamogeton cf. pusillus*) are common in the open water. Sea level rise does not pose a threat to Ice Pond because it is not connected to the ocean through surface waters.

Wooded Wetlands

Pitch Pine Bog

There is a small area (~6 ac) of Pitch Pine Bog, a rare community type in Maine (S2), on the margin of the saltmarsh on the north side of the Todd's Point causeway. The margin of the marsh here is strongly influenced by groundwater and supports freshwater dependent plant species. Bayberry and black huckleberry (*Gaylussacia baccata*) dominate the shrub layer and occur beneath a sparse tree canopy of pitch pine (*Pinus rigida)* with red spruce (*Picea rubens*), white pine (*Pinus strobus*) and red maple (*Acer rubrum*) interspersed throughout. Pitch pine is more common near the tidal marsh and white pine and red spruce become more common toward the upland. The wet hummocks and depressions of the bog are sphagnum-dominated, and support patches of three seeded sedge (*Carex trisperma*) and northern long sedge (*Carex folliculata*), as well as other characteristic bog vegetation such as large cranberry (*Vaccinium macrocarpon*), pitcher plant (*Sarracenia purpurea*), Labrador tea (*Rhododendron groenlandicum*), and cotton grass (*Eriophorum* sp.).

View to pitch pine bog from saltmarsh

Bog orchid rose pogonia (*Pogonia ophioglossoides*) in the pitch pine bog

This weakly elevated natural community sits less than one foot above the adjacent saltmarsh and is highly likely to be impacted as sea level rise increases and diminishes the freshwater influence on its vegetation. Currently, the causeway, which appears to be restricting the full tidal hydrology of the upper portion of the saltmarsh, may be benefiting the Pitch Pine Bog by preventing the highest tides from routinely reaching this part of the marsh.

Uplands

There are 246 acres of upland forest within the park boundary. These systems are unlikely to be impacted greatly by sea level rise. However, other impacts of climate change including increased frequency of severe storm events, changing microclimates, and increased activity of non-native tree pests and invasive species could affect upland forests. Most of the forest is mixed composition of hardwoods and soft woods, and of intermediate age. Species dominance varies locally, but the most common trees are red spruce, white pine, red maple, and red oak (*Quercus rubra*), with lesser amounts of American beech (*Fagus grandifolia*), paper birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*). Red spruce and balsam fir are more prevalent in lower elevation areas and toward the coast. Red oak is more common on more elevated areas and away from the immediate coast. Within the forest there is a series of linear, raised, exposed bedrock outcrops that support partially open patches of the rare Pitch Pine Woodland (S3) natural community.

Pitch Pine Woodland

Pitch Pine Woodlands occur in small patches scattered widely through the upland portion of the park, comprising a total of 20 acres, or ~ 3% of the park. The Pitch Pine Woodlands are variable in size, shape, and to some degree, canopy cover. In general, these natural communities occur on raised, relatively flat, north-south oriented ridges, and are dominated by a

One of seven areas of pitch pine woodland that occur on dry ridges in Reid State Park somewhat open canopy of pitch pine interspersed with patches of exposed bedrock that support lichen-blueberry cover. White pine and red spruce are commonly part of the woodland composition, and red oak and red maple are occasional or absent in some of the patches. Wavy hair-grass (*Deschampsia flexuosa*), black huckleberry, bayberry, low-bush blueberry (*Vaccinium angustifolium*), and cow-wheat (*Melampyrum lineare*) are the most common plants in the understory of the woodlands.

A relict stonewall is evidence of past agricultural use, in this Pitch Pine Woodland at the park

Fire has likely played a role in the distribution and maintenance of Pitch Pine Woodlands, preventing colonization of fire sensitive hardwood tree species and shrubs. The droughty condition of the thin or even non-existent soils at these sites is another limiting factor for the colonization of other species. The open habitat of Pitch Pine Woodland communities likely provides preferred habitat for bird species such as the Pine Warbler (*Setophaga pinus*) and Prairie Warbler (*Setophaga discolor*). The oblique zale (*Zale obliqua*) and southern pine sphinx moth (*Lapara coniferarum*) utilize pitch pines as larval host plants, and may occur in these natural communities, though formal surveys have not been conducted (Gawler and Cutko 2010).

A small powerline corridor passes through an area of Pitch Pine Woodland

The majority of the area of this type within the park is undisturbed. One large patch is bisected by a stonewall suggesting past agricultural uses (~ pasture), but the community is well developed and characteristic for the type, and evidence of the historic disturbance is limited to the persistent stonewall. Two other areas have been impacted by powerline corridors. The clearing for the relatively narrow powerline corridors has resulted in loss of the pitch pine canopy but mostly allowed for the continued persistence of characteristic understory vegetation. Sea level rise is not expected to alter the distribution and characteristics of the Pitch Pine Woodlands found in Reid State Park. It is unclear whether other impacts from a changing climate such as stronger storms, warmer temperatures, and increases in forest pests would adversely impact the Pitch Pine Woodlands, which are more common in southern New England and the central Atlantic states, and generally resilient to stressful conditions. The recent destruction of pitch pine woodlands on Long Island from the southern pine beetle are one indication of the vulnerability of this type to expanding ranges of forest pests. In addition, lack of future natural fire and continued fire suppression may over the long term lead to changes in the species composition and alter their woodland status.

Spruce - Northern Hardwoods Forest / Red Oak - Northern Hardwoods – White Pine Forest

The current composition of the dominant forest in the park is best described as a mosaic of the two common types, Spruce - Northern Hardwoods Forest and Red Oak - Northern Hardwoods – White Pine Forest. Species dominance varies locally, but the most common trees are red spruce, white pine, red maple, and red oak, with lesser amounts of American beech, paper birch, and balsam fir. Red spruce and balsam fir are more prevalent in lower elevation areas and toward the coast and red oak is more common on more elevated areas and away from the immediate coast. American witch-hazel (*Hamamelis virginiana*), low-bush blueberry, black huckleberry, starflower (*Lysimachia borealis*), and bunchberry (*Chamaepericylmenum canadense*) are often found growing in the understory.

These forest types provide nesting habitat for a number of passerine bird species, including Sharp-shinned Hawk (*Accipiter striatus*), Cape May Warbler (*Setophaga tigrina*), Swainson's Thrush (*Catharus ustulatus*), Scarlet Tanager (*Piranga olivacea*), Ovenbird (*Seiurus aurocapilla*), Black-throated Green Warbler (*Setophaga virens*) and Blackburnian Warbler (*Setophaga fusca)*. Mature examples of these forest types, which have yet to develop within Reid State Park, also provide habitat for cavity nesting species (Gawler and Cutko 2010).

At Reid State Park, matrix forest areas are important upland buffers, protecting adjacent wetlands from sedimentation.

Climate-change related threats to these forests are invasive tree diseases and invasive plant species. Red spruce and balsam fir are likely the most vulnerable of the tree species to a warming climate because of their affinity for cool, montane and sub-boreal conditions. In contrast, red oak is at the north end of its range in Maine, and with a preference for warmer sites, may stand to gain in dominance with long term climate change.

Maritime Shrubland

Several small areas adjacent to the headlands and dunes systems support patches of shrub dominated cover that are characteristic of Maritime Shrublands. The shrubs and herbs living in this exposed coastal habitat must be tolerant of salt spray and high wind. Most of the areas where this type occurs on Maine's coast have an extensive disturbance history, and were often grazed by sheep. Many examples also have a history of fire (Gawler and Cutko 2010). The largest area (~ 2 ac) is located just southwest of the parking lots at the Todd's Point end of the park. This area is dominated by winterberry (*Ilex verticillata*), meadowsweet (*Spiraea alba*), red raspberry, alder (*Alnus incana ssp. rugosa*), and tall white-aster (*Doellengria umbellata*) near to the shore, with increasing amounts of stunted black cherry (*Prunus serotina*), staghorn sumac (*Rhus hirta*), and red maple slightly more inland. The shrubs and stunted trees form dense thickets that provide good cover and nesting habitat for some species of birds. Portions of this area were cleared in the past, and there are currently several well used beach access paths crossing through it.

Open Headland

Open Headland occurs along the majority of the shoreline between the north end of Mile Beach and the north end of the park, and includes the shores of Outer Head Island. These bedrock outcrops and ledges provide the immediate coastline with excellent protection from the ocean, especially in high tide and

Open Headland at Reid State Park

storm events.

While these areas are primarily bare rock, various herbaceous plant species will carve out a home here by growing in the cracks or in shallow depressions with very little soil. This habitat is some of the harshest on the coast. It gets pounded by wind, salt spray, sun, and cold. During the winter the wind and salt keep the snow from piling up and insulating the area, while in the summer the limited soil can dry out very quickly in the sun. This thinly vegetated habitat most commonly supports goosetongue (*Plantago maritima*), common yarrow (*Achillea millefolium*), seaside goldenrod (*Solidago sempervirens*), and several species of grasses and sedges. The faces of the more elevated rocks also typically host a suite of lichens, including the lime-green map lichen and the orange *Xanthoria* lichen.

These areas are commonly walked on by park visitors with only the heaviest use areas near access points being noticeably impacted. These areas have some loss of vegetation, as well as limited soil erosion at the bare rock – upland soil interface.

Management Considerations

Under current conditions, the Dune Grassland and the nesting habitats of Least Tern and Piping Plover are the only significant natural features at the Reid State Park that require active management, which is already taking place. Signage and judicially placed fencing keep visitors from both trampling sensitive dune vegetation and from harming the nesting birds. Other near term activities that could benefit sensitive features at the park includes:

- Periodic monitoring for pests and invasive species, particularly in the Pitch Pine Woodlands, Dune Grasslands, and Spartina Saltmarsh. These natural communities currently have little to no colonization of invasive species, and will benefit from being kept free of these pests.
- Periodic monitoring of sensitive areas for impacts from recreational activity, particularly the Dune Grasslands. This community currently receives very little visitor use. If usage patterns change to the detriment of the community they should be addressed.

- Allowing natural succession and disturbance processes to occur unimpeded in unmanaged areas with exceptions for public safety.
- Investigating the degree to which free tidal flow is restricted by culvert under the Todd's Point access road to better in anticipation of any opportunity to address it warranted.
- Incorporation of information on vulnerable rare species into park planning particularly Piping Plover, Least Tern, Saltmarsh Sparrow, and Saltmarsh Tiger Beetle.

In regards to climate change, multiple rare natural features within the park are vulnerable to impacts from sea level rise and increased storm intensity and frequency due to a warming climate. The Bureau of Parks and lands has a high responsibility for several features within the park because of their extreme rarity within the state, and their disproportionate occurrence on state park lands. Those features include Dune Grasslands, Piping Plover (E) - Least Tern (E) Essential Habitat, Saltmarsh Sparrow, and Saltmarsh Tiger Beetle. The Spartina Saltmarsh along the Little River both within and adjacent to the park is also considered significant on a statewide basis due its intact condition, never having been ditched to modified, as has been the case with nearly all of Maine's larger saltmarshes.

While the habitats unable to adapt to sea level rise such as Pitch Pine Bog will likely be lost, other habitats such as Beach Strands, Dune Grasslands, and Spartina Saltmarsh may be able to adapt to sea level rise by migrating inland. The mechanics allowing each coastal habitat to move inland are different. At Reid State Park the Spartina Saltmarshes will provide room for the landward movement of the dune formation and the associated Dune Grassland. There is relatively less room for the Spartina Saltmarshes themselves to migrate landward as sea level rises, and if some or all of the existing marsh cannot keep up with the continued tidal elevation increases, areas of marsh will be lost.

A summary table listing the projected impacts and respective management considerations for each rare or exemplary feature are listed starting on the next page.

Summary of Potential Impacts to Significant Natural Features

(note that only approximate median amount of sea level rise (3.3’) is addressed in this summary, the lower amounts of 1’ and 2’ of seas level rise will have less impacts and the higher amount of 6’ can be expected to have far more dramatic impacts.)

Dune Grassland (S2/G4?) **Size:** 27 acres

Associated special features:

- Beach Plum (E/S1/G4)

State Priority: very high priority, best example in Maine (AB rank), there are less than 250 acres of this type statewide, feature is also a priority site for Saltmarsh Tiger Beetle because of minimal disturbance and location at the edge of the species’ range.

3.3' Sea Level Rise inundation acreage: 5 acres lost.

Projected Change: possible migration, the feature has the potential for landward movement in its entirety due to existing marshes on its landward side. The survival of the rare species dependent on this habitat will depend on the continued persistence of the community and each species specific habitat needs there in.

Vulnerability to one-time events (storms): vulnerable to storms but has recovery potential. Frequent storms could prevent reestablishment.

Management considerations: State Parks have a high responsibility for this type. Recommend not impeding movement if dunes progress landward, monitor for impacts from human use, learn from outcomes in other affected east coast locations, periodically monitor for invasive plants. If catastrophic events occur that cause drastic erosion and / or loss of portions of the dunes, there will likely no way to recover lost habitat (note that this is not a likely scenario at this location).

Pitch Pine Bog (S2/G3G5) **Size:** 6 acres

State Priority: A small example in good condition (B rank), moderate priority, highly vulnerable.

3.3' Sea Level Rise inundation acreage: 6 acres.

Projected Change: Feature occurs at a very low elevation and will be vulnerable to loss with as little as 1 foot of sea level rise, at which point it will be colonized by Spartina Saltmarsh.

Vulnerability to one-time events (storms): Pitch pine has moderate tolerance to salt water spray, and can likely tolerate brief or limited salt exposure events. Increased frequency of salt exposure events may stress or possibly kill the pitch pines as well as the other woody vegetation in this community.

Management considerations: The feature will almost certainly be lost as sea level rises. The current tidal restriction under the Todd's Point access road which appears to limit the full extent of the tide from flowing into this area, may be helping the Pitch Pine Bog persist at this location at present.

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Pitch Pine Woodland (S3/G2) **Size:** 20 acres

State Priority: Low vulnerability to climate change, ~small example in good condition (BC rank), ~2000 acres statewide.

3.3' Sea Level Rise inundation acreage: 0 acres.

Projected Change: No effect, elevated.

Vulnerability to one-time events (storms): Minimal, vulnerable to wind throw.

Management considerations: If visitor usage of these areas increases significantly for blueberry picking or other activities, periodically monitor for impacts. At present, increased use of these areas seems unlikely. The most likely threat to this type may be native or non-native pests, including the southern pine beetle.

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Spartina Saltmarsh (S3/G5) **Size:** 160 in park (263 total acres)

Associated special features:

- Saltmarsh Sparrow (SC/S3B/G4)
- Saltmarsh Tiger Beetle (SC/G5)
- Tidal Wading Bird and Waterfowl Habitat

State Priority: High priority, type is widespread on coast, full occurrence (park & beyond) is one of the largest, most intact examples in the state, with no historic ditching (A rank). These marshes are also recognized as one of the best locations in the state for the rare Saltmarsh Sparrow, and are the northern most location for the rare saltmarsh tiger beetle.

3.3' Sea Level Rise inundation acreage: 21 acres inundated on adjacent, non-tidal, park lands.

Projected Change: There are no significant large areas with low elevation profiles that will accommodate marsh migration in or near the park. The Todd's Point access road causeway may need to be increased in size to accommodate increased tidal flow on its north side. There are already hampered flow pools on either side of the existing culvert. If sea level rise exceeds sediment accretion rates, areas of marsh will be lost. Sea level rise will negatively impact Saltmarsh Sparrow, as their nests are vulnerable to subtle increases above normal tidal elevations, as well as increased frequency of maximum tide events.

Vulnerability to one-time events (storms): Not for vegetation, but Saltmarsh Sparrow nests (and likely salt marsh tiger beetles) are vulnerable to unusually high flooding across the marsh surface.

Management considerations: Assess merits of action if any, learn from others already experimenting with management (i.e., southern New England and mid-Atlantic states). There are currently no proven adaptive strategies for saving tidal marshes that cannot keep up with sea level rise other than allowing them to migrate where local topography allows. If the existing tidal marshes are overwhelmed by sea level rise, and available migration areas are limited, tidal marsh area will be lost with no opportunity to mitigate for it. Additionally, marsh migration into available adjacent areas may be affected by existing soils in those areas, with organic soils being more readily colonized than inorganic soils.

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Piping Plover (E) - Least Tern (E) Essential Habitat **Size:** N/A

State Priority: Top priority for both species, considered excellent habitat.

3.3' Sea Level Rise inundation acreage: N/A

Projected Change: The maintenance of the habitat for these species follows the fate of dune system, but could be lost due to other variables such as increased predation.

Vulnerability to one-time events (storms): Nesting is routinely vulnerable to unusually high water events. More events would lead to poor nesting success.

Management considerations: State Parks have high responsibility for this type. Monitor for human use impacts, and allow any natural progression of dunes in a landward direction.

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Roseate Tern (E) Essential Habitat - Outer Head Island **Size:** N/A

State Priority: Low priority, not active habitat.

3.3' Sea Level Rise inundation acreage: N/A.

Projected Change: Some decrease in island area, though limited.

Vulnerability to one-time events (storms): No effect.

Management considerations: None at this time.

Inland Wading Bird and Waterfowl Habitat - Ice Pond **Size:** N/A

Associated special features

- Great Blue Heron

State Priority: Low vulnerability, lower priority, the type is wide spread.

3.3' Sea Level Rise inundation acreage: N/A

Projected Change: No effect - elevated

Vulnerability to one-time events (storms): No effect

Management considerations: None

Deer Wintering Area **Size:** N/A

State Priority: Low vulnerability, lower priority, wide spread.

3.3' Sea Level Rise inundation acreage: N/A

Projected Change: Little to no effect from sea level rise. Presumably the coastal location will continue to provide a local climate conducive to spruce growth. An overly warm climate could cause spruce to decline, and a decrease in the quality of the Deer Wintering Area.

Vulnerability to one-time events (storms): No effect

Management considerations: None

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Appendix 1: Table of Exemplary Features

Exemplary Natural Communities

Feature Name	Scientific Name	State Rank	EO Rank	Size (ac)
Dune Grassland	Dune Grassland	S1	AB[1]	11-33[1]
Spartina Saltmarsh	Spartina Saltmarsh	S3	B	350
Coastal Dune-Marsh Ecosystem	Coastal Dune-Marsh Ecosystem	S3	A	1480
Pitch Pine Woodland	Pitch Pine Woodland	S3	C	5

Rare Plants

Feature Name	**Scientific Name**	**State Rank / Status**	EO Rank	Size (ac)
Beach plum	*Prunus maritima*	S1 / E	B	0.5
Saltmarsh false-foxglove	*Agalinis maritima*	S3 / A	A	10+

Rare Animals

Feature Name		Protection Rank	EO Rank	Size (ac)
Piping Plover	*Charadrius melodus*	E	-	-
Least Tern	*Sternula antillarum*	E	-	-
Saltmarsh Sparrow	*Ammodramus caudacutus*	SC	-	-
Purple Sandpiper	*Calidris maritima*	SC	-	-
Saltmarsh tiger beetle	*Cicindela marginata*	SC	-	-

Appendix 2: Maps

Map 1: Bedrock Geology at Reid State Park

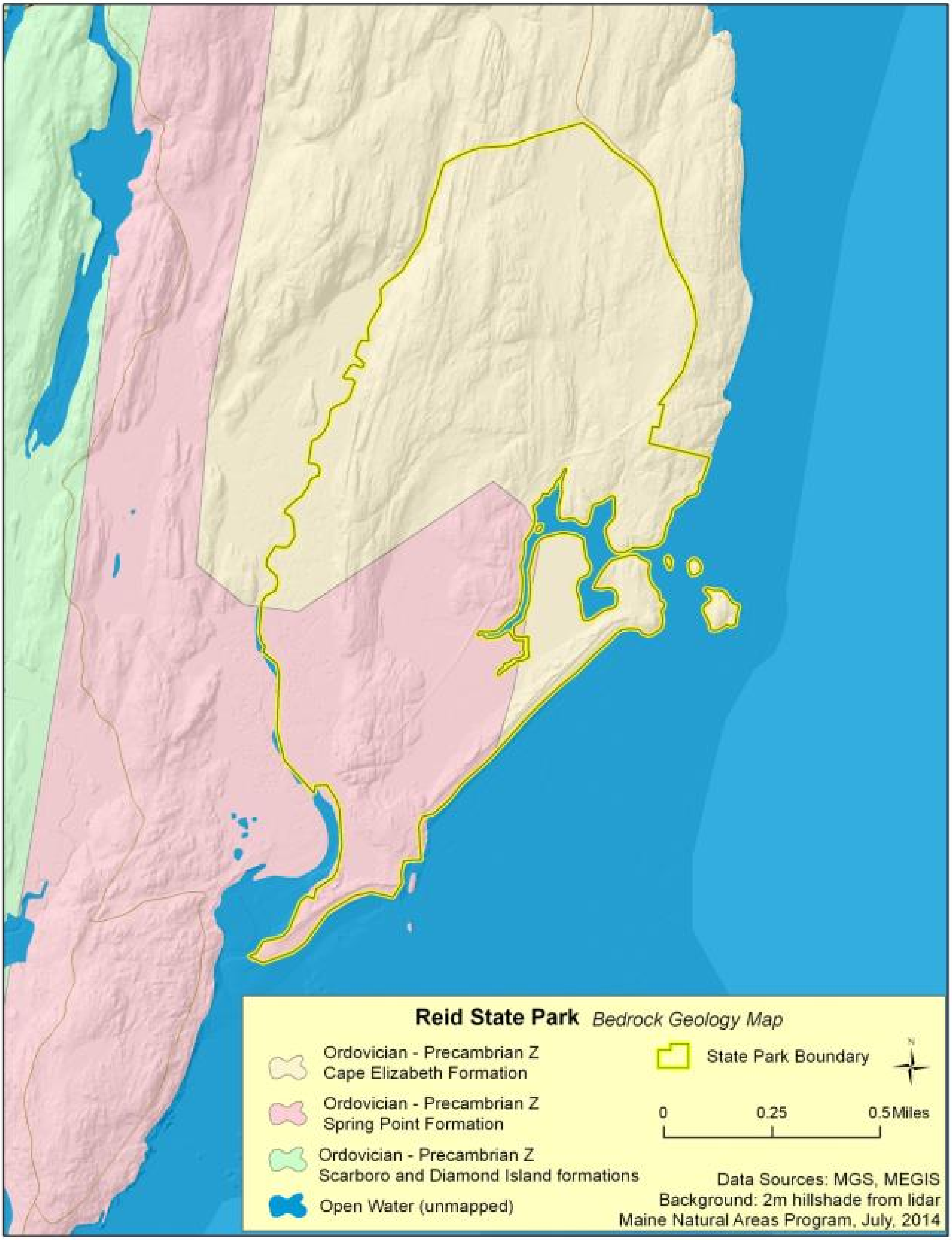
Map 2: Surficial Geology at Reid State Park

Map 3: Natural Communities at Reid State Park

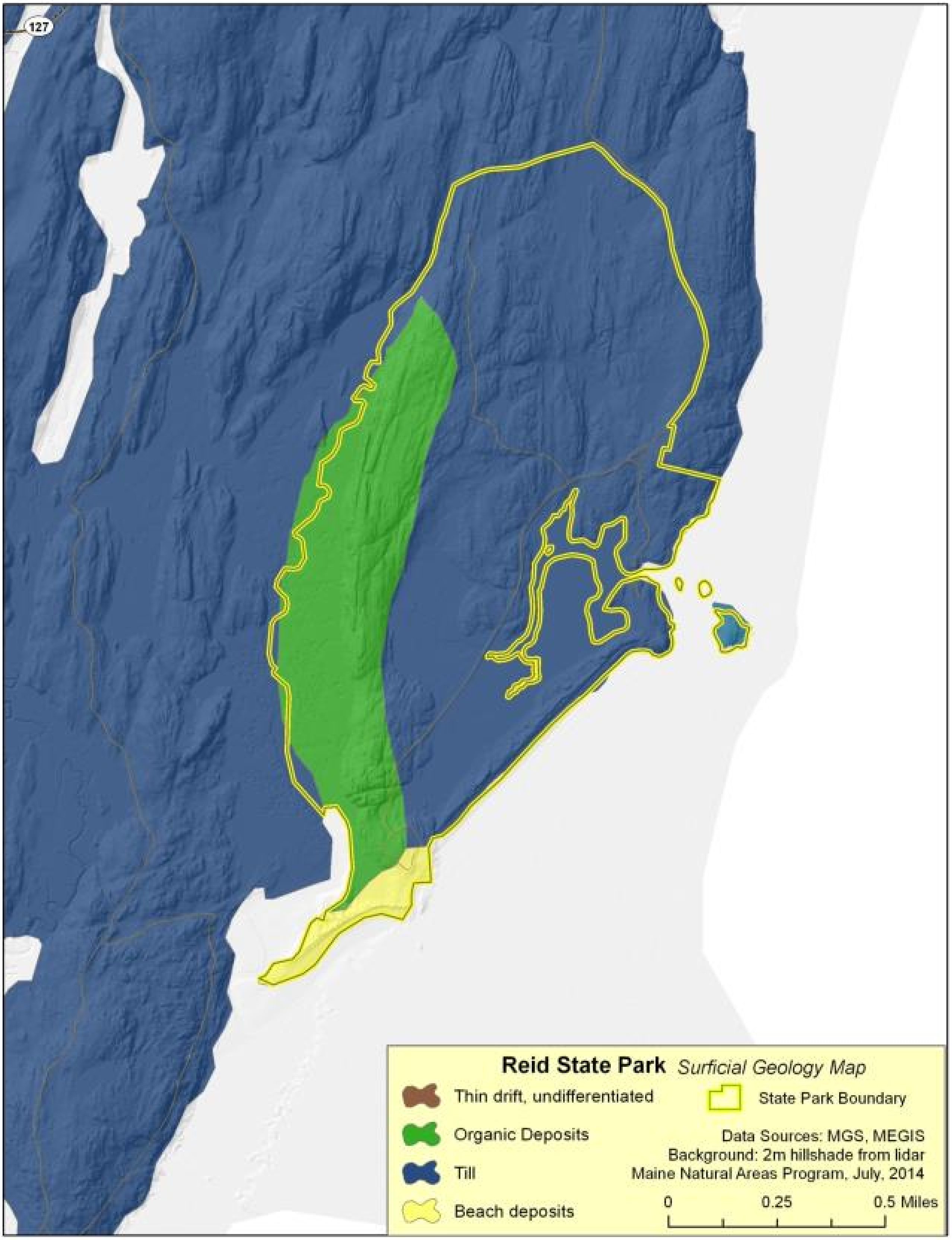
Map 4: Rare Plants and Animals at Reid State Park

Map 5: 1’, 2’, 3.3’ and 6’ Sea Level Rise Scenarios at Reid State Park

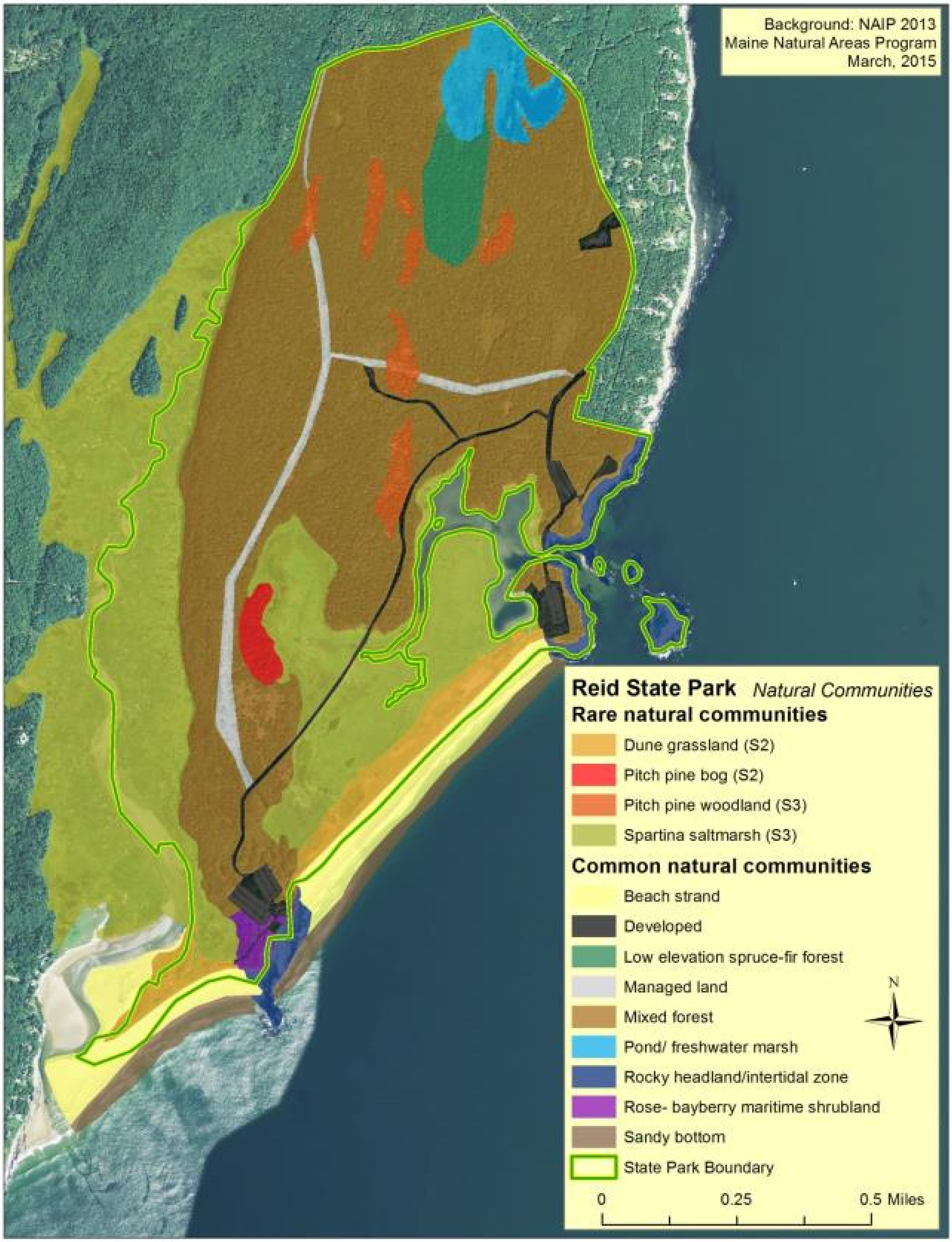
Map 1: Bedrock Geology at Reid State Park



Map 2: Surficial Geology at Reid State Park

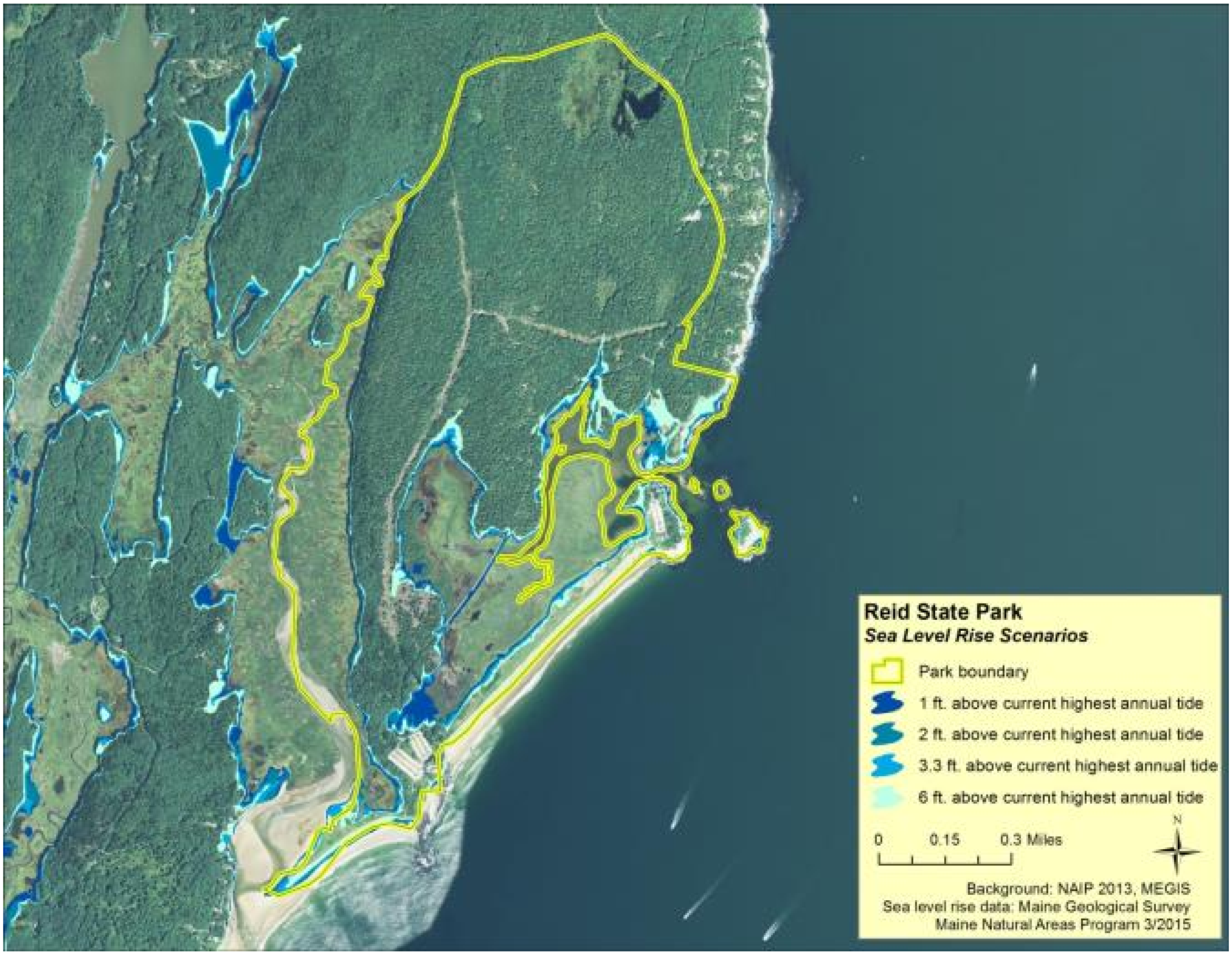


Map 3: Natural Communities at Reid State Park



Map 4: Rare Plants and Animals at Reid State Park

Map 5: 1', 2', 3.3' and 6' Sea Level Rise Scenarios at Reid State Park



Appendix 3: Rare Plant and Animal Fact Sheets

A Natural Resource Inventory of Crescent Beach, Kettle Cove, and Two Lights State Parks

Prepared by
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For the
Maine Bureau of Parks and Lands

2015

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Preface

This Natural Resource Inventory (NRI) for Crescent Beach, Kettle Cove, and Two Lights State Parks was conducted for the Bureau of Parks and Lands (BPL) by the Maine Natural Areas Program (MNAP) as part of a larger effort to assess risks presented by climate change to state parks. Research relating to the natural history of Maine's state parks and to relevant climate change impacts was reviewed, and new data were collected for ecological communities and rare plant species when other field records were old or incomplete. No additional data was collected for animal species. Data for rare animals is based on the most recent information that was available from the Maine Department of Inland Fisheries and Wildlife at the time the report was written. The report includes an overview of the geology and soils and the land use history of the park. These elements are followed by descriptions of the natural communities and ecosystems along with their respective rare species. Potential impacts from sea level rise and climate change are included within the respective community and ecosystem descriptions. A table at the end of the report summarizes the potential impacts from sea level rise and climate change and provides management considerations.

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Introduction

Combined, Crescent Beach, Kettle Cove, and Two Lights State Parks encompass ~290 acres along Maine's coast. They are some of the more popular State Parks in Maine as they together host a mile long sandy beach plus scenic lighthouses and dramatic rocky shoreline. They receive over 150,000 visitors each year (Morris, Roper and Allen 2006), and are only twenty minutes by car from the City of Portland. Crescent beach was recently voted one of the top 10 beaches in Maine (Nangle 2013). Popular activities include swimming, birding, fishing, hiking and other beach-based recreation.

Summer recreation at Crescent Beach State Park

Due to the low profile of Crescent Beach, the fragile Dune Grassland and Beach Strand habitats it supports have historically provided important nesting habitat for the state endangered / federally threatened Piping Plover (*Charadrius melodus*) and the state endangered Least Tern (*Sterna antillarum*). If these communities can persist, it is likely that those species will once again nest on Crescent Beach. The rare Brackish Tidal Marsh and Pitch Pine Dune Woodland behind the dunes are also of concern due to climate change and sea level rise. An increase in the frequency and intensity of major storms combined with rising sea level as results of climate change could put these already rare natural systems at greater risk of extirpation.

The shrublands, maritime and successional, present in all three parks has been designated as critical habitat for the state endangered New England cottontail (*Sylvilagus transitionalis*), and is necessary habitat for the cottontail to make a recovery. Other scrubby wetland habitats may provide important habitat for rare bird species such as the Least Bittern (*Ixobrychus exilis*) and the Common Gallinule (*Gallinula galeata*).

The rocky Open Headland at Two Lights provides important habitat for the state threatened harlequin duck. This bird requires rough surf for winter feeding along the

Maine coast. These foamy waters are generated by steep, rocky, and exposed coastlines line like those at Two Lights State Park.

There are other common natural community types present in these parks that will also be affected by sea level rise. In this natural resource inventory, we examine the various factors influencing all of the natural systems at Crescent Beach, Kettle Cove, and Two Lights State Parks, and evaluate the adaptability of each of these systems to climate change.

Regional Overview

Crescent Beach, Kettle Cove, and Two Lights State Parks lie on the northern boundary of the South Coastal biophysical region of Maine, which stretches from Kittery to Cape Elizabeth and extends 20 miles inland. This region is generally covered by glacial sand, silt, and clay and can be characterized by a relatively smooth coastline with broad bays and deep sand beaches. It is much less dramatic than coastal areas farther east in Maine, as the terrain here is relatively flat with elevations rarely exceeding 100' (McMahon 1990).

The South Coastal region hosts the mildest and warmest climate in Maine, with the longest frost-free period in Maine (160-170 days) and with the average maximum July temperature of 83° F. With these characteristics in mind, this region receives the least annual snowfall (55"), which is less than half the state average (McMahon 1990).

While Crescent Beach is relatively small compared to other beaches in the region (Old Orchard Beach – seven miles long), it is part of Maine's famous beaches region, a popular summer vacation destination.

Geology and Soils

Bedrock:

The areas of exposed bedrock at Crescent Beach, Kettle Cove, and Two Lights are largely limited to the coast, where the ocean's waves have eroded surficial and bedrock deposits to create bluffs and small cliffs. The Ordovician Cape Elizabeth formation found under Kettle Cove and Two Lights State Parks is composed of tan quartzite and dark gray phyllite. The phyllite is a soft metamorphic rock that splits easily, while quartzite is a very hard and resistant metamorphic rock that is composed largely of quartz. Together, these rocks look very similar to petrified wood, and are commonly mistaken as such. There is also basalt and veins of quartz mixed into the bedrock, which further add to its complexity (A. M. Hussey 1982).

The Ordovician Scarboro formation found under Crescent Beach State Park is best viewed at the rocky outcrops at Jordan Point on the western end of the beach. Here medium gray limestone is intermixed with thin beds of dark gray phyllite. There are also beds of rusty-stained, contorted phyllite and gray quartzite, all of which are folded in places, with quartz veins intruding (A. M. Hussey 1982). A map of the bedrock present at the parks can be found in Appendix 2.

The glaciers that passed over this area 20,000 and 13,000 years ago left their mark on the bedrock, carving marks into the rock in some places, while polishing the rock smooth in others. The last glacier left large amounts of till, an assortment of glacial sediments, behind on top of the bedrock.

Surficial:

Two major surficial deposit types occur at Crescent Beach and Kettle Cove State Parks: beach and till. Only till deposits occur at and Two Lights State Parks. A map of surficial deposits is found in Appendix 2, while beach is not visible in the data on the map, it is a significant part of the two parks.

Beach Deposits

The beaches at Crescent Beach and Kettle Cove developed only recently in geologic time. Between 8,000 and 5,000 years ago, when the glaciers were melting the fastest, the sea level was likely changing too rapidly for beach formation. But since then, sea level change has been much less dramatic, which has allowed the beaches to form. Sand has since been blown inland to create dune grasslands and woodlands (A. M. Hussey 1982).

Till Deposits

Till is an unsorted heterogeneous glacial material deposited by receding glaciers, and is the predominant surficial deposit in upland sites. Till generally has not been sorted by the movement of water, so therefore includes rock and sediment of all sizes. Soils that form from till tend to be very stony and are rarely prime for farmland, but are used for pasture. The soils derived from till at Crescent Beach and Kettle Cove State Parks are of the Sebago, Hollis, and Deerfield series. The Sebago series soils are that of the boggy and swampy areas, and are very deep with thick organic deposits. They are generally saturated with water as they are very poorly drained. The soils of the Hollis series are typically well drained and form a thin layer of soil that is low in iron sulfides such as gneiss, schist and granite. Deerfield soils are generally composed of well drained loamy sand and can be quite acidic (Soil Survey Staff 2013).

Land Use History

Crescent Beach, Kettle Cove, and Two Lights State Parks are part of what is now the town of Cape Elizabeth. Historically, the area was inhabited by the Armouchiquois Indians. Europeans first arrived in the area in 1605 when a party landed on Richmond Island, which is just off shore of Crescent beach. The island was the site of various European trading posts that came and went as the local Native Americans defended their lands, periodically running the Europeans off the island. In 1630, the mainland shore across from the island near the Spurwink River (just west of Crescent beach) was settled by George Cleeve and Richard Tucker. From there, the town developed but was attacked and destroyed many times by various wars and battles. Cape Elizabeth was incorporated in 1765 (G. J. Varney 1886). The town became famous when the lighthouse at Fort Williams to the north of Crescent Beach became one of the most visited sites in Maine.

These State Parks were designated as such in the 1960s although Crescent Beach had long been a beach destination for city dwellers in Maine.

Park Vulnerability to Projected Sea Level Rise

Climate scientists predict a wide range of possible sea level rise outcomes due to the uncertainty of future glacial melt rates in the Greenland and Antarctic Ice Sheets. However, most models predict a minimum of 0.6-1’ of sea level rise by 2100 (based on continuation of current rates of sea level rise), and some models incorporating increased glacial melt and other complex factors predict as much as 6.5’ of sea level rise (National Research Council 2010). Using 2 meter resolution LIDAR digital elevation model data, the Maine Geological Survey has spatially projected scenarios for 1', 2', 3.3' and 6' of sea level rise. These scenarios as they apply to Crescent Beach, Kettle Cove, and Two Lights State Parks are shown in Appendix 2.

Currently, 3.2 acres or 1.7% of Crescent Beach S.P., 1.7 acres or 2.6% of Kettle Cove S.P., and 0.2 acres or 0.6% of Two Lights S.P. are flooded during the highest annual tide. At Crescent Beach and Kettle Cove State Parks, the areas flooded are primarily intertidal beach. Existing non-tidal lands will become increasingly flooded as sea levels increase. Two Lights S.P. will be the least impacted of the three parks with only about 0.8% non-tidal lands inundated with 1' of sea level rise, and 2.5% inundated with 6' of sea level rise. Crescent Beach S.P. will be the most impacted with about 3.5% non-tidal lands inundated with 1' of sea level rise, and 45% inundated with 6' of sea level rise. Projections for all three parks across the four sea level rise scenarios are in Table 1 below. It is important to note that the effects of sea level rise are complex, with many variables. The impacts may be greater or lesser than projected high tide lines may suggest, depending on sedimentation rates of coastal wetlands and the fluidity of sandy environments.

Table 1. Acreage and percentage of current non-tidal land area flooded at Crescent Beach, Kettle Cove, and Two Lights State Parks at highest annual tide under the four different sea level rise scenarios.

Crescent Beach S.P. sea level rise	acres	% of current non-tidal land
1'	6.7	3.7%
2'	18.2	10%
3'	42.6	23.3%
6'	82.2	45%

Two Lights S.P. sea level rise	acres	% of current non-tidal land
1'	0.4	0.8%
2'	0.5	1.1%
3'	0.7	1.6%
6'	1.1	2.5%

Kettle Cove S.P. sea level rise	acres	% of current non-tidal land
1'	2	2.3%
2'	2.3	3.4%
3'	2.9	4.2%
6'	6.4	9.4%

Ecological Features and Potential Effects from Sea Level Rise and Climate Change

Characteristic ecological processes of the rare and exemplary natural communities, as well as other dominant habitat types, are addressed in this section. Rare plants, rare animals, Significant Wildlife Habitats, and Essential Wildlife Habitats are discussed in the context of the natural communities in which they occur. The potential impacts from sea level rise and climate change on the natural resource features is discussed under each natural community or dominant habitat type.

Natural communities present at Crescent Beach, Kettle Cove, and Two Lights State Parks can be divided into three general categories: sandy habitats, wetlands, and uplands. A complete vegetation map can be found in Appendix 2.

Sandy Habitats

Sandy habitats develop as a result of sediment deposition through wave action, current, and wind. Species living here are well adapted to a constantly changing environment, including both erosion and deposition of sand. These species are also tolerant of salt spray and exposure. Many coastal sandy habitats statewide are especially vulnerable to sea level rise because adjacent uplands and back dunes are developed, a rigid boundary that will prevent landward sand movement, or because the elevation profile of adjacent lands is too steep to accommodate movement of these features. Natural communities in sandy habitats include Sandy Bottom, Beach Strand, Dune Grassland, and Pitch Pine Dune Woodland.

Sandy Bottom

These low tidal areas constitute sandy parts of the beach that are largely submerged, as well as areas of the beach that regularly are exposed to wave action (surf zone). Due to the constantly shifting substrate and wave disturbance, these areas are un-vegetated, but provide important habitat for mollusks, crustaceans, and fish species. These, in turn, are important food sources for shorebirds.

Animals have adapted in a number of ways to this environment. A number of species bury themselves in the sand in sub-tidal areas to hide from predators or wait for prey including moon snails (Family Naticidae), whelks (various families), sand dollar (*Echinarachnius parma*), lady crab (*Ovalipes ocellatus*), and American lance (*Ammodytes* spp.). Mole crabs (*Emerita* spp.), razor clam (*Ensis directus*), and coquina clams (*Donax* spp.) inhabit the surf zone and are important prey species for shorebirds (Tyrell 2005). Shorebirds using this habitat during the summer months include the state endangered / federally threatened Piping Plover (see 'Beach Strand' section for more information about this species), Sanderling (*Calidris alba*), Semipalmated Plover (*Charadrius semipalmatus*), Semipalmated Sandpiper (*Calidris pusilla*), Willet (*Tringa semipalmata*), Whimbrel (*Numenius phaeopus*), Black-bellied Plover (*Pluvialis squatarola*) and others. In the winter months, shorebird composition shifts and includes northern migrants including Surf Scoter (*Melanitta perspicillata*), White-winged Scoter (*M. fusca)* and Eiders (*Somateria* spp.) (Maine Department of Inland Fisheries and Wildlife 1982-2013).

Sandy bottom area at Crescent Beach S.P., portion of beach that receives regular tidal submergence

Because they lack vegetation or other organisms providing biogenic habitat, such as eelgrass (*Zostera marina*), kelp, or mussel beds, sandy bottoms are some of the most resilient marine environments to human activities such as scouring from fishing nets or trampling by recreation (Tyrell 2005). It is unlikely that climate change and sea level rise will have significant impacts on these communities at Crescent Beach, as the few constituent species are highly mobile and adaptable, and because there is considerable habitat connectivity.

Beach Strand

Beach Strand communities constitute sparsely vegetated upper beaches and fore-dune areas only flooded at seasonally high tides. Many areas accumulate debris including driftwood, rotting kelp and eelgrass, which provide cover and constitute a seed bed for recruitment of several plant species. Plants occurring in this community are halophytes, highly adapted to salt spray, periodic flooding and sand deposition, and are specialized to the various micro-environments present on the beach strand. Plant adaptations to tolerate saltwater conditions include regulation of roots to salt uptake, extrusion of salt from salt glands and salt bladders, succulence to dilute the concentration of salt within the plant and provide other molecular-level benefits, and waxy leaves and stems that guard against salt absorption (Packham 1997). Vegetation in Beach Strands is often considered 'early successional' because it traps sand creating conditions conducive to the eventual colonization of beachgrass (*Ammophila breviligulata*).

Beach Strand at Kettle Cove S.P., sparsely vegetated area above the regular tide

While Beach Strand communities are relatively common in Maine and throughout New England, un-disturbed examples of this community are rare. Due to coastline development including the construction of jetties, seawalls and piers, as well as residential development, undisturbed beach strands have been reduced by over 75% throughout the northeast (Maine Department of Inland Fisheries and Wildlife 2014). This has had dire effects on the viability of a pair of bird species that depend on beach strand areas for nesting habitat: the Piping Plover and the Least Tern. Piping Plovers and Least Terns have been impacted across their range, and are listed as endangered under the Maine Endangered Species Act. Piping Plovers are also federally listed as a threatened species.

Piping Plovers and Least Terns make their nests in troughs in the sand in the spring, and are highly vulnerable to recreational activities occurring within their preferred nesting areas. Both native and non-native predators are more numerous in coastal zones than ever before. Predators including domestic dogs, cats as well as foxes, raccoons and others account for nearly all Piping Plover mortalities during nesting season. Maine Audubon, U.S. Fish and Wildlife Service, and Maine Department of Inland Fisheries and Wildlife have worked in partnership to protect Piping Plover and Least Tern nests in Maine since 1981. Due to their efforts, which include roping off nesting areas, fenced exclosures around nesting sites, public outreach, and predator and pet control, nesting pairs of Least Terns and Piping Plovers have been increasing in Maine. No Plovers nested at Crescent Beach in 2012 and 2013 (Maine Audubon 2012, Maine Audubon 2013), but they did successfully in 2014, and have returned again in 2015 (L. Tudor, MDIFW personal communication, May, 2015).

Statewide, Beach Strand communities are highly vulnerable to climate change. In response to sea level rise, Beach Strands will likely migrate landward. If there is ample room to accommodate such migration (i.e. undeveloped back dune areas), there is a good chance that these habitats will continue to persist into the future. However, in areas where Beach Strand communities are backed by developed dunes (i.e. seawalls or coastal development), or by other upland land forms, it is likely these areas will be lost, with dire implications for the species that depend on them. The landward side of Crescent Beach abuts areas of low-lying wetlands in some areas, and park facilities including the bath house, parking lot, and maintenance access road in other areas. The beach and associated dune formation have the potential to migrate landward into to the low-lying wetlands but will not be able to migrate or only poorly so, onto the uplands that include park infrastructure.


Dune Grassland - west end of Crescent Beach

Dune Grassland

Dune Grasslands typically occur well above the mean high tide line, and are formed through the combined effects of sand accretion (as a result of wind, current and wave action) and the effects of dune vegetation, which collects and stabilizes sand.

Like the beach strand, the dune environment is especially harsh. Dunes are extremely dry and windswept, often well above the water table, and developed soils are completely absent. Because of this harsh environment, only a handful of plant species thrive in this habitat. Beachgrass is the dominant in near-shore areas. Well adapted to being buried by sand and forming deep root networks, this species is primarily responsible for the stabilization of dune sand.


Large patch of the coastal invasive rugosa rose in the Dune Grassland at Crescent Beach

At Crescent Beach, Dune Grassland borders the beach and is oriented East-West. The dune habitat is broken up by developed structures into two sections. On the western section, the dune is relatively low profile, as there is very little change in elevation between the end of the beach and the start of the dune. On the east side of the snack shack, the dune is slightly higher and somewhat more defined. The vegetation within the site is composed of beach grass, beach pea (*Lathyrus japonicus*), bayberry (*Morella caroliniensis*), and red raspberry (*Rubus ideaus*). There are also large patches of invasive plants such as multiflora rose (*Rosa multiflora*), Japanese knotweed (*Fallopia japonica*), and shrubby honeysuckle (*Lonicera morrowii*) interspersed within the core of the dune. There are a few large patches of beach wormwood (*Artemisia stelleriana*) in the fore dune, and low, open patches of false heather (*Hudsonia tomentosa*) on the landward side. Heading east, the dune gradually becomes narrower and eventually ends about 300’ before the edge of the park at Ocean House Road. Given the land forms and usage in this park, approximately 75% of the beach and dune system (~3,000 linear feet) have the potential to migrate landward in response to increased sea level. About 25% (~1,000 linear feet) that is located in front of the parking is more likely to be lost.

Some fringing Dune Grassland is found at Kettle Cove State Park, in each of the two larger coves, but it is too narrow and patchy to be mapped or tracked. Sandwiched between the beach and the wide footpath on the upland side, the patches of Dune Grassland at Kettle Cove vary from 10-30ft wide and 100ft long. It is likely that the Dune Grassland at Kettle Cove has been encroached upon by the network of trails, and was historically more extensive.

Dune grasslands have been drastically reduced from their historic extent by development and are considered rare (S2) in Maine with less than 250 acres currently documented. Even light foot traffic can cause unintended consequences that have long lasting impacts to dune systems (Gawler and Cutko 2010).

Crescent Beach and the beaches at Kettle Cove have seen some erosion in the past ten years, mostly during the series of northeasters in May 2005 and during the 2007 Patriots' Day Storm. The vegetation along Kettle Cove Beach receded about -0.6 m/yr. between 2004 and 2007 causing nearly 2m of lost dune elevation. Many parts of Crescent Beach are also eroding quite rapidly, with rates of more than -1 m/yr. of shoreline change between 2003 and 2007 (Slovinsky 2009). While these data were observed directly following a few years of severe storms, and it is possible that the dunes have recovered since, if we are to see more frequent, more intense storm events in the future due to climate change, these dunes and beaches are likely to erode further and faster.

Like Beach Strand communities, Dune Grassland is important habitat for Least Terns and Piping Plovers. Many other common shorebird species utilize dunes for nesting habitat including some of the most common denizens of beaches such as the Herring Gull (*Larus smithsonianus*), Ring Billed Gull (*Larus delawarensis*), Spotted Sandpiper (*Actitis macularius*), and Greater Black Backed Gull (*Larus marinus*) (all ground nesters). Other ground nesting bird species that may utilize the sandy habitats at Crescent Beach State Park include the Common Tern (*Sterna hirundo*), and the Short Eared Owl (*Asio flammeus*).

Dune Grassland is equally if not more vulnerable to climate change than Beach Strand communities. Evidence at some Maine beaches indicates that the current rate of sea level rise paired with cross-shore currents may be too great to develop new landward dunes, with sand being moved offshore (Stephen Dickson, personal communication).

With moderate rates of sea level rise, Dune Grassland will likely move landward. Where dunes or back dune areas are developed, there will be little room for these systems to move and they may be lost. To help preserve the dunes and decrease their erosion, placement of naturally occurring seaweed within the first several feet of the frontal dune may help catch sand and hold it in place.

Pitch Pine Dune Woodland

Pitch Pine Dune Woodlands are stable back-dune communities with open (+/- 35% closure) canopies. Eolian (windblown) sand continues to be deposited in these areas, restricting the vegetation that can occur there. These woodlands are largely south-coastal in distribution and reach their greatest extent on Cape Cod. In Maine, these natural communities are very rare (S1), with many of the historic examples having been developed.

Pitch Pine Dune Woodland at Crescent Beach S.P. The noticeable brown color of the pitch pine needles indicates current tree stress at this site.

Pitch pine came to Maine, along with the state's other fire adapted pines 7-8 thousand years ago during a climactically dryer period, where natural (and possibly human caused) fires were more common (Barton, White and Cogbill 2012). As the climate cooled, the extent of fire adapted species became increasingly restricted to a collection of isolated sites where xeric environments and/or continued fire regimes allowed them to persist. For pitch pine, this includes dry bedrock outcrops, coastal bogs, back-dunes, and sandy outwash plains in southern Maine where regular fire intervals allow pitch pine recruitment. While pitch pine dune woodlands may not require fire disturbance to persist, the fire adapted species that occur in these communities were likely able to spread here as a result of landscape-scale fires. It is unclear when the last fire in the Crescent Beach area occurred, or if it has ever burned.

Pitch Pine Dune Woodland occupies a relatively small area of ~1.3 acres of Crescent Beach S.P. and is not present in either Kettle Cove or Two Lights State Parks.

The site at Crescent Beach is a broad, low, forested, dune formation that abuts a freshwater wetland on the landward side. The canopy is composed of pitch pine (*Pinus rigida*) and red oak (*Quercus rubra*), with quaking aspen (*Populus tremuloides*) and red maple (*Acer rubrum*) forming the sapling layer. The sapling layer has a higher cover along the sunnier margins of the woodland with taller canopy trees becoming less frequent. The shrub layer is composed primarily of bayberry and high-bush blueberry (*Vaccinium corymbosum*) with bayberry also in the herb layer along with crinkled hair grass (*Deschampsia flexuosa*), low-bush blueberry (*Vaccinium angustifolium*), and starflower (*Lysimachia borealis*). Many of the pitch pines appear to be stressed with many dead individuals present, and it is unclear what is specifically causing the pines so much stress. There is a small foot path that runs through this area which has little to no effect on the overall community.

Extensive wildlife surveys have not been performed in the Pitch Pine Dune Woodland at Crescent Beach State Park. However, it is possible that songbirds including Pine Warbler (*Setophaga pinus*) and Prairie Warbler (*Setophaga discolor*) may utilize this open habitat. Additionally, a number of rare moths that use pitch pine, including the oblique zale (*Zale obliqua*), pine pinion (*Lithophane lipida lipida*), and the southern pine sphinx (*Lapara coniferarum*) also may occur at this site. Note that the small size of this occurrence likely limits its usage by some species.

Pitch Pine Dune Woodland is extremely vulnerable to climate change, as there is no mechanism for an established Pitch Pine Dune Woodland community to migrate landward. Eolian deposition rates are likely not great enough to counter balance sea level rise; Pitch Pine Dune Woodlands are comprised of land based vegetation that colonizes sand dunes after they have been stable for many years. Climate change and sea level rise are likely to bring about a period of extreme instability to beach and dune systems, and will likely lead to loss of most of our dune forests. The woodlands at Crescent Beach are already quite small (1.2 acres), and will likely disappear quickly. A majority of the woodland will be lost with 3.3’ of sea level rise, and with the added potential effects of erosion and over-wash from severe storms, it is possible the woodland will lost long before that depth is reached. Once lost, the pitch pine dune woodland will only reestablish if there is a persistent and stable dune formation. If desired, reestablishment can probably be accelerated by planting pitch pine on an established dune provided there is a minimum buffer between the dune and the ocean.

Wetlands

The wetlands represented in the three parks are concentrated in Crescent Beach and Kettle Cove State Parks, where Cattail Marshes, Brackish Tidal Marshes, Red Maple – Sensitive Fern Swamps, Grassy Shrub Marshes, Alder Thicket, and open fresh water can be found. Some of the areas of open water may have been created or altered by the construction of roads and the large parking lot. Most notably, a significant portion of Richards Pond was filled in to construct the parking lot at Crescent Beach (1956 aerial photography).

Cattail Marsh

Cattail Marsh is present in three areas at Crescent Beach State Park. The largest, most intact area (~ 7 ac) occurs in a broad margin around the open water marsh on the west side of the park, just north of the pitch pine dune woodland. This area of marsh is dominated by high cover of broad leaf cattail (*Typha latifolia*). Given the low elevation of this area, and the direst connection of its drainage channel to the beach front, it is possible the marsh is subject to saltwater intrusion at astronomical high tides or during intense storm events. With two feet of sea level rise, about 15% of the large Cattail Marsh at Crescent Beach would be inundated by seawater at least on the highest annual tide. The More frequent tidal flow into the marsh will alter plant species composition, first to brackish tolerant species, and eventually to salt marsh species. At 3.3’ of sea level rise the entirety of this cattail marsh, along with some of the adjacent shrub and forested swamp, will become tidal.

Cattail Marsh in the wetlands behind the west end of Crescent Beach

Two other areas at Crescent Beach State Park with cattail marsh include the wetlands on the west side of the Brackish Tidal Marsh (~ 1 ac), and the wetlands just to the east of the park parking lot. These two wetland areas are connected by a drainage channel that was historically straightened; they are also bisected by the lane that provides access to the beach for the Inn by the Sea hotel to the north. A portion of the access lane was likely filled affecting the natural hydrology of these marshes.

Cattail Marsh provides excellent habitat for many species of animals, especially birds. Rare species associated with Cattail Marsh include Least Bittern (*Ixobrychus exilis*), Common Moorhen (*Gallinula chloropus*) (there are documented individuals of both species on Great Pond, just to the North), and American Coot (*Fulica americana*). There are also a suite of more common birds that are regularly associated with Cattail Marshes. Virginia Rail (*Rallus limicola*), Red-winged Blackbirds (*Agelaius phoeniceus*), and Marsh Wrens (*Cistothorus palustris*) all use this habitat for foraging and breeding (Gawler and Cutko 2010).

Brackish Tidal Marsh

A Brackish Tidal Marsh is found at Crescent Beach. This rare (S3) community contains both freshwater and brackish water species, often in bands corresponding to salt water exposure. The vegetation of these areas is a mix of tall graminoids and rosette-forming herbs. Freshwater species that tolerate some saltwater intrusion such as freshwater cordgrass (*Spartina pectinata*) may grow in this habitat, while other freshwater species that are intolerant of saltwater will not (Gawler and Cutko 2010).

Brackish Tidal Marsh at Crescent Beach S.P.

At Crescent Beach, the Brackish Tidal Marsh is a level, tidally-influenced marsh located behind the dune grassland. It is likely only higher high tides reach the marsh through the relatively small, sinuous drainage channel that cuts through the dune and across the beach. Within the marsh, there are some low hollows and hummocks interspersed with occasional standing water that create varyied microhabitats and consequently patch distribution of plant species. The low end of the marsh, closest to the ocean, is dominated by saltmarsh hay (*Spartina patens*). Farther inland narrow-leafed cat-tail (*Typha angustifolia*) and hard-stemmed bulrush (*Schoenoplectus acutus*) intermix with patches of Torrey's bulrush (*Schoenoplectus torreyi*), marsh straw sedge (*Carex hormathodes*), and sweet grass (*Anthoxanthum nitens*). The area is crisscrossed with narrow drainage channels and is near to formerly developed as adjacent to graded raod beds to the south and west. Narrow-leafed cat-tail is considered to be of European origin and not native to Maine (Haines 2011).

This habitat can provide important nesting habitat for Nelson's Sparrow (*Ammodramus nelsoni*), Seaside Sparrow (*Ammodramus maritimus*), and the rare Saltmarsh Sparrow (*Ammodramus caudacutus*). The New England silt-snail (*Floridobia winkleyi*) also prefers coastal marshes where the water ranges from fresh to upper brackish. Many wading birds also prefer Brackish Tidal Marsh for foraging. Given this habitat's proximity to the coast in southern Maine, much of the uplands adjacent to these marshes have been developed, or historically cleared, which has degraded many of these systems. Leaving a larger buffer between the wetland and developed areas would help reduce degradation (Gawler and Cutko 2010). Conservation of coastal marshes is important for protecting upland areas and development. These systems provide flood abatement during storm events, as they provide a significant buffer from the ocean (Batzer 2012).

As sea level rises it is likely that the Brackish Tidal Marsh at Crescent Beach S.P. will increase in size, and gradually shift to Spartina Saltmarsh. This is clearly evidenced by the map documenting different levels of sea level rise at Crescent Beach S.P. (Appendix 2). The tidally influenced marsh area will more than double in size with just one foot of sea level rise. It will be interesting to see how the plants of this community will respond to the increased saltwater intrusion. The marsh is also confined by various human developments on several sides. There is room for it to grow, but once it doubles in size, it will hit its confines.

Red Maple – Sensitive Fern Swamp

A patch of common red maple dominated swamp is present in Crescent Beach State Park on the low-lying area north and east of the main parking lot. The understory of this type is generally dominated by sensitive fern (*Onoclea sensibilis*) and bluejoint grass (*Calamagrostis canadensis*), along with a variety of other wetland herb and shrub species. There are a few bird species often associated with this habitat, such as the Louisiana Waterthrush (*Parkesia motacilla*) and Yellow-throated Vireo (*Vireo flavifrons*), it is unknown whether these species regularly use the habitat at Crescent Beach State Park. The lower elevation portions of this community will start receiving tidal flow with just above 2' of sea level rise. At 3.3' of sea level rise, about one third of this area will become tidal marsh.

Alder Thicket

This shrub dominated wetland is characterized by speckled alder (*Alnus incana*), which generally forms a monotypic, often dense overstory, with abundant herbaceous plants growing beneath. These wetlands form in basins rather than along waterways, often in old beaver meadows. Herbaceous plants common to this type include flat-topped white aster (*Doellingeria umbellata*), sensitive fern, and tussock sedge (*Carex stricta*). Given the dense nature of these thickets, they often provide excellent habitat for many common bird species such as Common Yellowthroat (*Geothlypis trichas*), Alder Flycatcher (*Empidonax alnorum*), Wilson's Warbler (*Cardellina pusilla*), and others (Gawler and Cutko 2010).

This natural community is common and well distributed throughout Maine, making it a type of least conservation concern in the state. Similar to the grassy shrub marsh, the examples of Alder Thicket at Crescent Beach S.P. may begin to see saltwater intrusion as the sea level rises. Alder Thicket is an early successional type, so as the wetland areas in the park are pushed around by sea level rise; Alder Thicket will likely be able to easily colonize new territory.

Upland Areas

There are approximately 243 acres of upland area within the three state parks. Most of this land has been cleared in the past, most likely for agriculture. About 100 acres is currently forested with mostly young to intermediate age trees. About 30 acres of the uplands are developed with roads, boardwalks, parking lots, or structures. The remaining acres are either successional meadow and shrubland, rocky outcrops, or mowed fields. There is minimal predicted impact to the uplands within the three parks from sea level rise of up to 3.3'. However, other impacts of climate change including increased frequency and intensity of severe storm events, increased activity of non-native tree pests and other invasive species, and changing microclimates could affect upland forest areas.

Upland communities at the three state parks include Oak-Pine Forest, Maritime Shrubland, Early Successional Forest and Shrubland, and Open Headland. Other, less well defined, upland cover types also occur within these parks. Many areas of the upland communities are heavily colonized by invasive plants.

Oak-Pine Forest

Oak-Pine Forest is the one of the most common upland forest types across much of the Southern Maine. It primarily occurs on land that has been previously cleared and farmed before leaving it to fallow. The ~80 acres of this forest type at Crescent Beach, Kettle Cove, and Two Lights were all cleared at one time for pasture or farmland, and now exist in early-mid successional state.

Invasive black swallowwort in the shade of a mixed forest at Two Lights S.P.

In general, the forest is less than 100 years old, with red oak (*Quercus rubra*) and white pine (*Pinus strobus*) dominating the overstory of this community. Red maple (*Acer rubrum*), and red spruce (*Picea rubens*) are also occur here. In the northeast portion of Crescent Beach State Park, there are some scattered large red oaks, likely remnant trees that were left for fence rows during agricultural times. The forest here is fairly dry and open, the few understory plants present include lowbush blueberry (*Vaccinium angustifolium*), starflower (*Trientalis borealis*), Canada mayflower (*Maianthemum canadense*), and black huckleberry (*Gaylussacia baccata*).

Oak-Pine Forest provides nesting habitat for a number of passerine bird species, including Wood Thrush (*Hylocichla mustelina*), Scarlet Tanager (*Piranga olivacea*), Ovenbird (*Seiurus aurocapilla*), Eastern Wood Pewee (*Contopus virens*), and Pine Warbler (*Setophaga pinus*). More mature examples of this community can provide habitat for cavity nesting species (Gawler and Cutko 2010). While most of the forest is relatively young at these parks, the large scattered remnant oak trees can likely provide some cavity habitat. Those larger trees should be of higher conservation concern when thinking about the forest in the three parks.

Although a common type in southern Maine, large, good quality, mature examples of Oak-Pine Forest are rare due to the region's history of land clearing and other land uses. At Crescent Beach, the upland forests provide buffers, protecting adjacent wetlands from sedimentation.

Climate-change related threats to these forests are invasive tree diseases and invasive plant species. The invasive hemlock wooly adelgid is active in most towns along Maine's coast from the midcoast south to Kittery. The adelgid was first detected in south-most York County in 2003, and has rapidly spread rapidly to most coastal towns up through the midcoast. The hemlock wooly adelgid stresses hemlock trees, ultimately killing them and is likely to further expand its range as mean annual temperatures rise. Another invasive tree pest that could potentially impact trees at Crescent Beach, Kettle Cove, and Two Light State Parks is the winter moth, a non-native pest that uses a variety of deciduous tree species as its host. In parts of Southern New England, winter moth caterpillars have been reported defoliating native trees on a large scale (Department of Enviornmental Management 2014).

All three of these state parks have significant amounts of invasive plant colonization. Open and shrubby areas tend to be the most heavily infested, with some forested areas also having significant amounts of invasive plants, while others do not.

Maritime Shrubland

The open, wind sculpted slopes above the rocky headlands at Two Lights State Park are prime locations for Maritime Shrubland. The shrubs and herbs living in this exposed coastal habitat must be tolerant of salt spray and high wind. Most of the areas where this type occurs on Maine's coast have an extensive disturbance history, and were often grazed by sheep. Many examples also have a history of fire (Gawler and Cutko 2010). Within the three parks, only Two Lights S.P. has coastal shrublands that are intact enough and generally with the natural species composition that typifies this community. Native species present include Carolina rose (*Rosa carolina*), bayberry (*Morella caroliniensis*), staghorn sumac (*Rhus hirta*), meadowsweet (*Spiraea alba*), black cherry (*Prunus serotina*), common juniper (*Juniperus communis*). The shrubs form dense impenetrable thickets that provide good cover and nesting habitat for some species of birds.

Maritime shrubland at Two Lights S.P.

Unfortunately, only a small area at Two Lights State Park supports maritime shrubland with a majority of cover of native species. Most of the rest of the extensive shrubland area is a mix of native species and non-native invasive species, with invasive species being the dominant cover in many areas. The most common invasive species Morrow's honeysuckle (*Lonicera morrowii*), multiflora rose (*Rosa multiflora*), Asiatic bittersweet (*Celastrus orbiculatus*), and beach rose (*Rosa rugosa*). It is likely that the invasive species will continue to spread throughout the Shrubland as well as the neighboring habitats, and that the overwhelming majority of habitat at this park will be comprised of non-native species.

Maritime shrublands on wind swept slopes above rocky headlands at Two Lights S.P.

There are narrow, coastally influenced shrublands behind the dune grasslands at Crescent Beach and Kettle Cove beaches, but these areas are also largely overrun with invasive shrubs and vines, so much so that they are not representative of the maritime shrubland type.

The thickets and dense cover that characterize many areas within the three parks including along the immediate coast, whether dominated by invasive or native species, provide excellent habitat for the state endangered New England cottontail, which needs dense, early successional habitats for its survival. New England cottontail populations have declined across the species' range over the past 60 years. The species has lost over 80 percent of its habitat, and now lives in roughly five isolated populations across southern New England and eastern New York State. In Maine, New England cottontail are only found in the southernmost part of state in York and Cumberland counties. Approximately 60 years ago, much of the farming in this region ceased and led to the development of expansive thickets. Since that time, most of the farmland thickets have succeeded into forest (Fuller 2012). Since the existing farmland in southern Maine is largely still active, and human development is increasing, the net result has been drastically reduced habitat that can support the New England cottontail.


Black swallowwort at Two Lights S.P.


New England cottontail – photo: Kelly Boland

Crescent Beach, Kettle Cove, and Two Lights State Parks all have New England cottontail habitat mapped throughout them. Wildlife biologists working with the Department of Inland Fisheries and Wildlife have found New England cottontails throughout the three parks as well as on private property just to the west of Crescent Beach State Park.

Keeping these shrublands in their early successional state likely harmonizes with the management goals of the parks. Not only do they provide habitat for the New England cottontail, but keeping the vegetation low and not forested keeps the views open for visitors and provides habitat for song birds and other shrub dependent wildlife. So long as these habitats are not converted to lawn, or allowed to succeed to forest, they will remain crucial habitat for the cottontail, even if they are overwhelmed by invasive plants.

Open Headland

Jutting out between the coves of Kettle Cove S.P., then wrapping around the private land of McKenny point through Two Lights S.P., and continuing northward is a long strip of open rocky headland towering above the ocean surf. These cliffs and rocky areas provide the immediate coastline with excellent protection from the ocean, especially in high tide and storm events.

While these areas are primarily bare rock, various herbaceous plant species will carve out a home here by growing in the cracks or in shallow depressions with very little soil. This habitat is some of the harshest on the coast. It gets pounded by wind, salt spray, sun, and cold. During the winter the wind and salt keep the snow from piling up and insulating the area, while in the summer the limited soil can dry out very quickly in the sun. Only a few species were found growing in this habitat within the parks. Common yarrow (*Achillea millefolium*), goosetongue (*Plantago maritima*), and three-toothed cinquefoil (*Sibbaldiopsis tridentata*) were found growing in the rocks with a few scattered plants of black swallowwort (*Cynanchum louiseae*) and Asiatic bittersweet. The faces of the rocks also host a suite of lichens, including the lime-green map lichen and the orange Xanthoria lichen.


Rocky headland at Two Lights S.P.

In many parts of the parks there is a trail directly on top of these rocky bluffs, but in areas where there is not, it generally transitions into a maritime shrubland. In these areas you will find more of the species typically found in those shrublands, as well as the invasive species.

The tumultuous waters generated where the bedrock outcrops intersect with active surf at Two Lights State Park is excellent habitat for the state threatened Harlequin Duck (*Histrionicus histrionicus*), and has been designated as such by Maine Department of Inland Fisheries and Wildlife. Harlequin Ducks are regarded as one of the most beautiful waterfowl species in North America. They winter in the exact same location every year, and forage by diving in the foamy surf along rocky coastlines. Many individuals of the species winter along the rocky Maine coastline, while they breed along inland streams in Eastern Canada. This species saw historic declines due to overharvesting by hunters, but strict regulations were put in place and have stabilized the population. They are now making a slow recovery (Maine Department of Inland Fisheries and Wildlife 2011).

The Harlequin Duck's habitat is unlikely to be greatly affected by sea level rise, but the warming Gulf of Maine could pose a bigger threat, as their current food sources may become less plentiful. It is unclear how the duck will cope with climate change. It is also threatened by development, offshore wind development, and oil spills.

Successional Shrubland and Early Successional Forest

Each of the three parks supports areas of successional shrubland and early successional forest. All of these areas were previously open fields, likely for agricultural purposes, and have been slowly succeeding to woody cover since their abandonment. Open grass and forb dominated patches are still present at Crescent Beach S.P. at either end of the park behind the shore zone. There is also a patch in the interior of Kettle Cove S.P., and several small patches are scattered among the shrub thickets at Two Lights S.P. These patches are all surrounded by encroaching shrublands, mostly dominated by a mix of the invasives shrubby honeysuckle and Asiatic bittersweet. Invasive multiflora rose is also present in some areas. Native shrubs including bayberry and Carolina rose are also present but generally less dominant than the invasive species.

Successional shrublands grade into early successional forest in many areas of the park. Like successional shrublands, early successional forests are very broadly defined, but in the case of Two Lights and Kettle Cove State Parks, these areas are dominated by big toothed aspen (*Populus grandidentata*), red maple, paper birch (*Betula papyrifera*) and black cherry (*Prunus serotina*). This community grows in after a major disturbance, it could be post-fire, logging or agriculture; anything that would completely remove a stand. The disturbance histories of these habitats and the presence of invasive propagules have been conducive to heavy colonization of invasive species. As note previously, these habitats provide good quality habitat for New England cottontail. Without management, early successional forest will eventually grow into mature forest, and in Crescent Beach, Kettle Cove, and Two Light State Parks, that will likely be Oak-Pine Forest.

Management Considerations

Under current conditions, the Dune Grassland and the New England cottontail habitat, are the only significant natural features among the three state parks that require active management, which is already taking place. Signage and judicially placed fencing keep visitors from both trampling sensitive dune vegetation. Other near term activities that could benefit sensitive features at the park includes:

- Periodic monitoring for pests and invasive species, particularly in the Dune Grasslands and the Brackish Saltmarsh. The Dune Grasslands currently have some areas colonized by the coastally invasive rugosa rose. This hardy non-native species can out-compete native dune vegetation to the detriment of the natural habitat. If a practical and effective means to remove it is developed, it would improve the quality and integrity of Dune Grasslands to eradicate it from the site. The brackish tidal marsh has some areas dominated by narrow-leaved cat-tail, also a non-native species. This species will not tolerate the full salinity of daily tidal inundation, and will die off as tidal flow increases into the site with rising sea level. It may however, move landward into new areas where brackish conditions develop.
- Periodic monitoring of sensitive areas for impacts from recreational activity, particularly the Dune Grasslands. This community currently receives very little visitor use, but is in close proximity high numbers of beach users. If usage patterns change to the detriment of the community they should be addressed.

- The New England cottontail habitat at the parks will require periodic maintenance to maintain high stem densities needed by the rabbit for cover. Potential techniques for managing New England cottontail habitat include periodic brush-hogging, periodic mowing, fire, and or the selective removal of canopy forming species.
- Park areas not managed specifically for recreation or for New England cottontail will benefit by allowing natural succession and disturbance processes to occur unimpeded. Areas already heavily infested with invasive plant species will likely be limited or slowed in their ability to develop into mature forests.
- Incorporation of information on vulnerable rare species into park planning particularly Piping Plover and New England cottontail.

As noted previously, these State Parks have some of the highest visitation rates, and contain some important and threatened coastal habitats for plants and animals. Some of these habitats are going to change and potentially disappear with sea level rise. Some habitats may be able to adapt by migrating landward as sea level rises, and other more elevated areas may be largely unaffected. Conserving both the environmental and recreational values of these parks will present challenges if predictions regarding sea level rise and coastal storm intensification are correct.

Due to the elevated topography of Two Lights S.P., it will not be significantly impacted by predicted sea level rise in the next 100 years. The rocky headlands that form the interface between the park and the ocean are sufficiently high to accommodate even six feet of sea level rise with no adverse effects to terrestrial habitats within the park.

Kettle Cove S.P. will see significant flooding, especially at the highest investigated scenario of six feet of sea level rise. It will mostly affect the beach and limited dune areas of the two large kettle coves. These features will be forced inland, and fortunately, there is no development preventing them from moving. The adjacent area of successional scrubland will shrink, which will decrease the amount of existing habitat available for New England cottontail.

At Crescent Beach S.P., habitats that are unable to adapt to sea level rise including the Pitch Pine Dune Woodland, Brackish Tidal Marsh, and Cattail Marsh may be lost. Other habitats such as beaches and Dune Grasslands may be able to adapt to sea level rise by migrating landward. Along with those changes, new habitats such as Spartina Saltmarsh will likely form in areas formerly occupied by other tidal (Brackish Marsh) and freshwater wetlands. While the mechanics allowing each coastal feature to migrate or to develop new are different, these systems are all similar in that they are confined in their ability to transgress landward by coarse barriers including bedrock outcrops and human development. As previously noted, there is room for landward movement of the beach and dunes where there is low-lying, undeveloped ground, in this case mostly wetlands, and no room where there is upland and development (i.e., the parking lot and other park infrastructure).

The future of the Pitch Pine Dune Woodland at Crescent Beach S.P. is very uncertain as it cannot gradually migrate like a beach or dune, and it is already very small and located in a sea level rise inundation zone. The dune that supports it will have to move and then remain static if pitch pine is to recolonize it. Recolonization of pitch pine can be facilitated by planting, or by disturbances that favor it including prescribed fire or scarification.

Coastal dune and wetland systems provide important buffers against storm surges for coastal development. When coastal dune and wetland systems are compromised or lost, the adjacent upland areas and associated development become increasing vulnerable to damage from storms. To reduce the potential for damage and the related costs of repairs, and to allow landward transgression of sensitive dune environments, new park infrastructure should be designed to be adaptable or moveable, or placed in areas where it won’t be affected by sea level rise and other climate change impacts.

Invasive Species

Crescent Beach, Kettle Cove, and Two Lights State Parks have significant infestations of invasive plant species, so much so, that there is currently no practical or cost effective way to reduce their impact. Most habitats within these parks have some invasive species. The extensive open meadows, successional fields, successional and maritime shrublands, and early successional forest are mostly heavily infested. The most abundant invasive species are shrubby honeysuckle, Asiatic bittersweet, and black swallowwort (*Cynanchum nigrum*). Black swallowwort is most abundant in Two Lights

State Park, where it is found in most habitat types, including the forests. The invasives, Japanese knotweed (*Fallopia japonica*), rugosa rose (*Rosa rugosa*), and multiflora rose (*Rosa multiflora*) are also present and locally abundant but not as ubiquitous and widespread as the aforementioned species. Fortunately, the only rare terrestrial species at these parks, the New England cottontail, seeks refuge in woody invasive species, so long as they provide the right mix of shrubland cover for its survival.


Successional shrubland at Kettle Cove S. P. with a heavy infestation of invasive Oriental bittersweet and shrubby honeysuckle

If resources and invasive species management technologies allow, some consideration should be given to limiting the impacts of invasive species in the rare Dune Grassland. Rugosa rose is already abundant at the west end of Crescent Beach and could, overtime spread throughout the Dune Grassland. Invasive shrubby honeysuckle is also capable of colonizing this community type but was not noted there during recent surveys. Periodic monitoring of the Dune Grassland could help prevent the colonization by this species.

A summary table listing the projected impacts and respective management considerations for each rare or exemplary feature or wildlife habitat are listed starting on the next page.

Summary of Potential Impacts to Significant Natural Features

(note that only approximate median amount of sea level rise (3.3') is addressed in this summary, the lower amounts of 1' and 2' of seas level rise will have less impacts and the higher amount of 6' can be expected to have far more dramatic impacts.)

Dune Grassland (S2/G4?) **Size:** 5.8 acres (Crescent Beach S.P.)

State Priority: High priority, there are less than 250 acres of this type statewide, this example is considered to be of fair quality (BC rank).

3.3' Sea Level Rise inundation acreage: Without movement of the dune 0.5 acres will be inundated when sea level has increased by 3.3'.

Projected Change: The feature has the potential for landward movement in areas where there are low-lying wetlands on its landward side, but not where there are higher elevation uplands such as the area with the parking lot at Crescent Beach S.P.

Vulnerability to one-time events (storms): This feature is vulnerable to storms but has recovery potential. Frequent, heavily eroding storms could prevent its reestablishment.

Management considerations: State Parks have a high responsibility for this type due to their disproportionate occurrence on state park lands. Allowing the dune grassland to migrate unimpeded in response to sea level rise may aid in its persistence in the park. Other considerations; 1) monitor for impacts from human use, 2) periodically monitor for invasive plants and consider management for invasive plants if practical and if there is a high likelihood of habitat improvement, and 3) learn from outcomes in other affected east coast locations with dune grasslands.

Pitch Pine Dune Woodland (S1/G2) **Size:** 1.2 acres (Crescent Beach S.P.)

State Priority: This example is a moderate to low priority, it is very small (CD rank) and highly vulnerable. It will likely be lost if sea level rises as predicted by 2100.

3.3' Sea Level Rise inundation acreage: More than half of the feature, 0.7 acres, will be inundated by the highest annual tide, and due to the level nature of the site, salt water intrusion into the dune will have killed all the trees and shrubs by the time sea level has increased to this amount.

Projected Change: This feature is likely to be lost due to its low elevation and small size, and due to its inability to migrate with the dune.

Vulnerability to one-time events (storms): Pitch pine has moderate tolerance to salt water spray, but low numbers of trees within this community make it more vulnerable to storm damage or impacts from pathogens.

Management considerations: The feature will most likely be lost at some point in the future, though how soon depends on the rare of sea level rise. Pitch pines along some areas of Maine's coast are also vulnerable to pitch pine shoot tip damage caused by two pests, the European pine tip moth (*Rhyacionia buoliana*) and Diplodia tip blight (*Diplodia pinea*). Both pests can affect the growth rate of affected trees, and cause them to appear stressed. Heavy damage can result in mortality, as bark beetles commonly attack severely weakened trees. Another potential pest if the southern pine beetle (*Dendroctonus frontalis*). The recent destruction of pitch pine woodlands on Long Island from the southern pine beetle is one indication of the vulnerability of this type to expanding ranges of forest pests. Pitch pines at Crescent Beach were clearly stressed when observed in 2014 including some mortality. It is unclear whether any of the above mentioned pests are the cause.

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Brackish Saltmarsh (S3/G5) **Size:** 2.5 acres (Crescent Beach S.P.)

Associated special features:

- Tidal Waterfowl and Wading Bird Habitat

State Priority: This feature is of moderate priority, the type is rare but this example is fair to poor quality because of a past history of disturbance, and because of its relatively small size.

3.3' Sea Level Rise inundation acreage: The feature already receives tidal flow, and will expand as sea level rises.

Projected Change: As sea level increases to highest annual tides of 3.3' the tidal marsh will expand to the adjacent freshwater wetlands increasing the size of the marsh to ~ 19 acres, but by that time much of the area will have shifted from Brackish to Spartina Saltmarsh. If sea level continues to rise even further, this tidal marsh will coalesce with other inundated back dune areas, and at 6' of sea level rise ~80 acres of Crescent Beach S.P. will be inundated at highest annual tides. The dune formation may change dramatically by the time sea level reaches these depths and actual areas of inundation and tidal marsh development will dependent on the dune's new location and configuration.

The Tidal Waterfowl and Wading Bird Habitat will increase in this area as the tidal marsh system expands.

Vulnerability to one-time events (storms): This brackish saltmarsh is not vulnerable to flooding as it is already a tidal system, but if in a catastrophic erosion event the beach and dune were lost, the marsh would become exposed to open ocean and its capacity to support vegetation could be compromised.

Management considerations: Accommodate the progressive increase in tidal flow by enlarging or removing the culvert under the park maintenance road. If tidal flow exceeds the capacity of the culvert, erosion will likely result above and below the culvert. As sea level increases, the culvert and or sections of the dune may eventually be washed out.

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Piping Plover (E) - Least Tern (E) Essential Habitat **Size:** N/A

State Priority: The beaches at both Crescent Beach and Kettle Cove S.P. are mapped as Essential Habitat for these rare bird species. After a two year hiatus, Piping Plovers started nesting on Crescent Beach again, with two successful nests (summer 2014). The birds are reported to have returned at the outset of the 2015 nesting season.

3.3' Sea Level Rise inundation acreage: N/A

Projected Change: The maintenance of the habitat for these species follows the fate of dune system, but could be lost due to other variables such as increased predation.

Vulnerability to one-time events (storms): Nesting is routinely vulnerable to unusually high water events. More events would lead to poor nesting success.

Management considerations: State Parks have high responsibility for this type. Monitor for human use impacts, and allow any natural progression of dunes in a landward direction.

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Tidal Waterfowl and Wading Bird Habitat (TWWH) **Size:** N/A

State Priority: Moderate vulnerability, the type is wide spread in the state, but vulnerable to loss if tidal marsh migration does not keep up with sea level rise. Marsh vulnerability will vary locally based on the degree of exposure, sedimentation rates, and the availability of low-lying areas on the adjacent landscape to accommodate migration.

3.3' Sea Level Rise inundation acreage: This habitat is mapped for three different settings at Crescent Beach and Kettle Cove State Parks, near shore waters, beach and sandy bottom areas, and back dune marsh in the area of the brackish tidal marsh. Areas of near shore waters will be unchanged by sea level rise. TWWH mapped along the beach and sand bottom areas will move inland following any movement of the dune system and beach, loss of beach area will mean also mean some loss of TWWH. The TWWH in the back dune marsh area will expand as sea level rises to 19 acres with 3.3' of sea level rise, and to as much as 80 acres at 6' of rise. Tidal flow will need to be accommodated where the channel passes under the existing maintenance road or natural marsh development will be impacted.

Projected Change: TWWH will expand behind the dune system on the east side of Crescent Beach. TWWH may be impacted if areas of beach are lost to sea level rise.

Vulnerability to one-time events (storms): Significant erosion of the beaches from one or more severe storms could impact the portion IWWH occurring in those areas.

Management considerations: Facilitating increased tidal flow into the back dune area will allow tidal marshes to expand there in a natural way. If the beach is damaged by severe storms, where practical promote the redevelopment and persistence of the beach.

Inland Wading Bird and Waterfowl Habitat (IWWH) **Size:** N/A

State Priority: Low vulnerability, lower priority, the type is wide spread in the state.

3.3' Sea Level Rise inundation acreage: All of the open canopy area of the IWWH will be likely come tidal (tidal marsh) when the highest annual tides are increases by 3.3', and will shift function from Inland bird habitat to tidal bird habitat.

Projected Change: This area of back dune IWWH will become tidal by the time sea level rise has increased by about 2'.

Vulnerability to one-time events (storms): A catastrophic erosion event could significantly widen the current narrow drainage channel of this marsh opening it future tidal flooding.

Management considerations: Let the marsh change naturally as sea level progressively increases and tides begin to affect the system.

New England Cottontail **Size: (**mapped throughout the three parks though actual occupied area is very localized)

State Priority: The habitat for this species within the three parks is a priority for the persistence of the species. The range of the species in Maine is relatively small, and within the range there are only a few much smaller locales that support populations.

3.3' Sea Level Rise inundation acreage: Acreage is small, but at 3.3' will inundate prime habitat for the species.

Projected Change: Lower lying areas, including areas currently occupied by shrub swamp, will be lost, particularly in Crescent Beach S.P., decreasing the amount of habitat that is currently essential to the species.

Vulnerability to one-time events (storms): Unclear, the habitat may be resilient, but the animals themselves may be vulnerable.

Management considerations: The primary concern for this species is that the scrub – shrub habitat that it depends on will succeed to forest. Management that stalls succession or creates new areas with shrub cover will be necessary for the long term maintenance of this species within the parks.

Harlequin duck **Size: (**mapped for waters abutting Two Lights S.P.)

State Priority: State Threatened species (S2S3N/G4), the Maine coast provides critical wintering habitat for this species. Habitat for the species is scattered along the entire coast though more densely in Hancock and Washington Counties than elsewhere.

3.3' Sea Level Rise inundation acreage: N/A, mapped habitat is primarily open ocean.

Projected Change: The submerged and emerged rocky shorelines needed for feeding and resting by this species are not likely to change their habitat character as a result of sea level rise.

Vulnerability to one-time events (storms): No effect.

Management considerations: Warming ocean temperatures, changes in ocean water chemistry, and invasive species all have the potential to change the habitat that supports harlequin ducks while they winter in Maine. Because of low reproduction rates, harlequin ducks are vulnerable to anything that causes mortality to birds of breeding age. The biotic and abiotic factors that might impact this species at Two Lights S.P. are not within the scope of the park system to manage.

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Appendix 1: Table of Exemplary Features

Exemplary Natural Communities

Feature Name	**Scientific Name**	**State Rank**	**EO Rank**	**Size (ac)**
Dune Grassland	Dune Grassland	S2	BC	5.8
Pitch Pine Dune Woodland	Pitch Pine Dune Woodland	S1	CD	1.2
Brackish Tidal Marsh	Brackish Tidal Marsh	S3	CD	2.5

Rare Plants

Feature Name	**Scientific Name**	**State Rank**	EO Rank	Size (ac)
none				

Rare Animals

Feature Name		Protection Rank	EO Rank	Size (ac)
Piping Plover	*Charadrius melodus*	E	-	-
Least Tern	*Sternula antillarum*	E	-	-
Harlequin Duck	*Histrionicus histrionicus*	T	-	-
Least Bittern	*Ixobrychus exilis*	E	-	-
Common Galinule	*Gallinula galeata*	T	-	-
New England Cottontail	*Sylvilagus transitionalis*	E	-	-

Appendix 2: Maps

Map 1: Bedrock Geology at Crescent Beach, Kettle Cove, and Two Lights State Parks

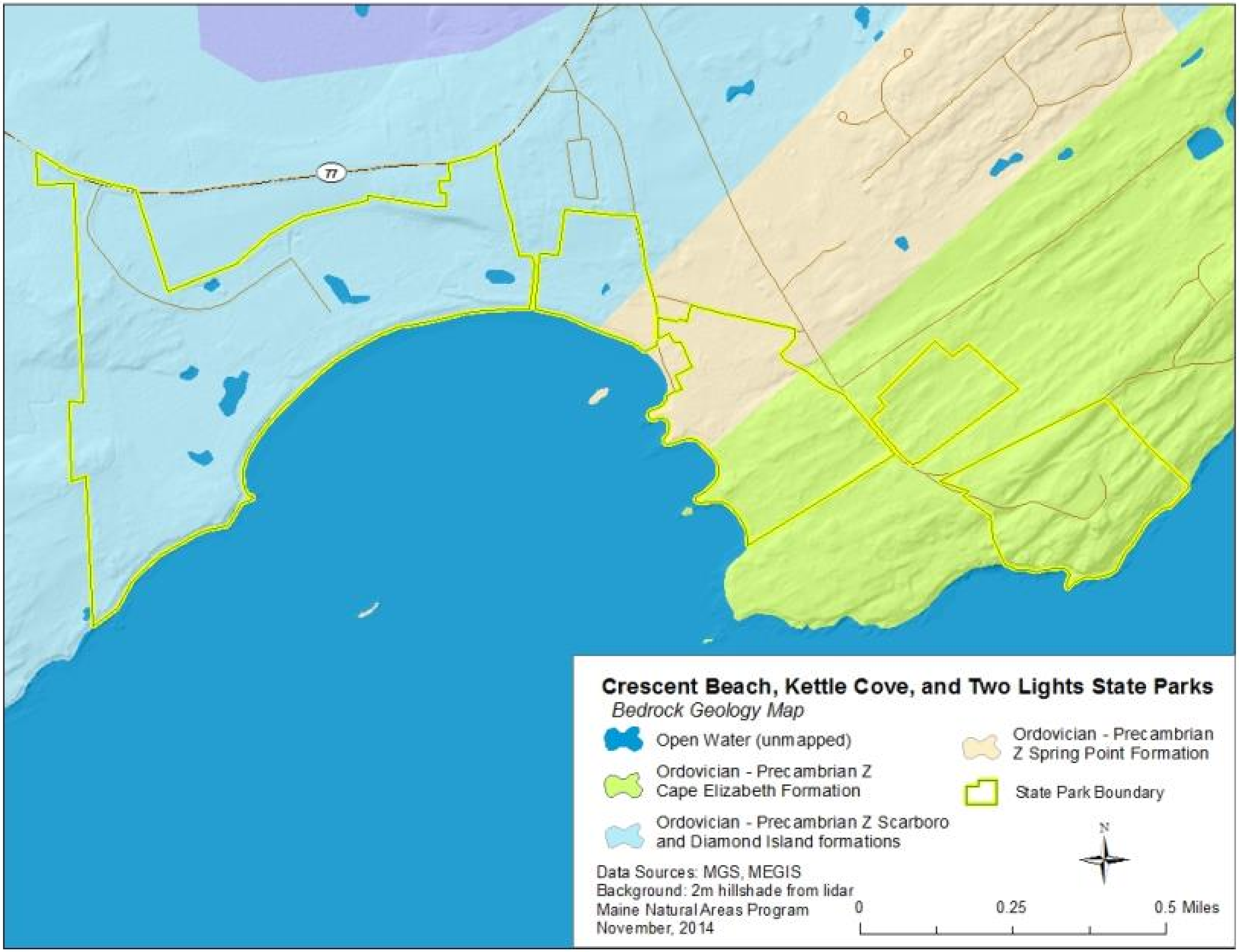
Map 2: Surficial Geology at Crescent Beach, Kettle Cove, and Two Lights State Parks

Map 3: Natural Communities at Crescent Beach, Kettle Cove, and Two Lights State Parks

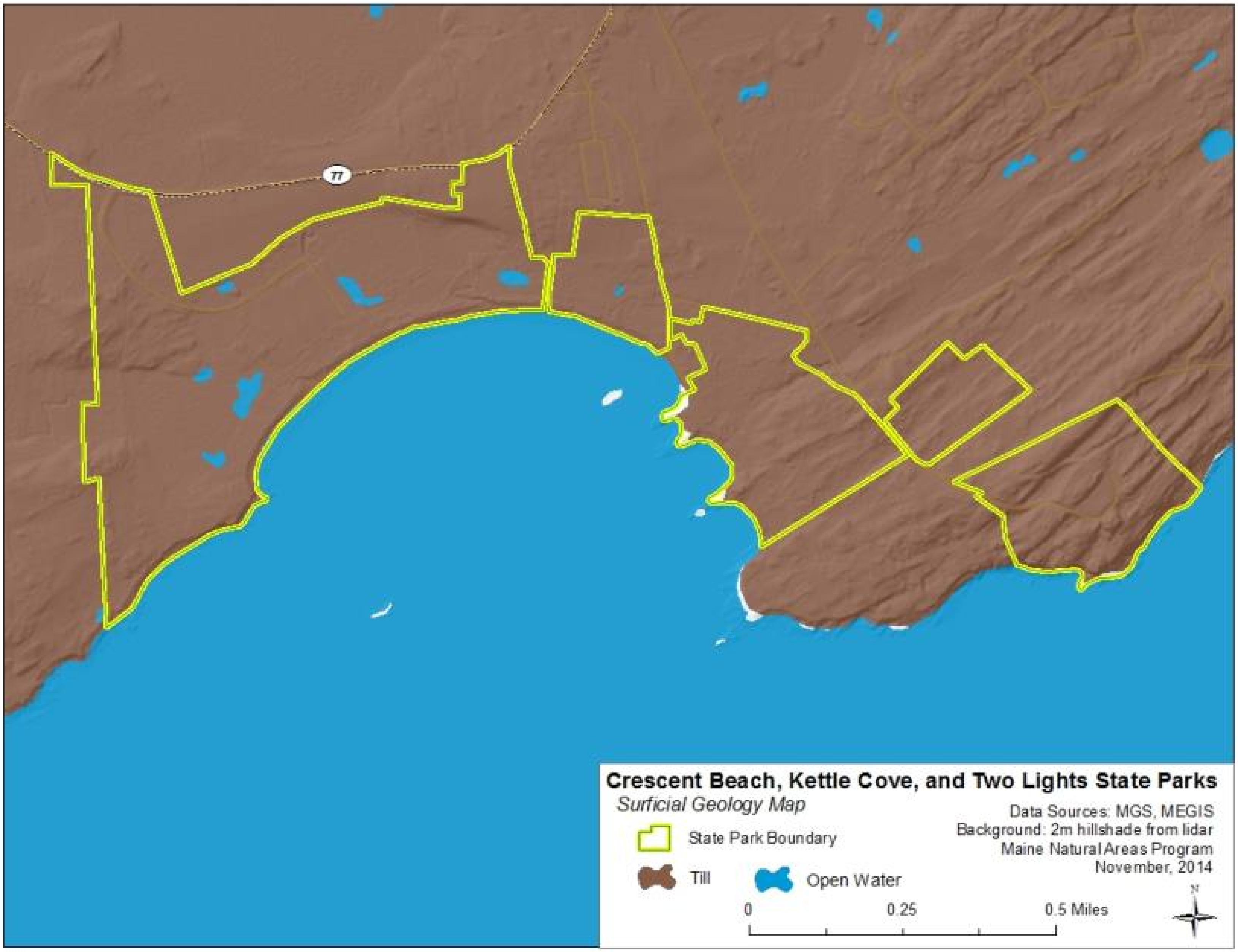
Map 4: Rare Plants and Animals at Crescent Beach, Kettle Cove, and Two Lights State Parks

Map 5: 1’, 2’, 3.3’ and 6’ Sea Level Rise Scenarios at Crescent Beach, Kettle Cove, and Two Lights State Parks

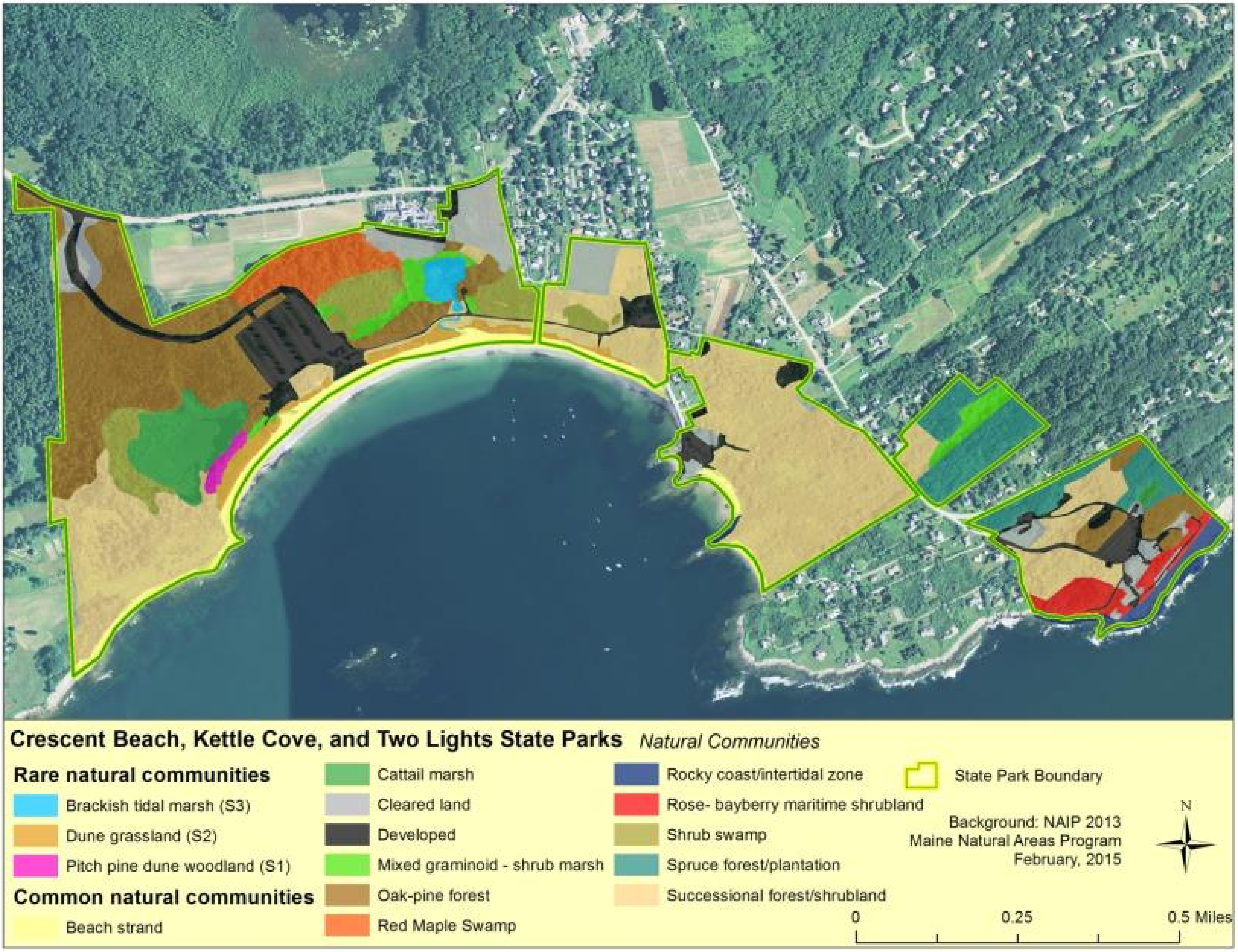
Map 1: Bedrock Geology at Crescent Beach, Kettle Cove, and Two Lights State Parks



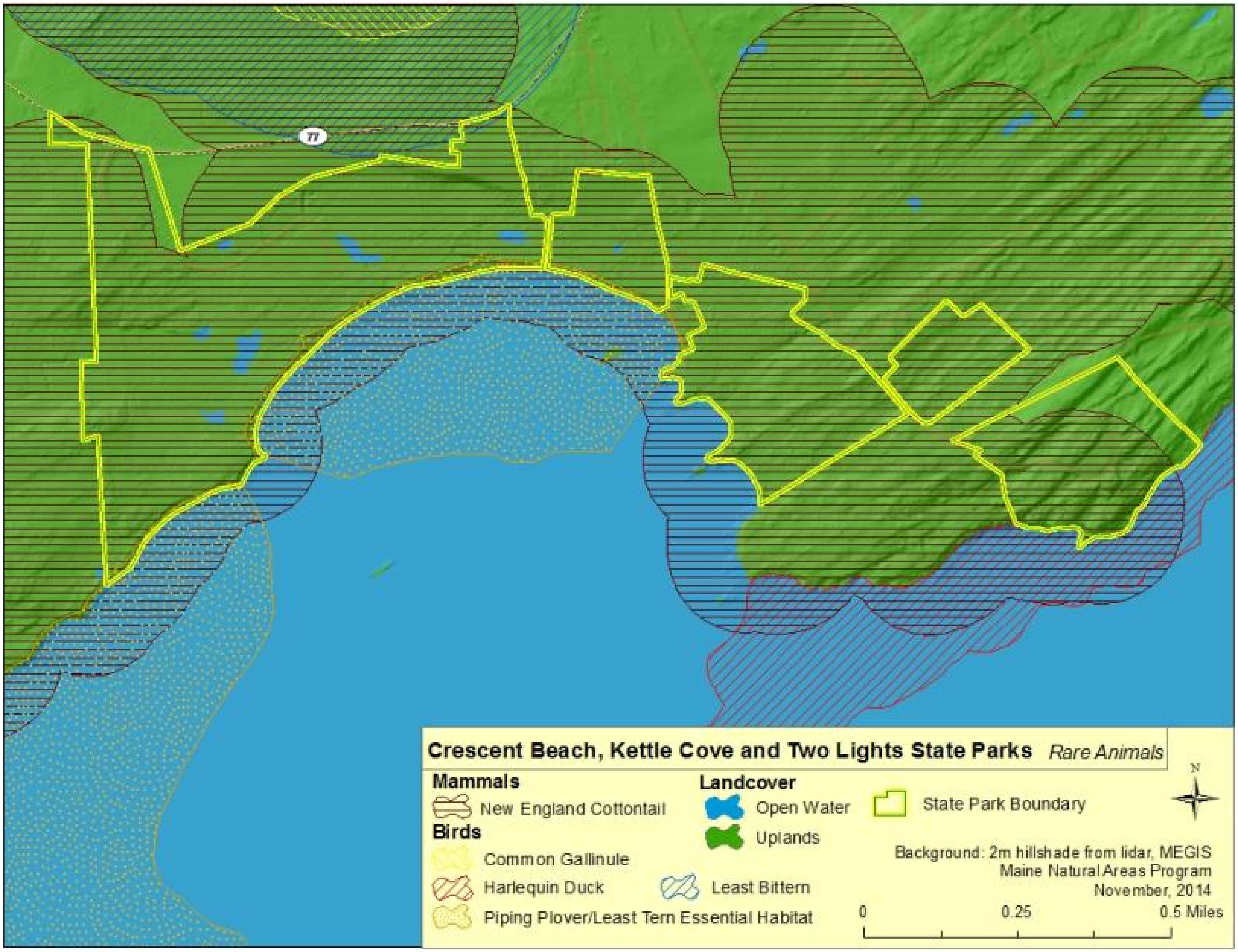
Map 2: Surficial Geology at Crescent Beach, Kettle Cove, and Two Lights State Parks



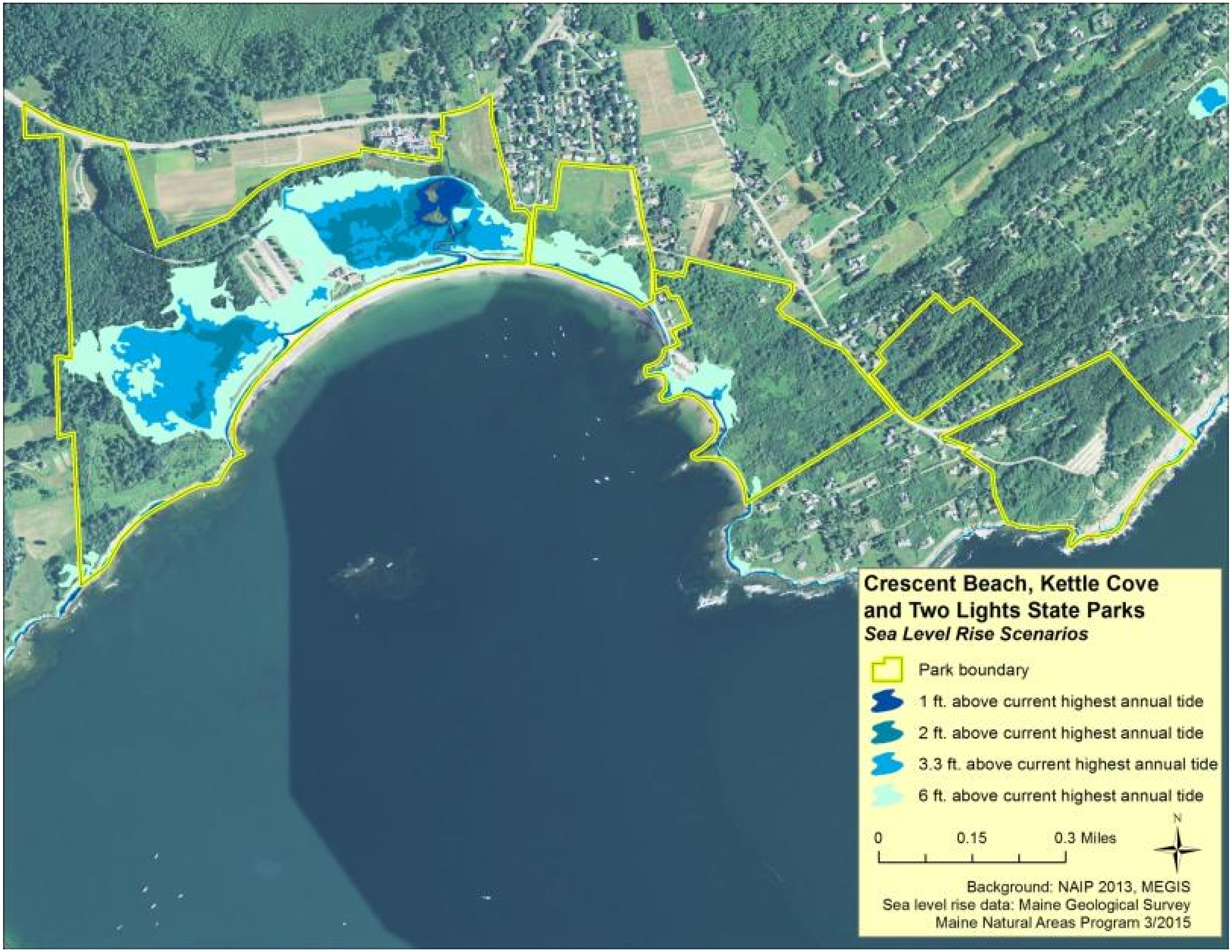
Map 3: Natural Communities at Crescent Beach, Kettle Cove, and Two Lights State Parks



Map 4: Rare Plants and Animals at Crescent Beach, Kettle Cove, and Two Lights State Parks



Map 5: 1', 2', 3.3' and 6' Sea Level Rise Scenarios at Crescent Beach, Kettle Cove, and Two Lights State Parks



Appendix 3: Rare Plant and Animal Fact Sheets

Appendix H

Popham Beach State Park
Time Series Google Earth Imagery
1997-2016

Figure H-1. 1997 aerial image of the Popham Beach State Park area showing different habitat and beach features in reference to the Morse River main channel. Note the expansive dune system fronting the parking lot. Imagery from GoogleEarth.

Figure H-2. 2003 aerial image of the Popham Beach State Park area. Note northeastward migration of the channel and subsequent erosion of the beach and dune.. Note eastward growth of the sand spit at Morse Mountain. Imagery from GoogleEarth.

Figure H-3. 2007 aerial image of the Popham Beach State Park area. Note continued northeastward migration of the channel and extensive erosion of the beach and dune in front of the parking lot. Note continued eastward growth of the sand spit at Morse Mountain and sand bar development blocking the main channel exit near Morse Mountain. Imagery from GoogleEarth.

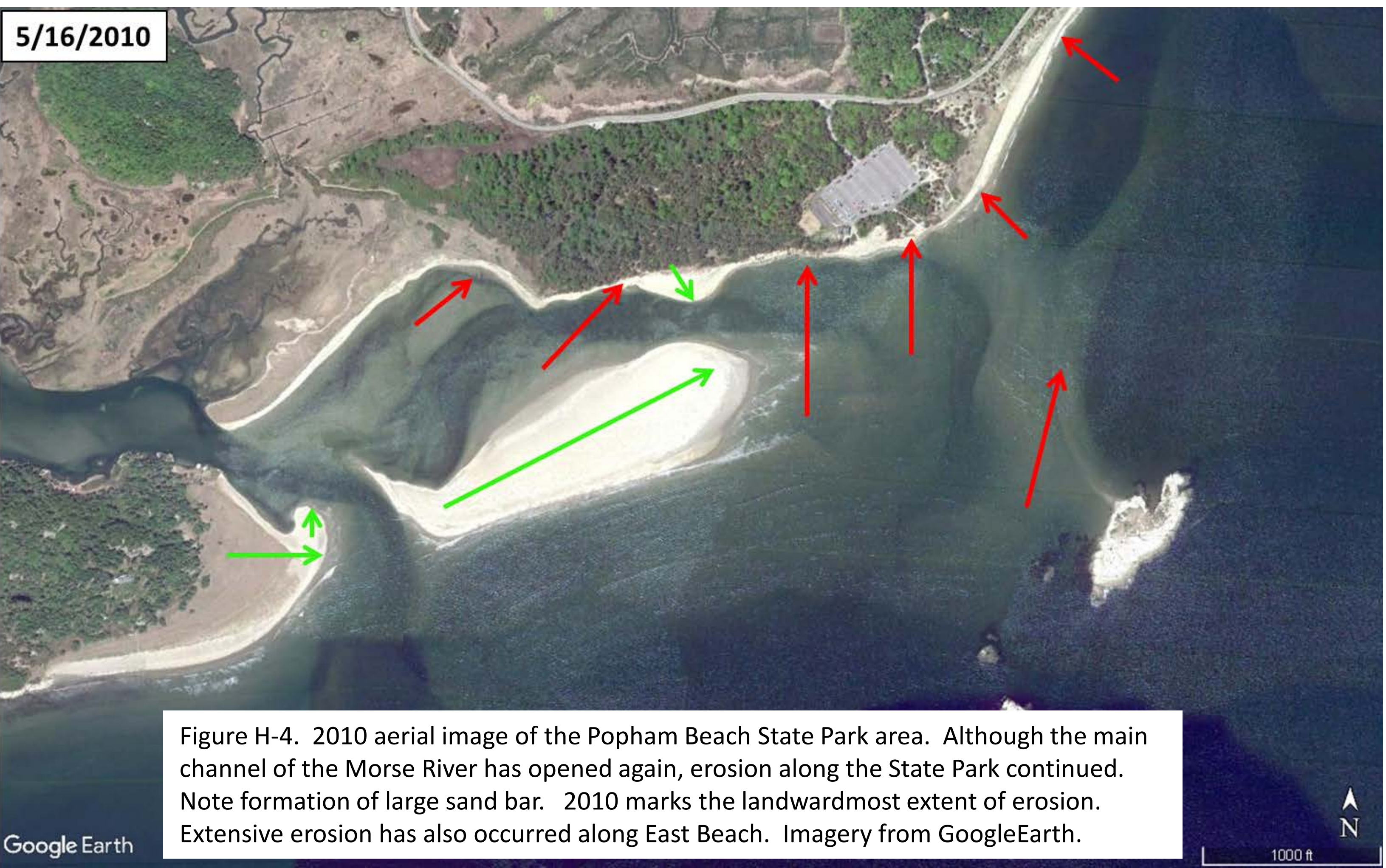


Figure H-4. 2010 aerial image of the Popham Beach State Park area. Although the main channel of the Morse River has opened again, erosion along the State Park continued. Note formation of large sand bar. 2010 marks the landwardmost extent of erosion. Extensive erosion has also occurred along East Beach. Imagery from GoogleEarth.

Figure H-5. 2011 aerial image of the Popham Beach State Park area. The main channel is beginning to migrate slightly eastwards again. Some dune growth along the State Park started, but erosion in front of the bath house continued. The large sand bar fronting the park has shifted to the east. East Beach continued to erode. Imagery from GoogleEarth.

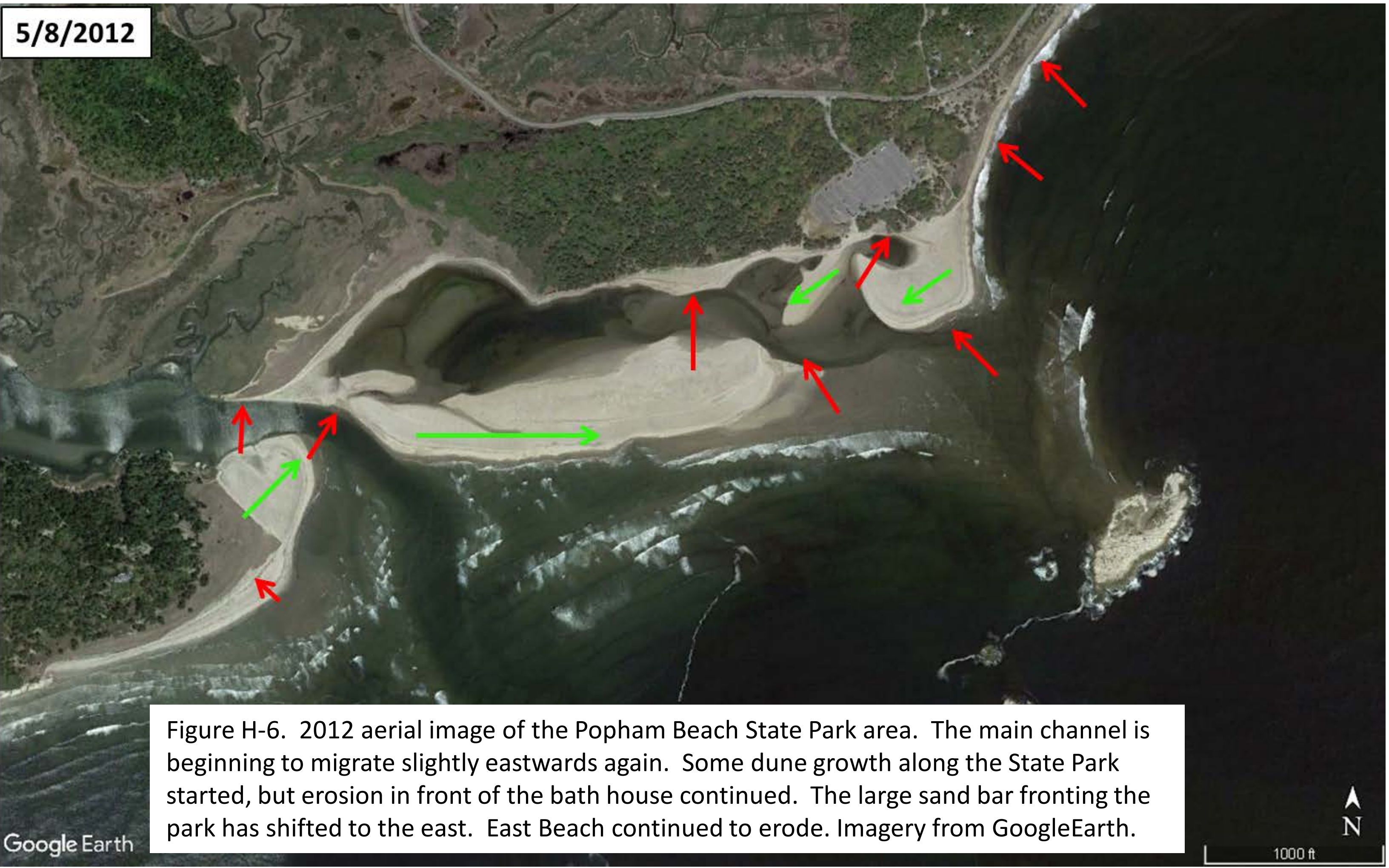


Figure H-6. 2012 aerial image of the Popham Beach State Park area. The main channel is beginning to migrate slightly eastwards again. Some dune growth along the State Park started, but erosion in front of the bath house continued. The large sand bar fronting the park has shifted to the east. East Beach continued to erode. Imagery from GoogleEarth.

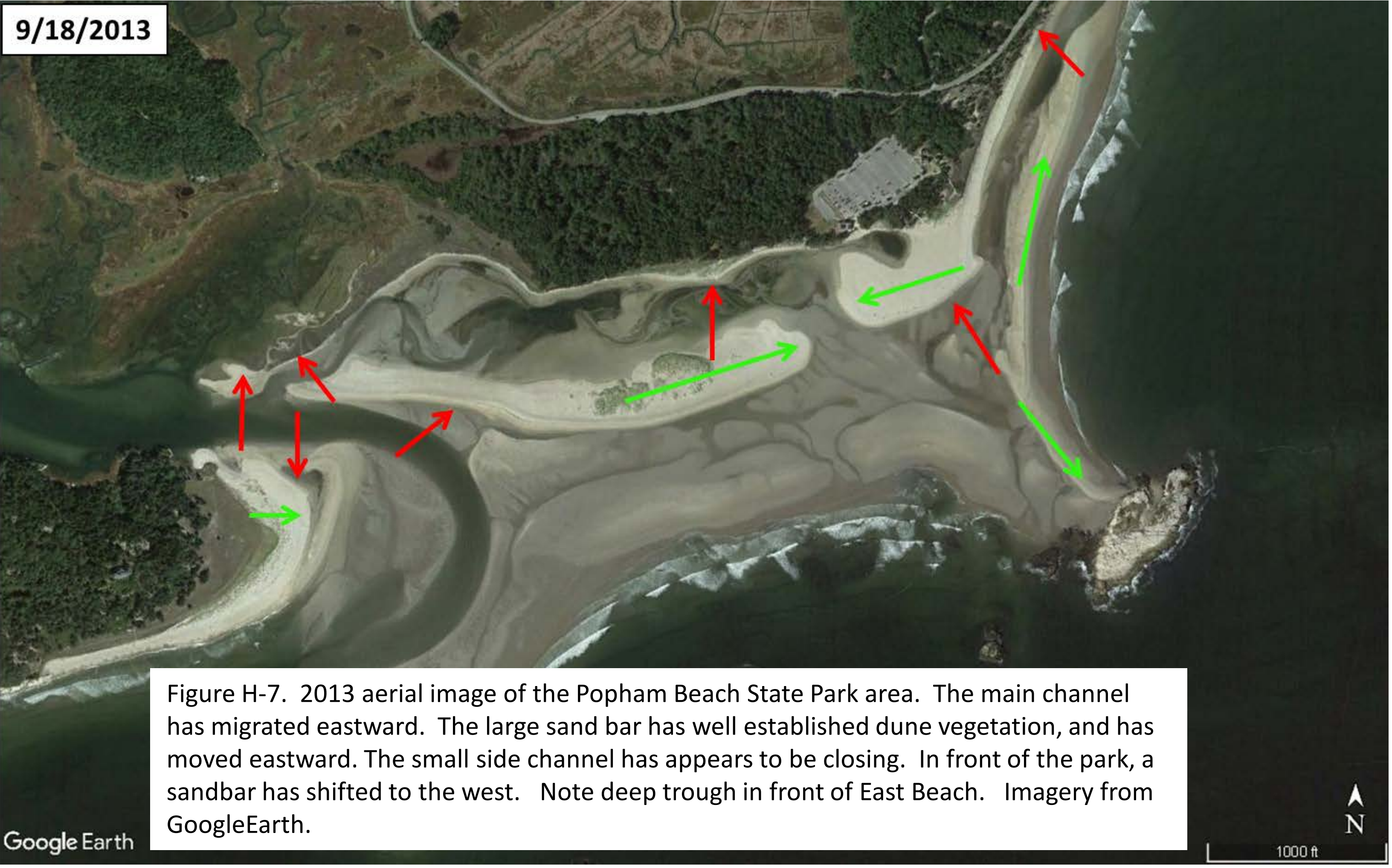


Figure H-7. 2013 aerial image of the Popham Beach State Park area. The main channel has migrated eastward. The large sand bar has well established dune vegetation, and has moved eastward. The small side channel has appears to be closing. In front of the park, a sandbar has shifted to the west. Note deep trough in front of East Beach. Imagery from GoogleEarth.

Figure G-8. 2014 aerial image of the Popham Beach State Park area. The main channel is migrating farther eastward, and is eroding the large sand bar. The small side channel has almost closed. In front of the park, a sandbar has shifted to the west, and the beach at East Beach has grown. Imagery from GoogleEarth.

Figure H-9. 2015 aerial image of the Popham Beach State Park area. The main channel migrated farther to the west, eroding the sand bar/dune, which is shifting. The area in front of the main parking lot has started to fill in. The deep trough in front of East Beach has filled. Imagery from GoogleEarth.

Figure H-10. 2016 aerial image of the Popham Beach State Park area. Note continued westward movement of the channel, and subsequent erosion and eastward migration of the sand dune/sand bar. Sand bars have almost closed the beach in front of the parking lot. Imagery from GoogleEarth.

Appendix 1.

2016 Changing Shorelines Popham Beach State Park Survey Instrument

Section 1: Popham Beach State Park - Current Perceptions of Changing Shorelines

Q1. Is today your first visit to Popham Beach State Park?
YES (1)
NO (2)….**Q1A. For about how many years have you been visiting Popham?**___________ YEARS

Q2. What do you like about Popham Beach State Park?

Q3. About how many days have you visited Popham Beach State Park this summer?

____________ DAYS...**Q3A. About what percentage of these visits were part of trips where you returned to your home (primary/second) on the same day?**
__________% (0-100 %)

Q4. Have you noticed any changes in the width, size, or shape of the beach and shoreline at Popham Beach State Park? YES (1)...**Probe: Q4A. What changes? What do you think are the causes?**
NO (2)

Q5. Have you seen signs posted at Popham Beach about erosion? YES (1) NO (2)

Q6. In your opinion, are there impacts of erosion happening at Popham Beach State Park?
YES (1)
NO (2)

Section 2: Changing Shorelines at Popham Beach State Park - Looking Ahead

The shoreline at Popham Beach is constantly changing. Potential negative impacts of changing shorelines at Popham include less beach space at high tide, less coastal habitat for plants and animals, and damage to park infrastructure such as bath-houses, parking areas, and picnic areas.

Q7. Overall, do you think the state should take actions to address changing shorelines or choose to let nature take its course at Popham?

TAKE MANAGEMENT ACTIONS (1)
LET NATURE TAKE ITS COURSE (2)

Probe: Q7A. Why?(for either answer above)

Q8. Actions to address shoreline change at Popham Beach State Park can take many forms. We are interested in your opinions of several potential actions. In your opinion, should each option below be a low priority, medium priority, or high priority action to increase the park's resiliency?

Building a seawall to harden the shoreline	LOW	MEDIUM	HIGH
Altering the channel of the nearby Morse River	LOW	MEDIUM	HIGH
Moving sand from one area of the beach to another	LOW	MEDIUM	HIGH
Bringing in sand from other areas to widen the beach	LOW	MEDIUM	HIGH
Relocating bath-houses to more inland areas	LOW	MEDIUM	HIGH
Relocating parking to more inland areas	LOW	MEDIUM	HIGH

Q9. What additional information, if any, would you like to have about changing shorelines at Popham Beach State Park or the options above?

Probe: If interested in some information - **Q9A What is the best way to get this information to you?**

Q10. If a future erosion event caused Popham Beach to be on average ONE HALF its current width over all tidal fluctuations, would this make your experience here WORSE, BETTER, or have NO EFFECT ONE WAY or the OTHER?

WORSE (1)...**Q10A. Would it worsen your experience enough to cause you to take fewer trips to this beach over a typical summer?** YES (1)....**Q10B**. **How many fewer visits to Popham do you**
NO (2) **think you would take over the summer?**

_____ fewer TRIPS or _____% (0-100) fewer TRIPS

Probe: Q10C. Tell me more about how it would affect your experience.

BETTER (2)...**Q10A. Would it improve your experience enough to cause you to take more trips to this beach over a typical summer?** YES (1)....**Q10B**. **How many more visits to Popham do you**
NO (2) **think you would take over the summer?**

_____ fewer TRIPS or _____% (0-100) fewer TRIPS

Probe: Q10C. Tell me more about how it would improve your experience.

NO EFFECT ONE WAY or the OTHER (3)

Section 3: Today's Visit to Popham Beach State Park

Q11. Did you/will you visit Fort Popham or Popham Colony today? YES (1) NO (2)

Q12. Did you look for information about the tides before coming to Popham today?
YES (1)...**Q12A. where did you look for this info?** ____
Q12B How did you use this information?____
NO (2)

Q13. What, if anything, could the state do to improve your experience at Popham Beach State Park?

Section 4: Your Background

This final section includes questions about your background, which will help us compare your answers to those of other people.

Q14. What is the zipcode of your primary residence?____
* If outside Maine, ask if they have a seasonal/second residence in Maine **Q14A** YES (1) NO (2)
*If outside U.S. –ask city and country. **Q14other**

Q15. In what year were you born? ____________(19XX)

Q16A. How many people, including yourself, live in your house?

_________ PEOPLE**..If > 1, Q16B. Are there children under age 18 in your household?** YES (1) NO (2)

Q17. Which of the following categories best represents the highest degree or level of school you have completed? (show card)

A. Some high school, no diploma
B. High school graduate or GED
C. Some college or Associates degree
D. College Graduate (Bachelor degree or equivalent)
E. Postgraduate (Master's, Doctorate, Law or other degree)

Q18. Which of the following categories best describes your current employment status? (show card)

A. Student
B. Employed part-time
C. Employed full-time
D. Take care of family full-time
E. Out of work
F. Retired

Q19. Which of the following categories best represents your total household income over the past 12 months? (show card)

A. Less than $10,000
B. $10,000-$49,999
C. $50,000-$74,999
D. $75,000-$99,999
E. $100,000-$149,999
F. $150,000-$199,999
G. $200,000 or more

Q20. Do you eat seafood? YES (1) NO (2)

Q21. One change to Maine's coastal areas is increased use of coastal waters for aquaculture production. Do you favor or oppose increased aquaculture production in Maine waters?

FAVOR (1)
OPPOSE (2)
NO OPINION (3)

Probe - Q21A. Why?

Q22. Is there anything else you would like to share today?

THANK YOU FOR COMPLETING THIS SURVEY. WE VALUE YOUR OPINIONS & TIME.

2016 Popham Beach State Park Changing Shorelines Survey

Technical Report

Kathleen P. Bell, Caroline L. Noblet, and Sophia Scott

September 2016

1865 THE UNIVERSITY OF MAINE

SCHOOL OF ECONOMICS

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Acknowledgements

Thank you visitors to Popham Beach State Park for taking the time to share your knowledge, opinions, and questions with our research team. Without your generosity and thoughtfulness, this report and related analyses would not be possible. We thank you for your time and consideration.

We acknowledge the key roles collaborators, colleagues, and volunteers played in the design and administration of the 2016 Popham Beach State Park Changing Shorelines Survey. The survey questions directly respond to information needs and emerging research questions of key collaborators and stakeholders about changing shorelines, beach recreation and tourism, and management and outreach opportunities. We also thank numerous colleagues involved with similar research projects nationally for their excellent feedback. Without the dedication and thoughtfulness of numerous volunteers, we would have missed the opportunity to engage with hundreds of visitors to Popham Beach State Park. Many thanks to these fabulous individuals. Strong collaborators strengthened the design and administration of our survey and the analyses of its responses. We acknowledge the valuable contributions of the *Changing Shorelines: Adaptation Planning for Maine's Coastal State Parks Project* team.

We extend special thanks to Kathleen Leyden and Theresa Torrent of Maine DACF's Coastal Program for their outstanding support of and collaboration with our research team. We also acknowledge the great data and GIS support of Peter Slovinsky (Maine Geological Survey).

Lastly, we thank Maine DACF, Maine EPSCoR, NSF, USDA NIFA and the Maine Agricultural and Forest Experiment Station for their support of this research.

Technical Report

In this technical report we provide a summary of responses to the 2016 Popham Beach State Park Changing Shorelines Survey. We begin by describing the design and administration of the survey and the subsequent sample of survey respondents. Next, we share findings from initial analyses of these survey data. We conclude the report by sharing detailed supporting information, including figures and charts summarizing the variation in responses by survey question and tabular results summarizing initial statistical regressions of multivariate relationships among these responses. This report is the first summary of these data. We welcome suggestions for future analyses. Please share your ideas and suggestions with our research team.

Survey Overview

Consistent with the information needs and interests of the *Changing Shorelines: Adaptation Planning for Maine's Coastal State Parks Project*, we conducted the survey to: (1) learn about visitors' perceptions of changing shorelines at Popham Beach State Park; (2) assess the impact of changing shorelines on visitor experiences, and (3) obtain feedback from visitors about potential future management, education, and outreach activities.

We designed and implemented the 2016 Popham Beach State Park Changing Shorelines Survey following scientific survey-research principles (Dillman, Smyth, and Christian et al. 2014; Vaske 2008). We developed the questionnaire in collaboration with key project partners (K. Leyden and T. Torrent, Maine DACF) and informed by the experiences of colleagues who have conducted similar surveys of beach visitors in other parts of the US (Landry et al. 2003; Huang et al. 2007; Whitehead et al. 2008; Loomis and Santiago 2013; Parsons et al. 2013). Given the onsite administration plans and beach setting, we designed a brief survey. We received approval from University of Maine's Institutional Review Board (i.e., human subjects approval) for the survey design, administration, and analyses and conducted our work in alignment with our approved research plans.

We designed the 2016 Popham Beach State Park Changing Shorelines Survey (see Appendix 1 for a copy of the survey instrument) to characterize visitor perceptions, behaviors, opinions, and characteristics of relevance to adaptation planning for coastal state parks. By including questions with open- and close-ended question formats, we collected visitor perceptions and opinions expressed using their own words and were able to characterize systematic patterns in visitor perceptions, opinions, and behaviors. We assembled information about visitors' trips to Popham Beach State Park, perceptions of shoreline and other changes at Popham Beach State Park, opinions about erosion impacts and adaptation strategies, information needs and interests, and demographic characteristics.

The 2016 Popham Beach State Park Changing Shorelines Survey was administered onsite at the park in August 2016. Seven interviewers with common training recruited participants and conducted the interviews. Consistent with an onsite systematic sampling approach (Vaske 2008) interviewers approached every third adult beachgoer at a single defined beach access point (i.e., West Side Entrance) and followed an established recruitment script. We restricted the sample to participants over the age of 18.

Interviewers conducted survey interviews on nine different days in August, 2016. By design, we tried to have surveying occur during the same four-hour block in the afternoon and over a mix of week-day (five) and weekend-days (four). The number of completed surveys and interviewers varied by day: August 12 (Friday, 17, two); August 16 (Tuesday, 45, one); August 19 (Friday, 55, two); August 20 (Saturday, 25, two); August 21 (Sunday, 46, three); August 22 (Monday, 32, three); August 24 (Wednesday, 33, two); August 27 (Saturday, 42, three); and August 28 (Sunday, 39, three). Interviews averaged 10 minutes in length. Interested participants received a Maine Coastal Program hat for participating in the survey interviews. Overall, interviewers contacted 571 potential respondents and asked them to complete the survey. Our final dataset includes completed surveys from 334 respondents, resulting in a response rate of 58.5 percent.

Survey Sample

Our sample of respondents includes 334 visitors to Popham Beach State Park. Hence, the results summarized in this technical report reflect the responses of these visitors. Though potentially representative of August 2016 visitors to Popham Beach State Park, we would expect the onsite sampling protocol to over-represent more frequent visitors and visitors more enthusiastic about the changing shorelines theme of the survey (Parsons et al. 2003). Accordingly, while these responses provide us with valuable information, they do not reflect the general public nor the full profile of visitors to Popham Beach State Park. The results summarized in this report have not been weighted or adjusted for sample selection or endogenous stratification.

Survey respondents ranged in age from 18 to 86 years, with an average age of 49 years. The final sample includes visitors from at least 4 countries and 20 different US states. About 61 percent of the sample are residents of Maine; Massachusetts (6.9%), Vermont (4.5%), and New York (4.5%) residents accounted for more than four percent of the sample. The survey respondents are highly-educated, with about 69 percent having attained a college degree or higher. More than 60 percent of the sample are employed full time and about 15 percent are retirees. Household incomes varied widely across survey respondents, with representation from multiple income categories. Compared to the Popham Visitors represented in a 2005 sample (n=121) by Morris et al., our sample is similar in age and education. The representation of Maine residents and non-residents in the two studies are also similar. Compared to Maine residents age 18 and over, our sample has more years of education (28.4% of Maine holds a bachelor's degree or higher (US Census 2015), in contrast 69% of the participants in our sample hold a bachelor's degree or higher) and a median higher income (Maine median is $48,804 (US Census 2015) sample median is $87,499). The age of our participants is reflective of Maine's population, with 18% of the sample and the population over age 65 (US Census 2015).

Findings

Park visitation and shoreline change. By definition, perceptions of change depend, at least partially, on baseline perceptions. Therefore, patterns in visitation to sites are likely to be associated with visitor perceptions of change at parks. Length and intensity of visitation to sites arguably affect visitors' awareness of changing shorelines at these sites. Popham Beach State Park attracts a diverse set of visitors, including a mix of first-time and long-time visitors. Twenty percent of our respondents were first-time visitors (Figure 1). Years of visitation by our respondents ranged from 0 (first-time visitors) to 84 years (Figure 2). On average, respondents have been visiting Popham Beach State Park for 16 years. Respondents also differed in the frequency or number of days they visit the beach during a typical summer. Days visiting Popham in Summer 2016 by our respondents ranged from 1 to 40 days, with an average of 3 day-visits to Popham Beach State Park this summer (Figure 5). Visitors shared very positive feedback about Popham Beach State Park. Respondents "like everything" about the beach (38%), commonly noting its large size and openness (23%), scenic views (21%), proximate islands (16%), and recreation opportunities (16%) as assets (Figures 3 and 4). Interestingly, some respondents (12%) specifically noted the appeal of Popham Beach State Park's dynamic and changing nature (Figure 4). Other common themes expressed by respondents when summarizing what they like about the park include the undeveloped character of the beach's surrounding landscape (12%) and the park's ocean waters (11%) (Figure 4). Looking ahead to the future, we would expect visitor perceptions of and responses to subsequent changes and adaptation to be influenced by the strength of their personal connections to Popham Beach and the extent to which they consider other beaches and parks as viable substitutes. The strong outpouring of praise for and repeat visitors to Popham suggests this park has numerous unique characteristics relative to other Maine beaches and parks. Human and natural systems influence change and options for coastal adaptation. As resource managers consider distinct adaptation strategies, understanding both social and biophysical drivers of change at coastal state parks is important.

Visitor perceptions of shoreline change. Public and visitor acceptance of coastal adaptation planning and actions depends at least in part on visitor perceptions of the issues addressed by these efforts. Numerous visitors to Popham shared information with our team about their perceptions of changing shorelines (Figures 6, 7, and 8). Indeed, the majority of our respondents recognized changes in the beach and shoreline at Popham Beach State Park. Respondents acknowledged different types of change and offered diverse explanations for these changes. Fifty-four percent of respondents reported noticing changes in the width, size, or shape of the beach and shoreline at Popham Beach State Park (Figure 6). Respondents most commonly noted changes to the size of the park/beach area (15.3%), flow of and access to ocean and river waters (15%), and characteristics of the beach and dunes (11.1%); they also described changes in the park's vegetative cover (5.7%), including loss of trees and grasses, and remarked on changing access to proximate islands (0.6%) (Figures 7 and 8). When prompted to describe the causes of such change in their own words, respondents noted the significance of storm events (17.4%), erosion (11.4%), wave action (6.3%), climate change (3.3%), and sea-level rise (1.5%) (Figures 7 and 8). When asked specifically about erosion at the park, seventy-two percent of respondents believed impacts of erosion were happening at Popham Beach State Park (Figure 10). Results of binary logistic regression analysis suggest respondents who have been visiting Popham Beach State Park for more years were more likely to note the occurrence of both changes in the beach and shoreline and erosion impacts at Popham Beach State Park (Tables 2 and 3). These same results suggest respondents who reported seeing signs about erosion at Popham and with college degrees were more likely to report erosion impacts at Popham Beach State Park (Tables 2 and 3). These initial empirical results call attention to the relationship between visitation patterns and perceptions of shoreline change.

Visitor opinions of adaptation strategies. When asked whether the state should take actions to address changing shorelines or choose to let nature take its course at Popham, respondents' responses were split, expressing distinct opinions about these implied action and no-action adaptation strategies (Figures 11, 12, and 13). Forty-nine percent of participants reported a desire for the state to *Take Management Action* to address changing shorelines, while forty percent of respondents indicated that the state should *Let Nature Take Its Course* at Popham in response to such changes (Figure 11). Dominant themes expressed by visitors' explanations of their choice of approach revealed interesting patterns. Common dominant themes expressed in support of action approaches included the willingness to keep the beach available and accessible to the public (25%), need for taking responsibility of human-driven problems (19%), desires to protect the park for future generations (13%), wishes to conserve park infrastructure (11%), and concerns for wildlife and their habitat (7%); respondents also noted the importance of science and expert-based management approaches (10%) (Figures 12 and 13). Common dominant themes expressed in support of no-action approaches included beliefs that nature knows best (33%) and that managers can't fight nature (18%) as well as the willingness to keep the park as natural as possible (21%); respondents also noted concerns with the unintended consequences of action-based management approaches (6%) (Figures 12 and 13). Results of binary logistic regression analysis reveal that Out of State (i.e., non-Maine) U.S. resident respondents were more likely to favor the *Take Action* approach as were households with children and those who reported that loss of beach width from a future erosion event would negatively affect their visits to Popham. In contrast, frequent visitors were less likely to support the state taking management action in response to changing shorelines at Popham (Table 4).

Our survey responses also conveyed interesting variation in opinions about more specific management and adaptation approaches. We asked all respondents to express their opinions regarding potential management actions, ranking each action on a scale of '1' low priority to '3' high priority (Figure 14). Of the six management actions presented, respondents preferred actions that managed existing infrastructure (Figure 14 and Table 5). Twenty-seven percent of respondents considered relocating bathhouses and parking to more inland areas a high priority. In contrast, only four-percent considered altering the channel of the Morse River to be a high priority, with 66% expressing that this action should be a low priority. Interestingly, tests of response distribution (chi-square) reveal that the rankings on the management of infrastructure (i.e. bathhouses and parking) did not significantly differ between individuals who had supported *Take Management Action* versus *Let Nature Takes Its Course* ($\chi 2= .419$, $p=.936$; $\chi 2=.880$, $p=.828$). Similar distribution tests reveal that individuals who indicated that there are impacts of erosion happening at Popham Beach were more likely to rank infrastructure management actions as high priority (30% bathhouse, 29% parking) than those who did not notice erosion impacts (16% bathhouse, 16% parking; $\chi 2= 18.049$, $p=.000$; $\chi 2=.15.271$, $p=.002$)). These priority rankings reflect visitors' opinions as of Summer 2016. Interestingly, these relative rankings indicate support of recent efforts at Popham Beach State Park to protect the bathhouses from erosion impacts (Kelly, 2013; Schlawin and Cameron, 2015). They also raise interesting questions about visitor support for further actions to alter the Morse River channel and move sand at Popham (Schlawin and Cameron, 2015).

Regression analysis revealed further information on these differences in opinions about the priority of specific management actions (Table 6). Individuals who expressed support for the state to *Take Management Action* ranked building a seawall, altering the channel of the Morse River, moving existing sand around Popham Beach and widening the beach using sand from another location statistically higher than those who indicated the state should *Let Nature Take Its Course* to address changing shorelines. Support of these distinct adaptation strategies (action versus no-action) did not significantly impact respondent's ranking of relocating the bath-house or parking areas. Individuals who noticed changes in the beach (width, size or shape/shoreline) were less supportive of management efforts that including movement of sand - either moving existing sand around the beach or bringing in sand to widen the beach (Table 6). Respondents who had seen signs posted at Popham regarding erosion were also less supportive of widening the beach by bringing in sand. These two sets of respondents may perceive that sand movement/replacement efforts have limited effectiveness given the changes they have already noticed or been warned about. Individuals who believe there are erosion impacts happening at Popham Beach were more likely to place a higher priority on relocating bathhouses and parking areas. Further, individuals who indicated that the impacts of beach loss would negatively impact their visit were more supportive of redirecting the Morse river or using sand from other areas to replenish the beach than those who indicated beach loss would not affect their beach visit. First time visitors were more supportive of building a seawall. Older individuals were less supportive of the sand movement, beach widening and seawall building management actions. These initial regression analyses hint at the complexity of understanding visitor perceptions and opinions of adaptation strategies. Themes and relationships revealed in these results reinforce an appreciation for the diversity and dynamism of visitor views and point to opportunities for information exchange. Gaining visitor and public support for specific coastal adaptation approaches may prove critical over time.

Impacts of erosion events on visitor experiences. Assessing the impacts and effectiveness of coastal adaption strategies necessitates understanding visitor responses to shoreline changes and management outcomes. We asked visitors to describe the impact of a future erosion event at Popham on their visitor experiences. Respondents expressed varied reactions to our future scenario, where an erosion event would cause Popham Beach to be on average one half its current width over all tidal fluctuations. Fifty-one percent of respondents stated this event would worsen their visitor experience; forty-seven percent of respondents stated this event would have no effect one way or the other; and about one percent of respondents indicated this outcome would improve their visitor experiences at Popham State Park (Figure 19). When asked to describe how this change would worsen their visitor experiences, respondents frequently noted concerns over visiting a more crowded beach with less personal space and room to roam (20%); other negative impacts raised in their open-ended responses included less options for recreating (4%; e.g., walking, playing, exploring), less beach area (3%), and concerns over habitat loss and impacts on birds and other animals (2%) (Figures 20 and 21). Five respondents indicated this future erosion event would improve their experience; visitors in this small sub-group linked improved experiences with less walking required for children and increased proximity to the bathrooms and other facilities (Figure 20). Seventeen percent of respondents indicated this future erosion event would worsen their experience enough to cause them to take fewer summer trips to Popham Beach State Park; less than one percent of respondents stated this event would improve their experience enough to cause them to take more summer trips to Popham Beach State Park.

Initial regression analyses revealed few significant factors explaining variation in these responses describing the impacts of future erosion events (Table 7). Regression results did suggest respondents who supported the state taking management actions to address shoreline change were more likely to describe negative impacts and less likely to describe no impacts on their visitor experiences from the future erosion event (Table 7). These initial analyses point to numerous opportunities for future research, including comparisons with other studies in the US (Landry et al. 2003; Huang et al. 2007; Whitehead et al. 2008; Loomis and Santiago 2013; Parsons et al. 2013). Changing shorelines at parks and beaches impact visitors differently. Tracing these impacts and their ultimate impacts on the welfare and local economies of coastal communities provides managers with important information about the human dynamics of coastal adaptation.

Information and adaptation. Visitors shared perceptions of shoreline changes and expressed numerous questions about change and management options. As coastal managers continue to make progress planning for adaptation at coastal state parks, it is important to assess how visitors are currently acquiring information and the extent to which information-sharing approaches can be improved. We asked respondents if they had noticed the current signs posted at Popham Beach or sought tidal information prior to visiting the beach and to describe what additional information, if any, they would like to have about changing shorelines at Popham Beach State Park and coastal adaptation strategies.

A majority of our respondents reported that they had seen signs at Popham Beach State Park regarding erosion (62.6%); whereas, 36.8 percent reported not seeing erosion signs at Popham (Figure 9). Initial regression analyses revealed few significant factors explaining variation in the seeing erosion signs responses (or not). Using inferential statistics to reveal and report these significant relationships, respondents who reported seeing signs regarding erosion at the beach were older (mean=51 years old) than respondents who did not see the signs (mean=44 year old) ($t=-3.99$, $p<.0001$). As noted previously, when asked to rank the priority of specific management actions, we observed statistical differences between those who did, and did not, see the erosion signs. Distribution of response analysis reveals that when looking at support for the beach widening policy, 6 percent of individuals who saw the erosion signs placed this management technique as a high priority, whereas 15 percent of those who did not see signs ranked this a high priority ($\chi2=14.427$, $p=.001$). Of those who saw the erosion signs, 14% ranked building a seawall as a 'high priority' in contrast to those who did not see the sign (11%) ($\chi2=5.55$, $p=.062$).

Given Popham Beach State Park's past use of tide advisories and the potential significance of tides to park visitors, we also asked visitors about their acquisition and use of tidal information. Since the tide at Popham Beach has a substantial impact on the look and size of the beach, we anticipated that some visitors would look for tidal information before making their beach plans. Fifty-two percent of our respondents indicated they had looked for tidal information, while forty-seven percent had not (Figure 22). Respondents obtained tidal information from different sources, with thirty-three percent of respondents seeking such information at websites (Figures 22 and 23). Respondents' explanations of how they use tidal information (Figure 25) suggested varied levels of planning and reinforced the potential for information to influence personal adaptation strategies to changing shorelines. Binary logistic regression analysis reveals that, unsurprisingly, first time visitors are less likely to look for tidal information, while frequent visitors were more likely to report looking at tidal information. However, there is no relationship between the choice to gather tidal information and noticing changes on the beach, believing there are erosion impacts at the beach or noticing the erosion signage (Table 9). Interestingly, analysis of response distribution reveals that more respondents who sought tidal information (51%) supported 'Let Nature Takes Its Course' when asked about management actions, in contrast to those who did not seek tidal information (38%) ($\chi 2$=4.32, p=.037). This may reveal that visitors who obtain tidal information are used to working with nature at Popham Beach and effectively are implementing their own adaptation strategies.

After asking Popham visitors to reveal their support generally of action versus no-action adaptation approaches and rank specific management actions in terms of priority, we asked respondents if they would like additional information about changing shorelines at Popham Beach State Park and coastal adaptation more generally. Twenty-four percent of our respondents were interested in additional information about scientific research and baseline information about change at Popham (Figures 15 and 16). Other commonly requested types of information included details on the environmental impacts of different action and no-action adaptation approaches (11%) and historical data and maps summarizing shoreline change (Figures 15 and 16). Other respondents (4%) expressed an interest in additional information about how the state makes decisions and opportunities for public engagement with such decision processes (Figures 15 and 16).

Regression analysis reveals that respondents more likely to want additional information were those who: thought that impacts of erosion were happening at the beach and thought that loss of beach width would decrease their enjoyment during a visit (Table 8). Respondents with higher household incomes were less likely to want additional information. Of interest, participants who selected *Take Management Action* were equally as likely to indicate they wanted more information as those who chose to *Let Nature Take Its Course*. In contrast, those who wanted additional information were those who were more likely to rank *Relocate Bath House* as a high priority (34%) than those who did not want additional information (22%) ($\chi 2$=5.12, p=.077).

In the remaining sections of this technical report, we share the detailed supporting information for our initial findings. We start by including figures and charts summarizing the variation in responses by survey question. To simplify the review of this information, we maintained the order of the questions from the original survey questionnaire (Appendix 1). Open-ended responses are shared in a separate document (Appendix 2). The tabular results summarizie initial statistical analyses of multivariate relationships among these responses. As noted previously, this report is the first summary of these data and our team welcomes suggestions for future analyses.

Response summaries by survey question

Popham Beach State Park - Current Perceptions of Changing Shorelines

Is today your first visit to Popham Beach State Park?

FIGURE 1. First-time visitors to Popham Beach State Park

For about how many years have you been visiting Popham Beach State Park?

Range: **0-84 years**
Mean (Standard Deviation):**16.48 (16.91)**

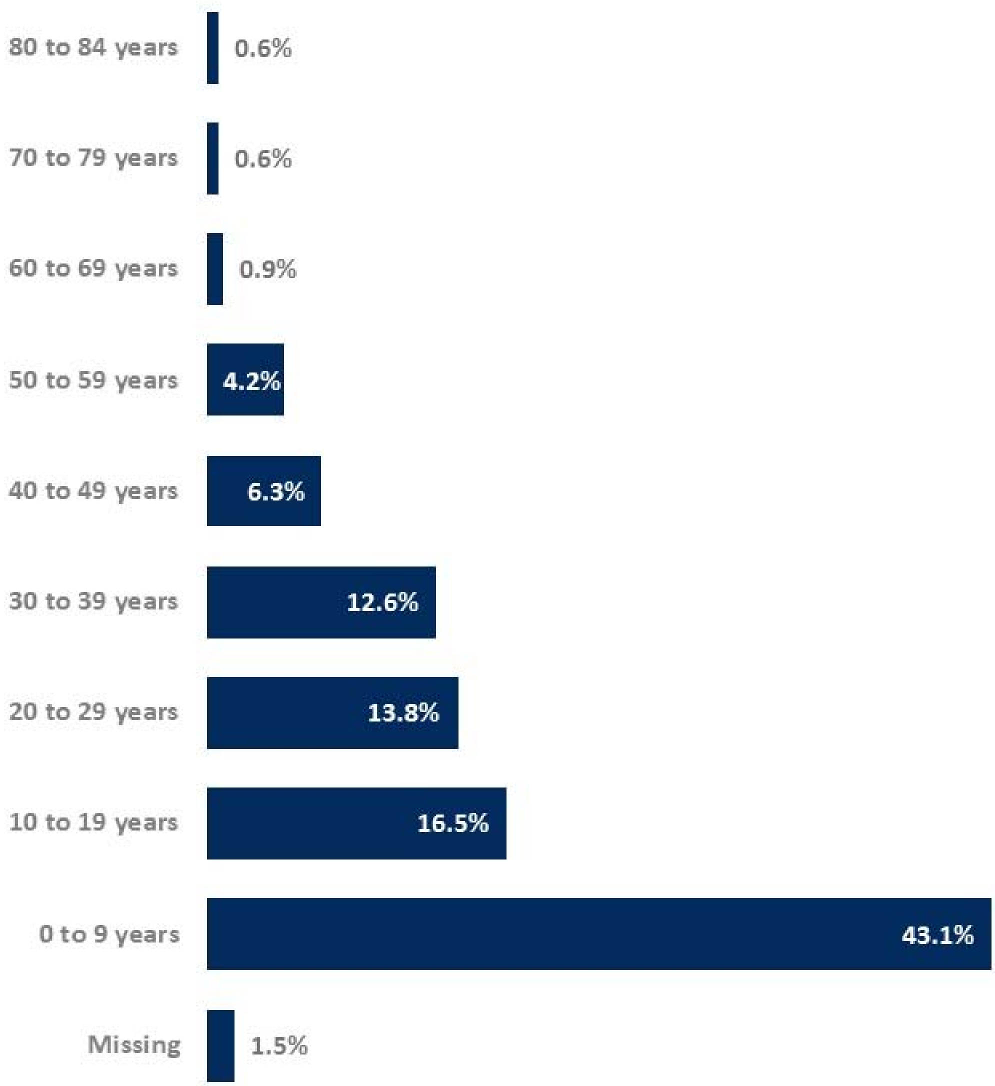


FIGURE 2. Years visiting Popham Beach State Park

* First-time visitors are coded as visiting for 0 years

What do you like about Popham Beach State Park?

FIGURE 3. What do you like about Popham Beach State Park (n=321)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

What do you like about Popham Beach State Park?

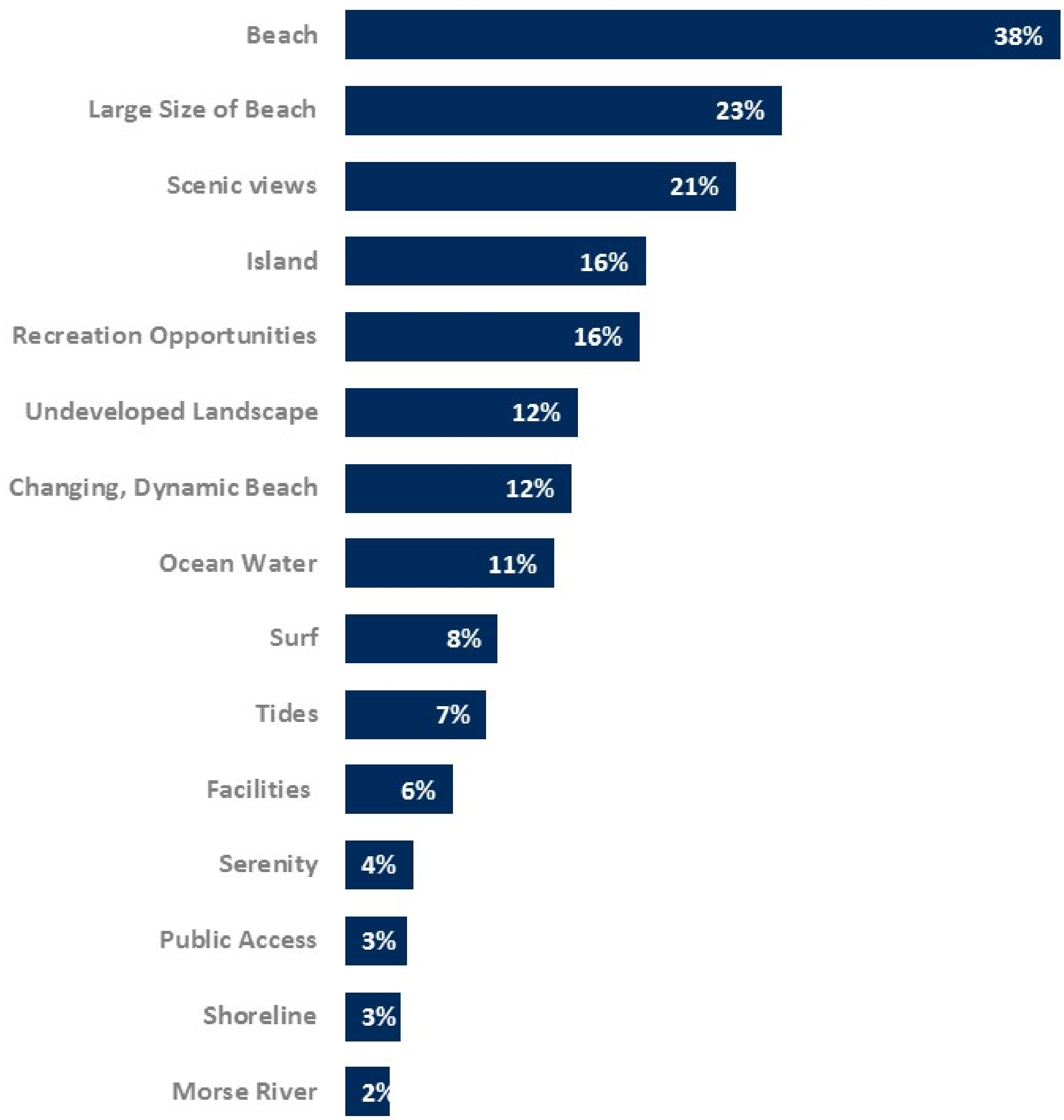


FIGURE 4. Features liked by visitors about Popham Beach State Park

* Percentages calculated based on full sample size (n=334)

About how many days have you visited Popham Beach State Park this summer?

Range: 1-40 days
Mean (Standard Deviation):3.41 (5.31)

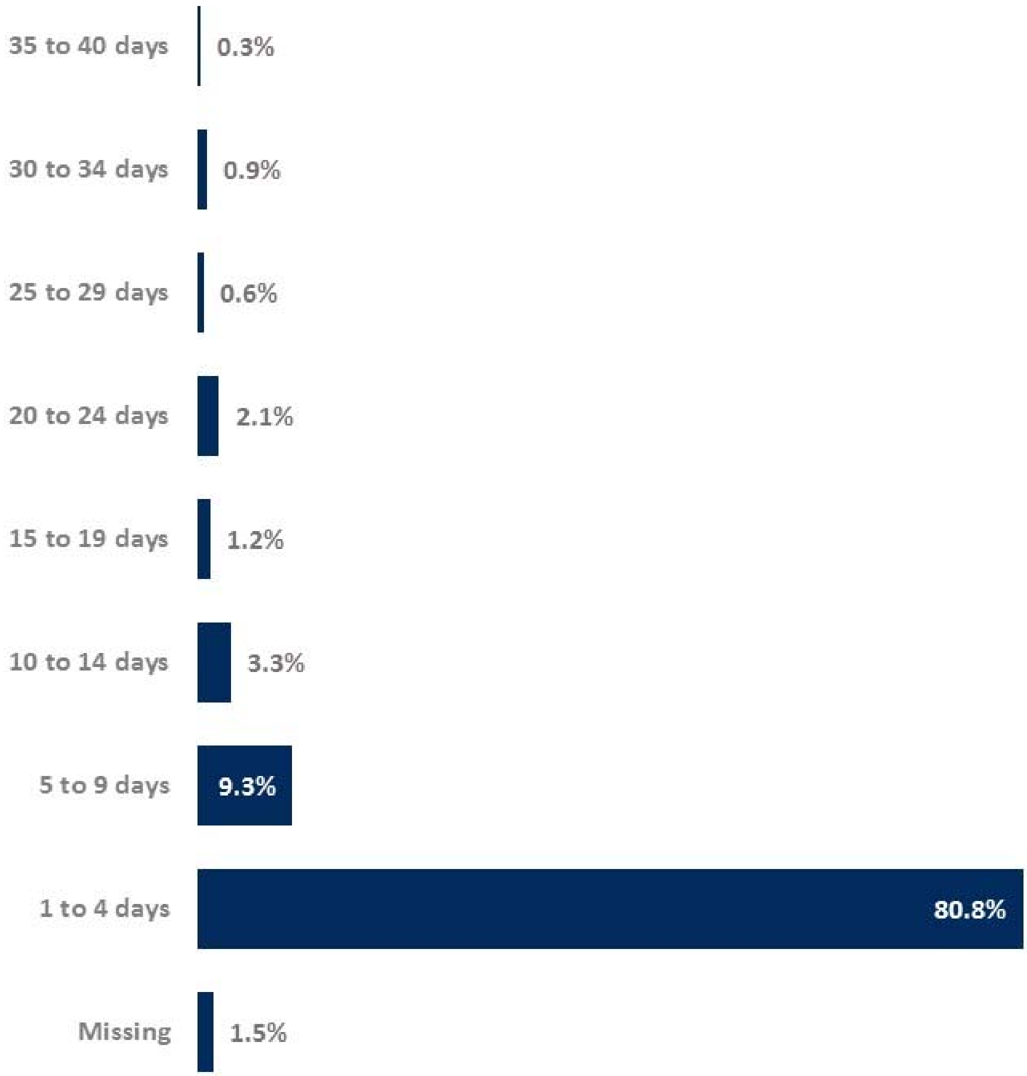


FIGURE 5. Number of Days Visiting Popham Beach State Park (Summer 2016)

Have you noticed changes in the width, size, or shape of the beach and shoreline at Popham Beach State Park?

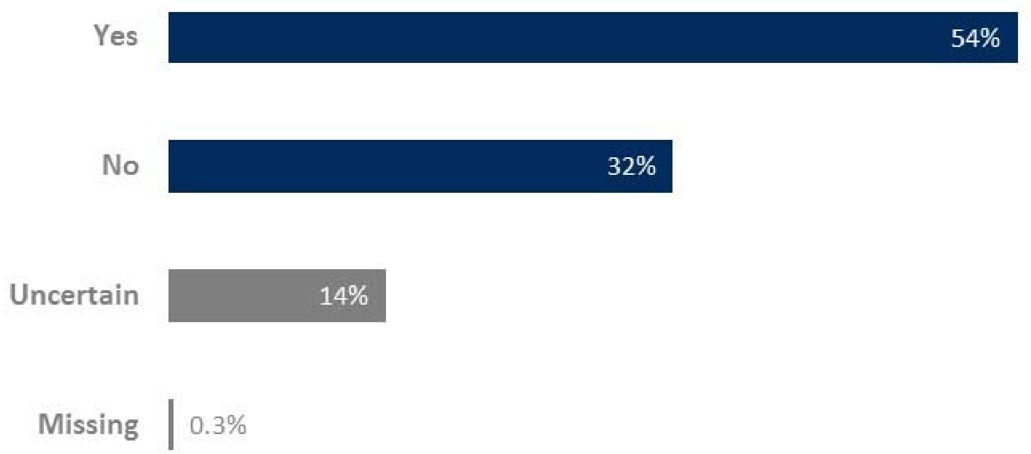


FIGURE 6. Visitors noticing shoreline and beach changes at Popham Beach State Park

What changes have you noticed? What do you think are the causes?

FIGURE 7. Changes and causes of change at Popham Beach State Park (n=168)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

Have you noticed changes in the width, size, or shape of the beach and shoreline at Popham Beach State Park? What changes? What do you think are the causes?

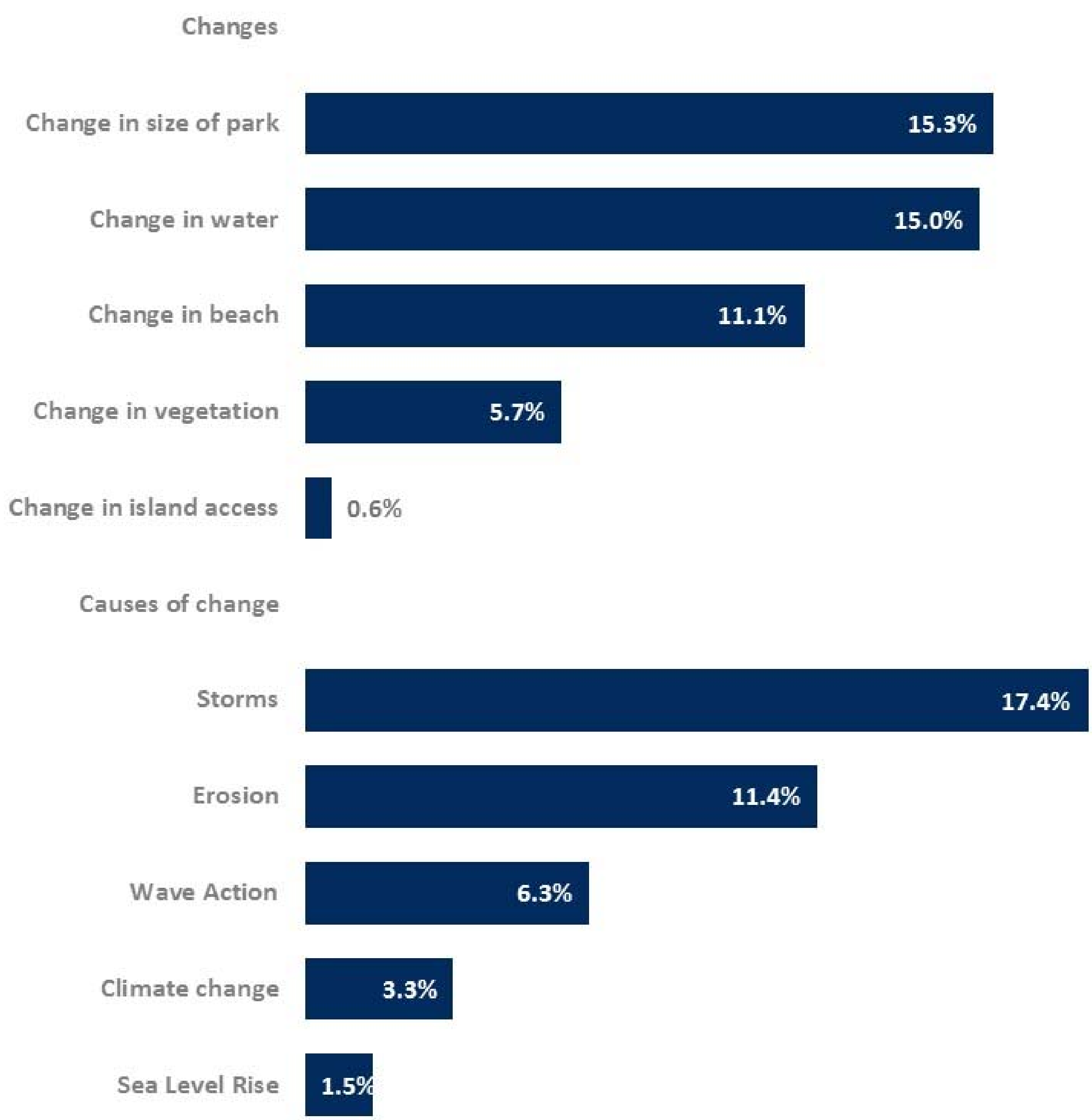


FIGURE 8. Perceptions of change and causes of change at Popham Beach State Park

* Percentages calculated based on full sample size (n=334)

Have you seen signs posted at Popham Beach about erosion?

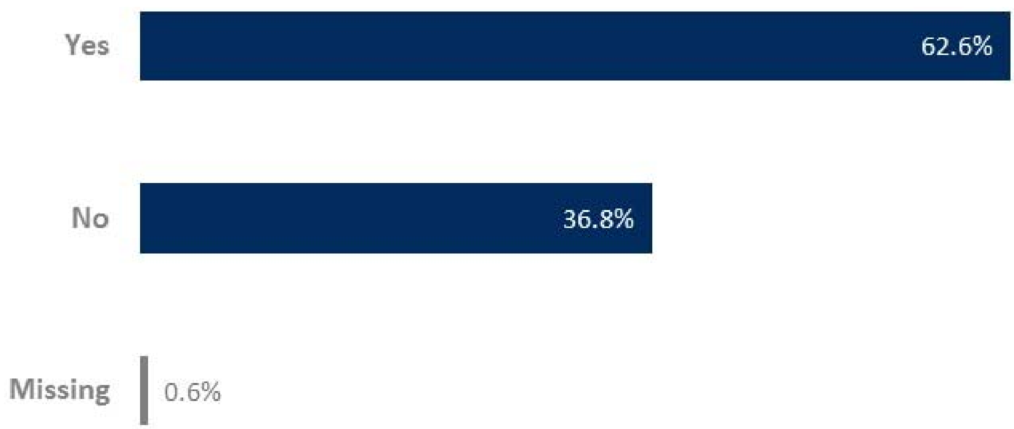


FIGURE 9. Visitors having seen signs posted at Popham Beach about erosion

In your opinion, are there impacts of erosion happening at Popham Beach State Park?

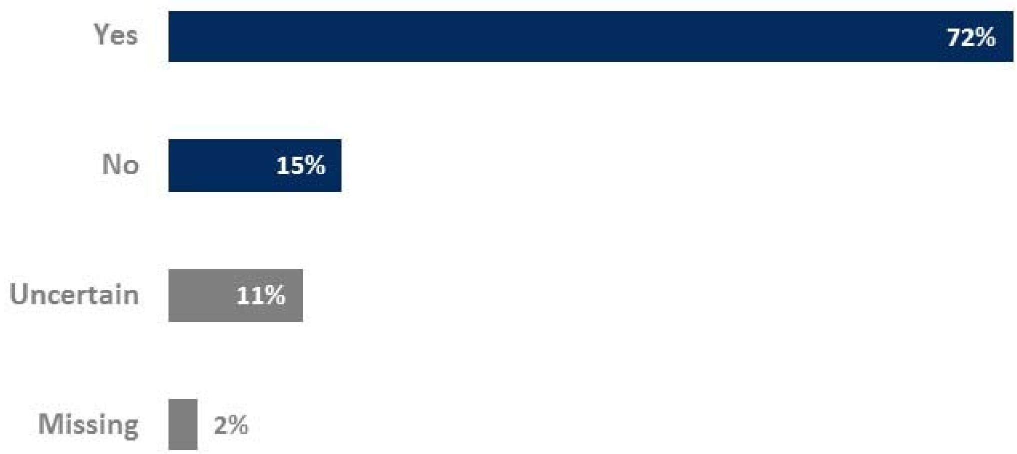


FIGURE 10. Visitor recognition of impacts of erosion happening at Popham Beach State Park

Changing Shorelines at Popham Beach State Park - Looking Ahead

Overall, do you think the state should take actions to address changing shorelines or choose to let nature take its course at Popham Beach State Park?

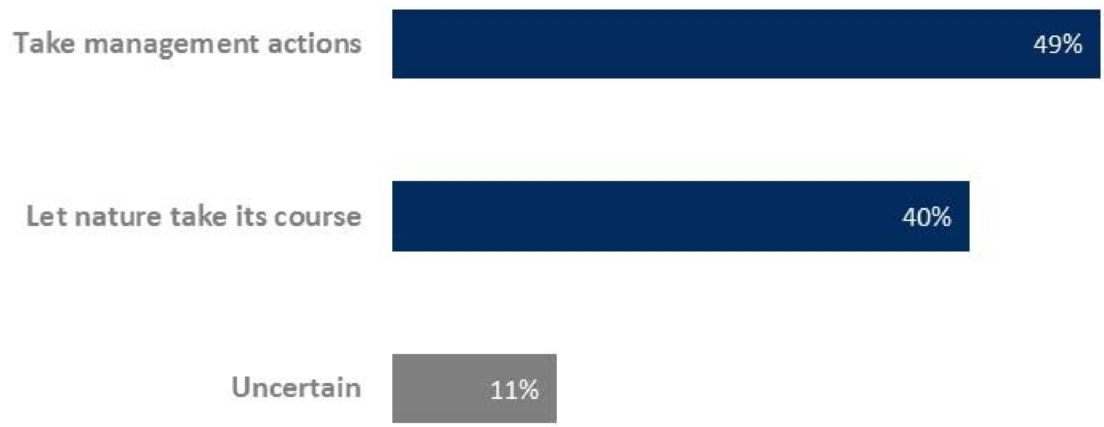


FIGURE 11. Taking actions or letting nature take its course to address shoreline change

Why do you think the state should take actions to address changing shorelines or choose to let nature take its course at Popham?

Take management actions

Let nature take its course

FIGURE 12. Addressing shoreline change at Popham Beach State Park (n=129 and n=83)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

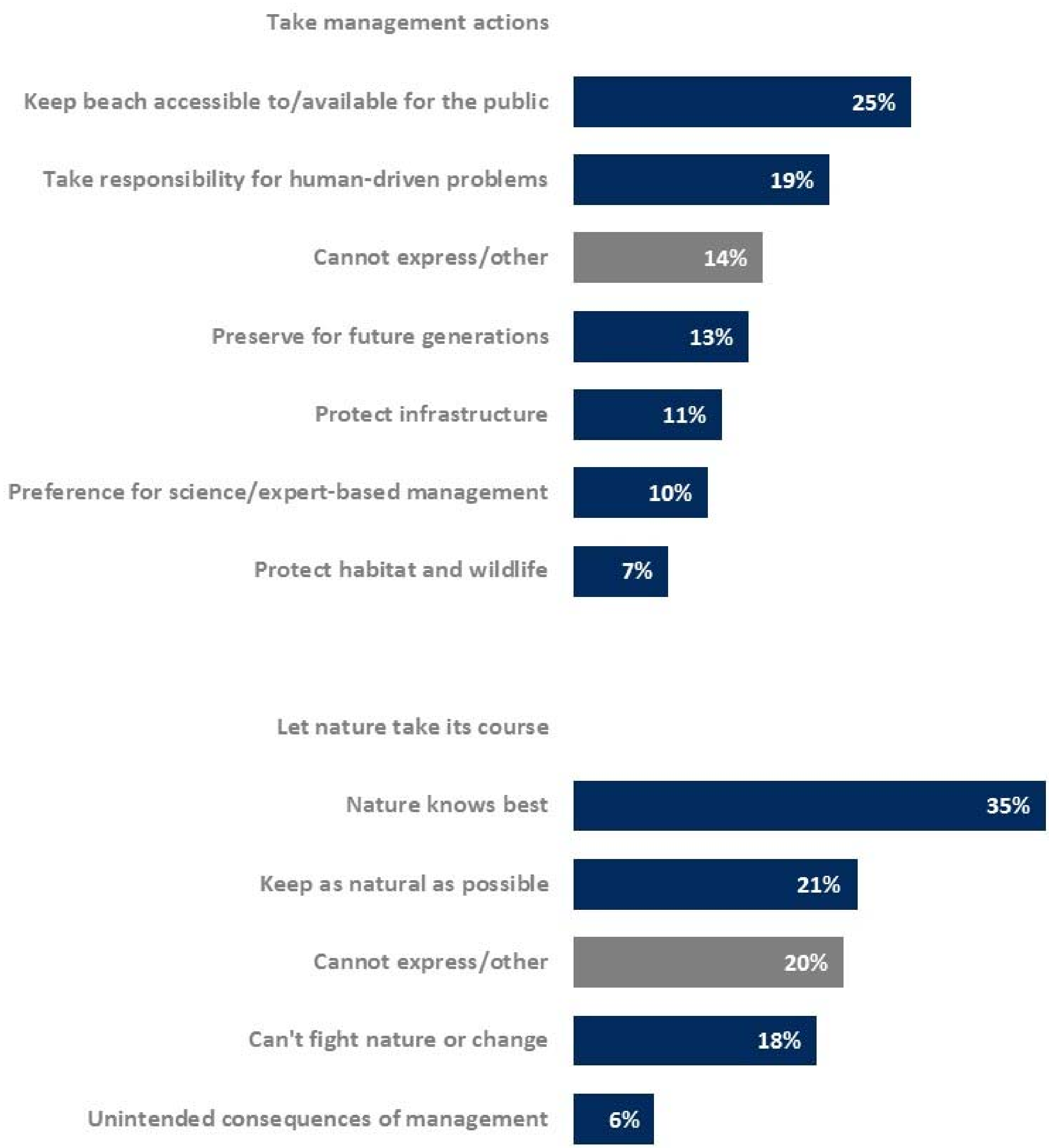


FIGURE 13. Common dominant themes explaining opinions about how the state should address shoreline change at Popham Beach State Park

* Percentages calculated based on full sample size (n=334)

Actions to address shoreline change at Popham Beach State Park can take many forms. We are interested in your opinions of several potential actions. In your opinion, should each option below be a low priority, medium priority, or high priority action to increase the park's resiliency?

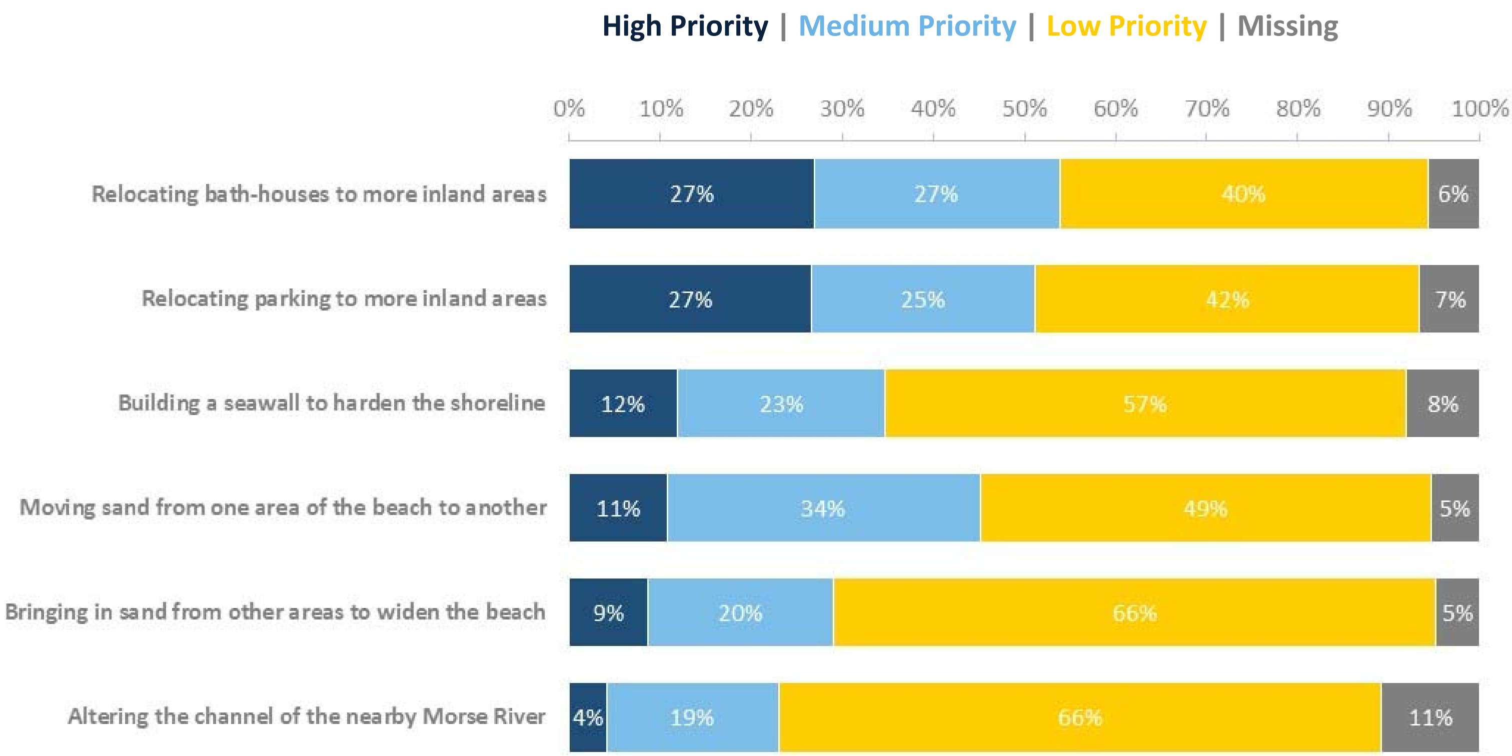


FIGURE 14. Opinions of potential actions to address shoreline change at Popham Beach State Park

What additional information, if any, would you like to have about changing shorelines at Popham Beach State Park or the options above?

FIGURE 15. Requests for additional information (n=189)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

What additional information, if any, would you like to have about changing shorelines at Popham Beach State Park or the options above?

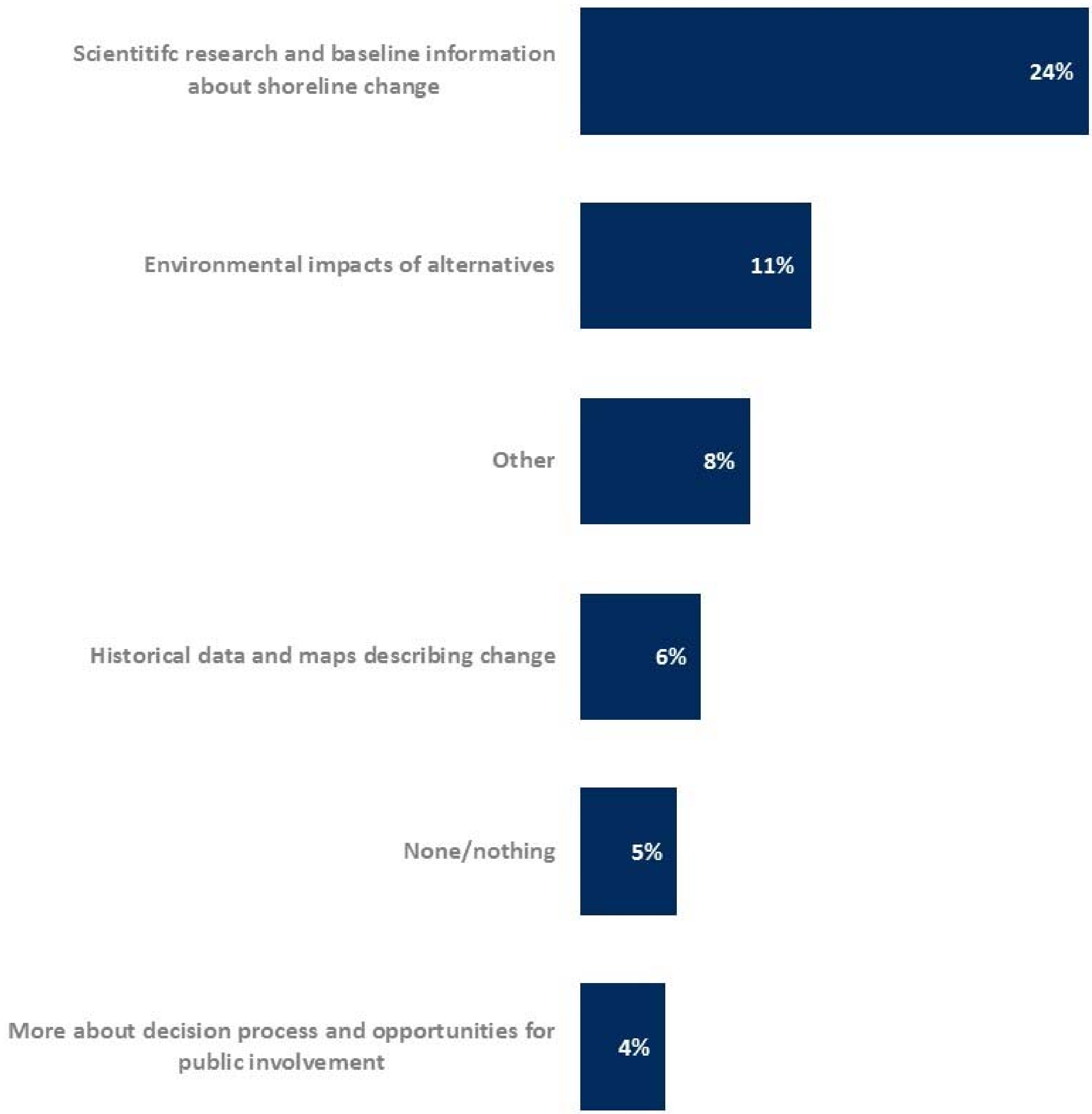


FIGURE 16. Requests for additional information about changing shorelines at Popham

* Percentages calculated based on full sample (n=334)

What is the best way to get additional information to you about changing shorelines at Popham Beach State Park or the options above?

FIGURE 17. Requests for additional information (n=157)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

What is the best way to get this information to you?

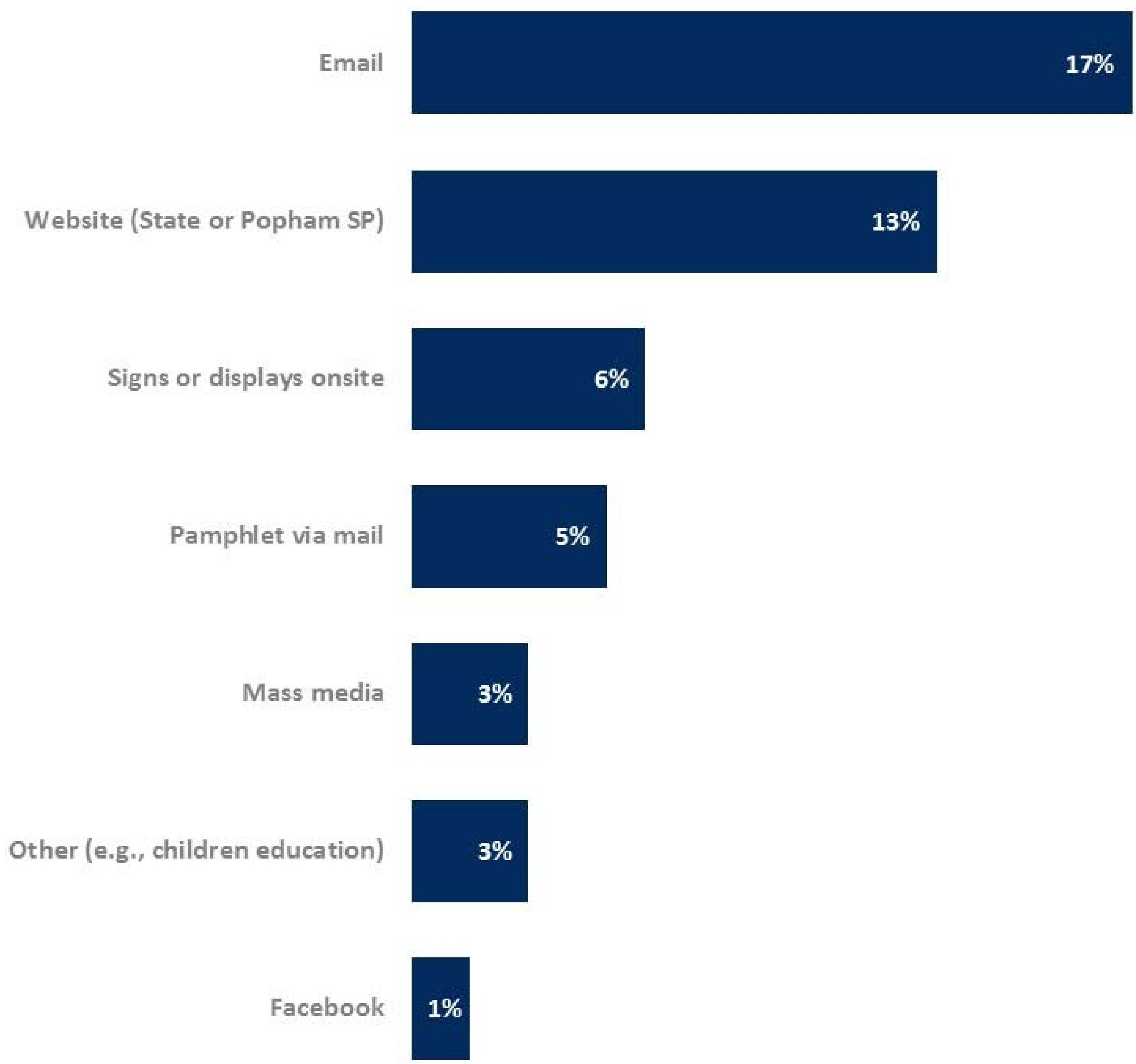


FIGURE 18. Requests for additional information

* Percentages calculated based on full sample of respondents (n=334)

If a future erosion event caused Popham Beach to be on average ONE HALF its current width over all tidal fluctuations, would this make your experience here WORSE, BETTER, or have NO EFFECT ONE WAY or the OTHER?

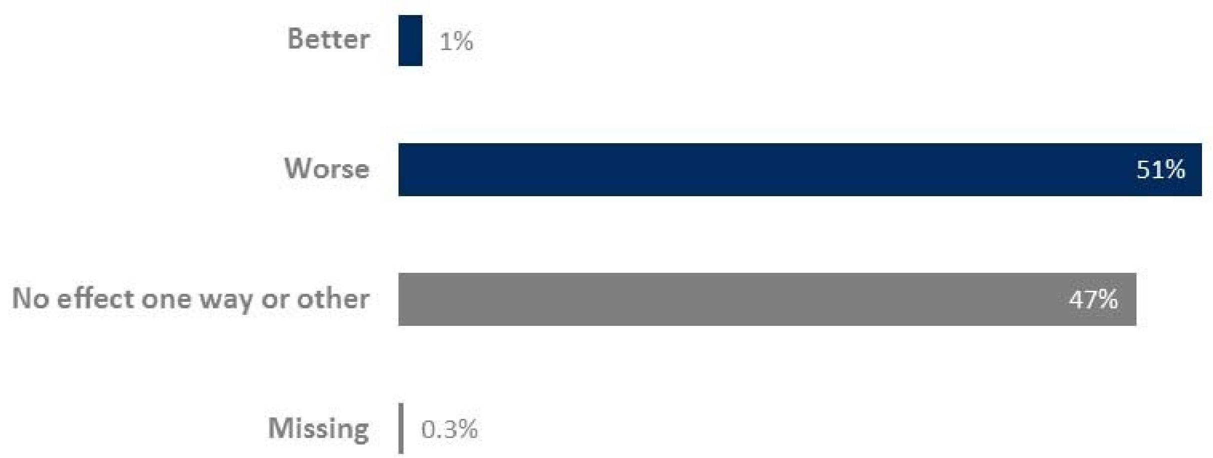
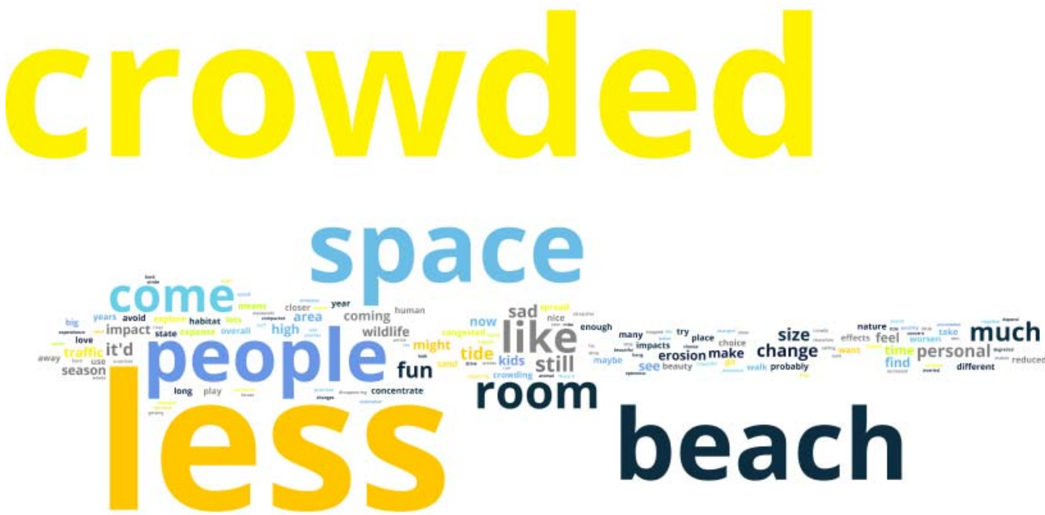


FIGURE 19. Impact on visitor experiences at Popham Beach from reduction in beach width by one half

Tell me more about how it would worsen your visitor experience.



Tell me more about how it would better your visitor experience.

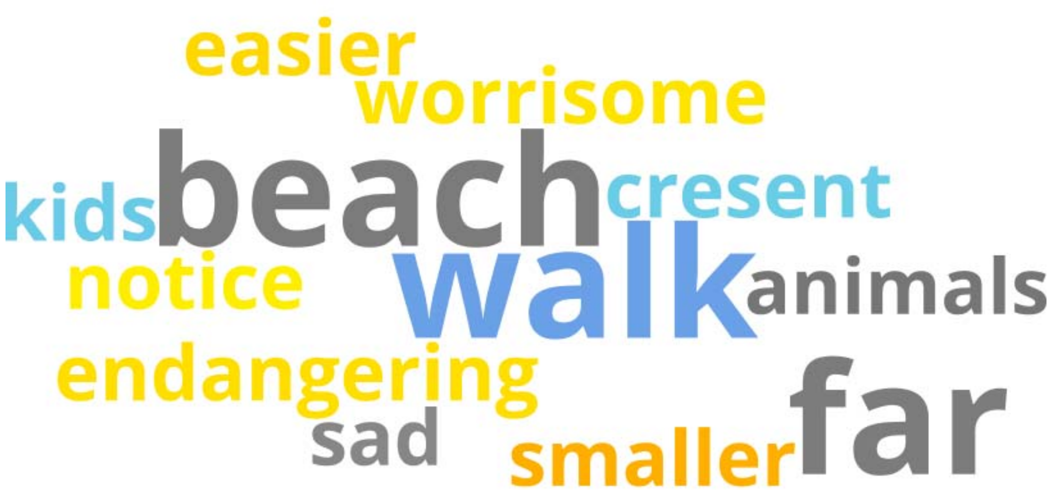


FIGURE 20. Changes in visitor experiences from reduction in beach width by one half (n=126 and n=4)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

Tell me more about how your visitor experience would be worsened if a future erosion event caused Popham Beach to be on average ONE HALF its current width over all tidal fluctuations.

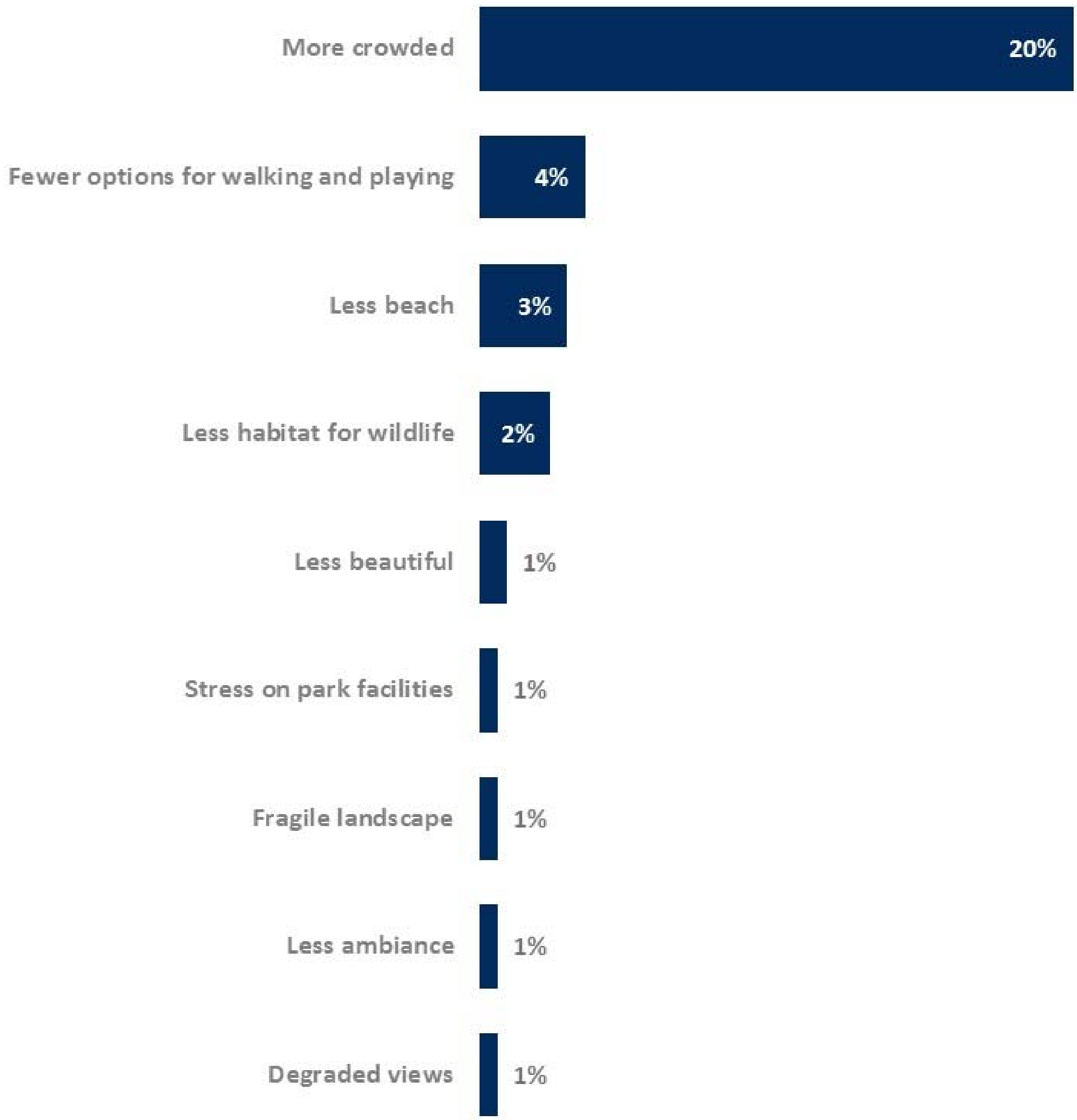


FIGURE 21. Ways in which a reduction in beach width by one half caused by a future erosion event would worsen visitor experiences at Popham Beach State Park

* Percentages calculated based on full sample of respondents (n=334)

Today's Visit to Popham Beach State Park

Did you or will you visit Fort Popham or Popham Colony today?

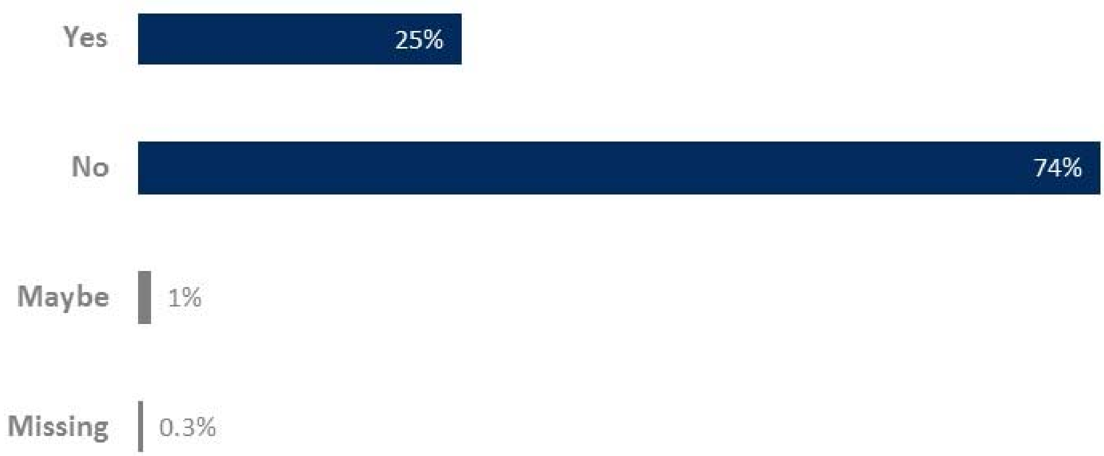


FIGURE 21. Visitation to Fort Popham or Popham Colony by Popham Beach State Park visitors

Did you look for information about the tides before coming to Popham today?

FIGURE 22. Tidal information searches by Popham Beach State Park visitors

Where did you look for information about the tides before coming to Popham today?

FIGURE 23. Where Popham visitors look for information about tides (n=166)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

Where did you look for information about the tides before coming to Popham today?

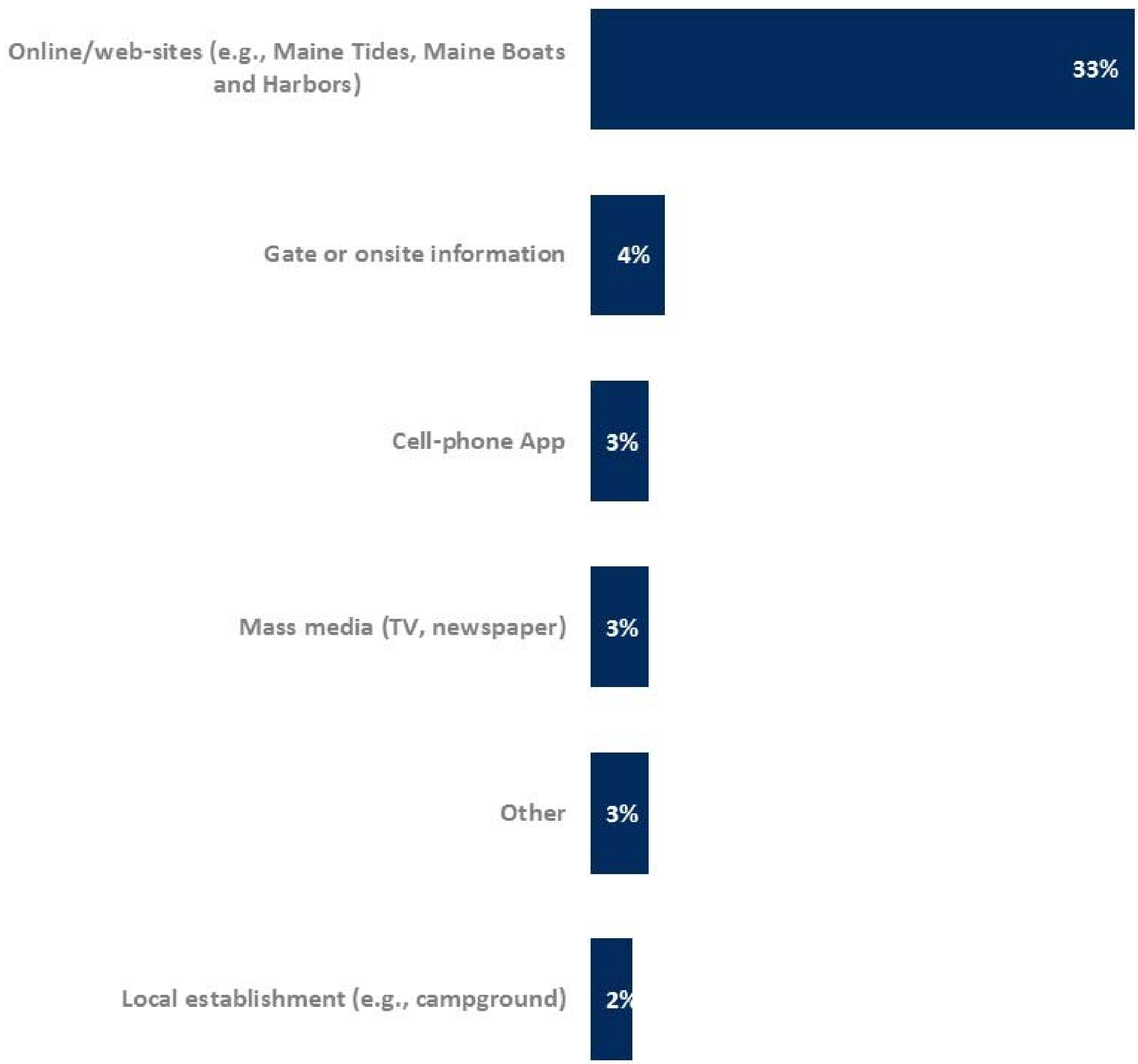


FIGURE 24. Means of access to information about tides at Popham

* Percentages calculated based on full sample (n=334)

How did you use the tidal information you looked for prior to visiting Popham Beach State Park?

FIGURE 25. How Popham visitors use information about tides (n=157)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

What, if anything, could the state do to improve your experience at Popham Beach State Park?

FIGURE 26. What the State could do to improve visitor experiences at Popham Beach State Park (n=293)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

Background & Demographics

What is the zipcode of your primary residence?

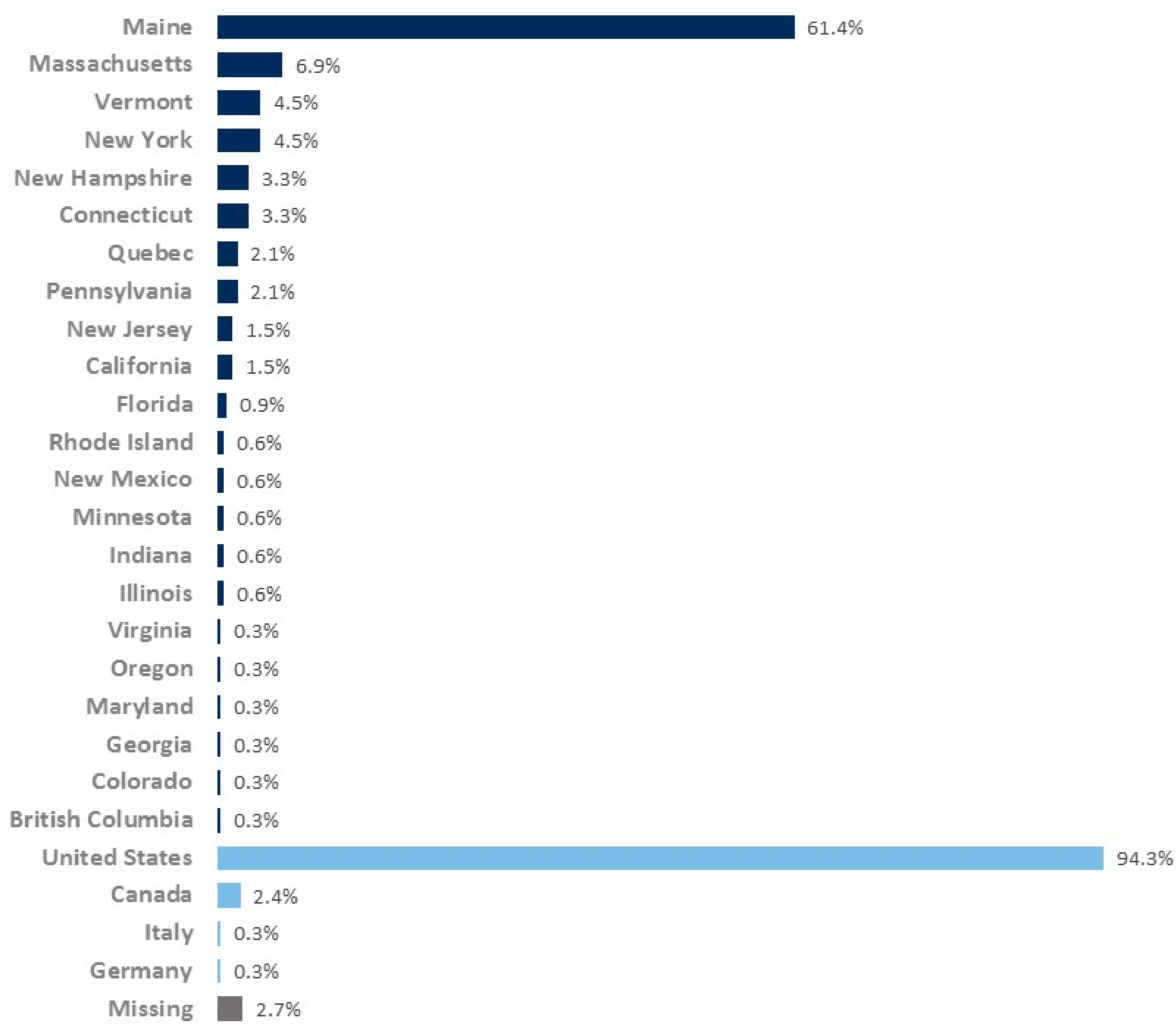
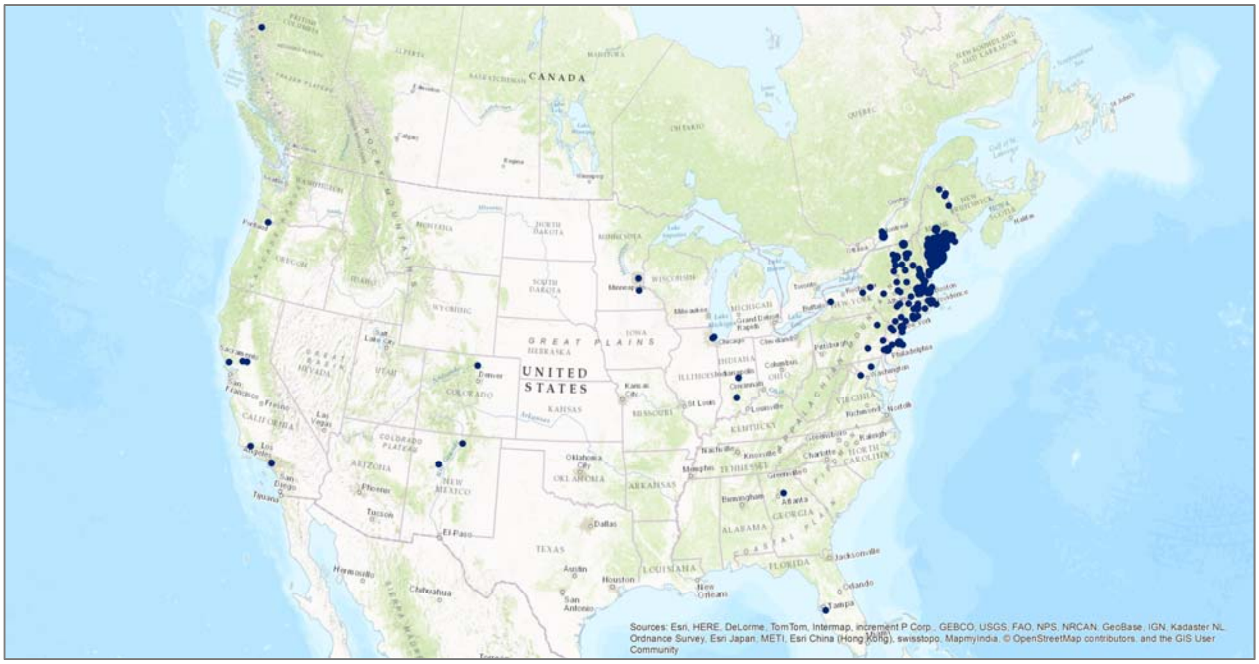


FIGURE 27. Primary Residence (States, Provinces, and Countries) of Popham Survey Respondents



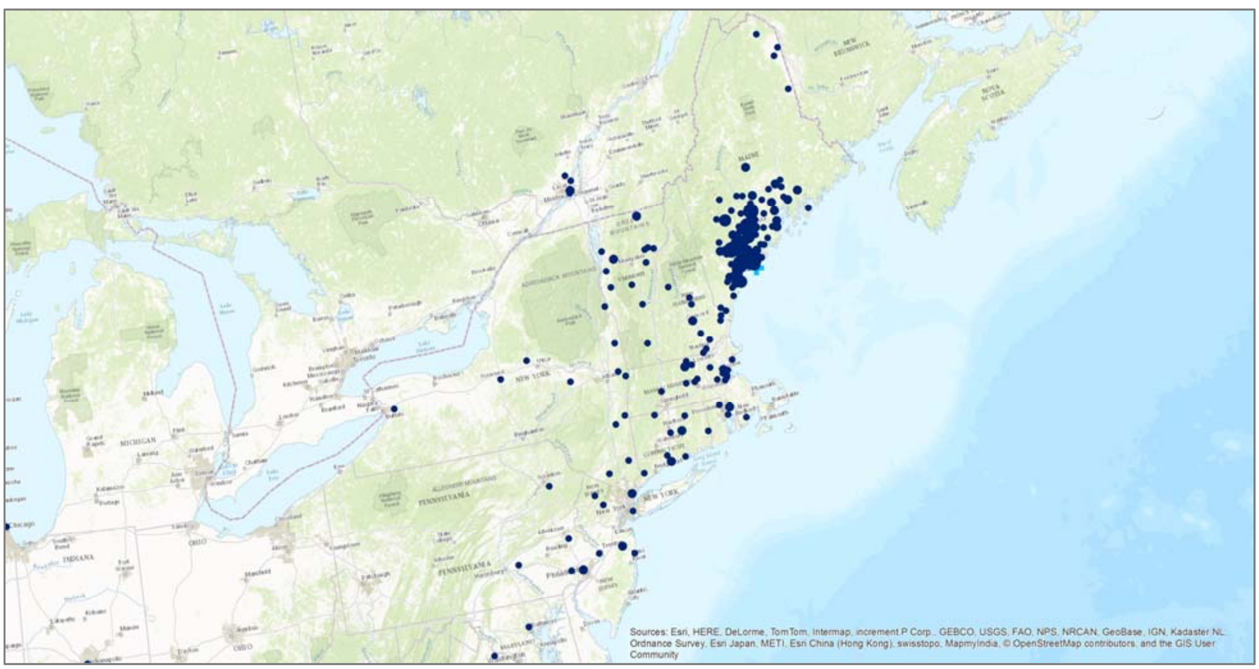


FIGURE 28. Spatial distribution of survey respondents based on postal codes (North America and Northeast Region)

* Graduate symbols, larger circles indicate more respondents

Age (years) (n=331)

Range: **18-86 years**
Mean (Standard Deviation):**48.6 (15.54)**

FIGURE 29. Age distribution of survey respondents

How many people, including yourself, live in your house?

Range: 1-13 people
Mean (Standard Deviation):3.11 (1.52)

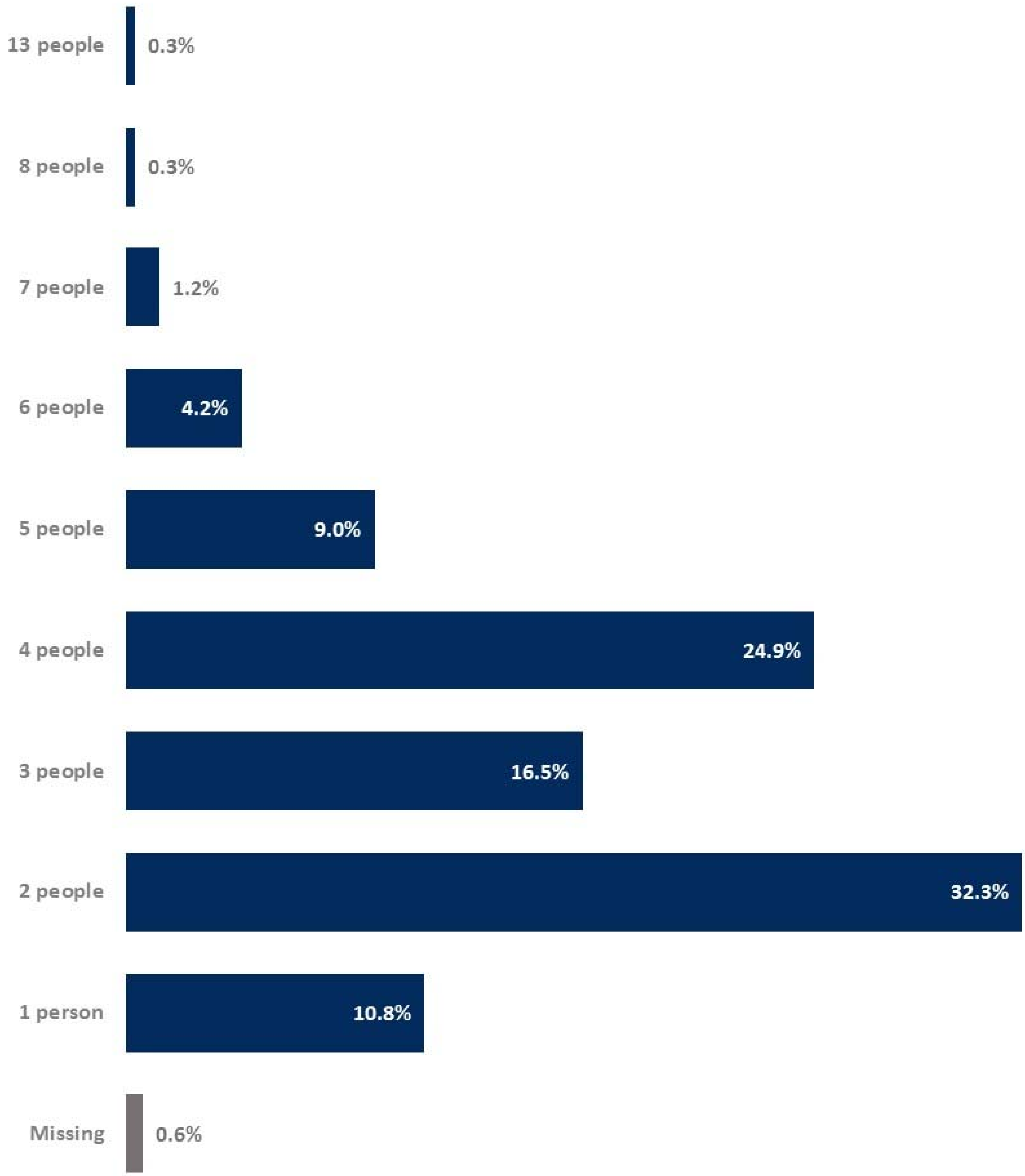


FIGURE 30. Household size distribution of survey respondents

Are there children under age 18 in your household?

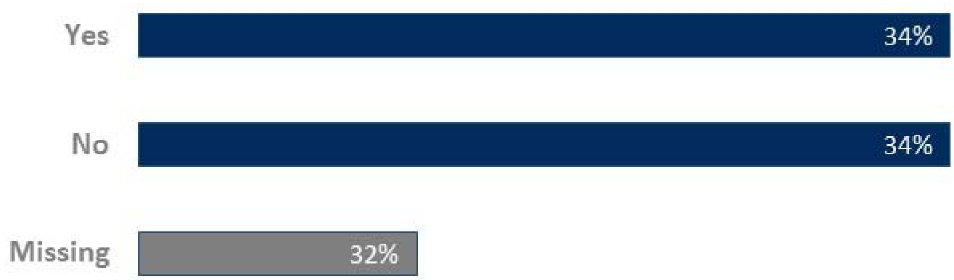


FIGURE 31. Presence of children in the household

Which of the following categories best represents the highest degree or level of school you have completed?

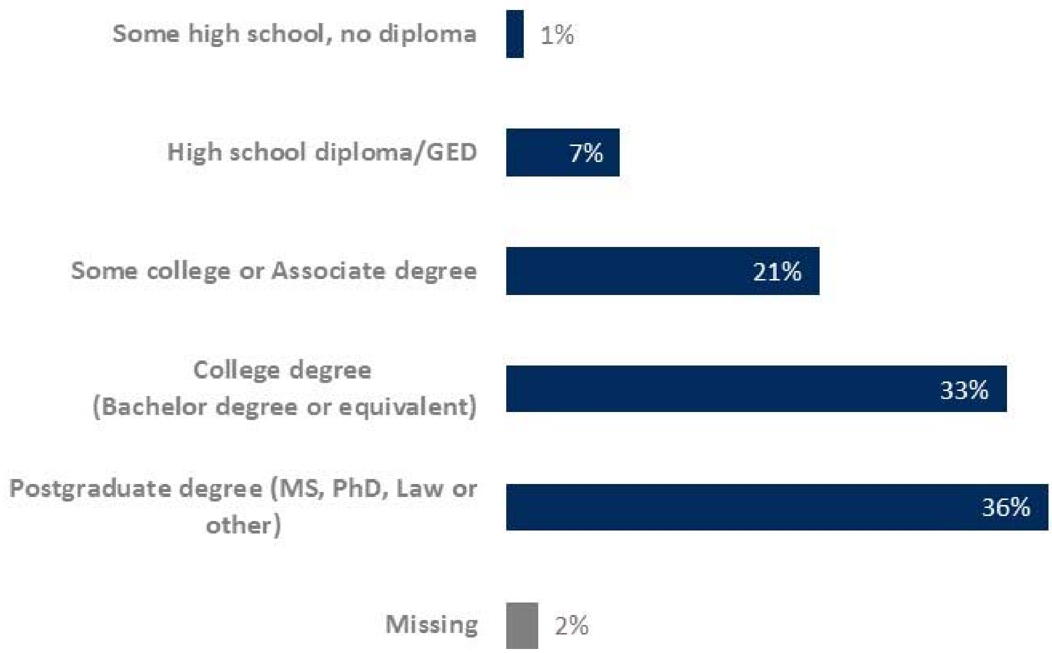


FIGURE 32. Highest level of education completed by survey respondents

Which of the following categories best describes your current employment status?

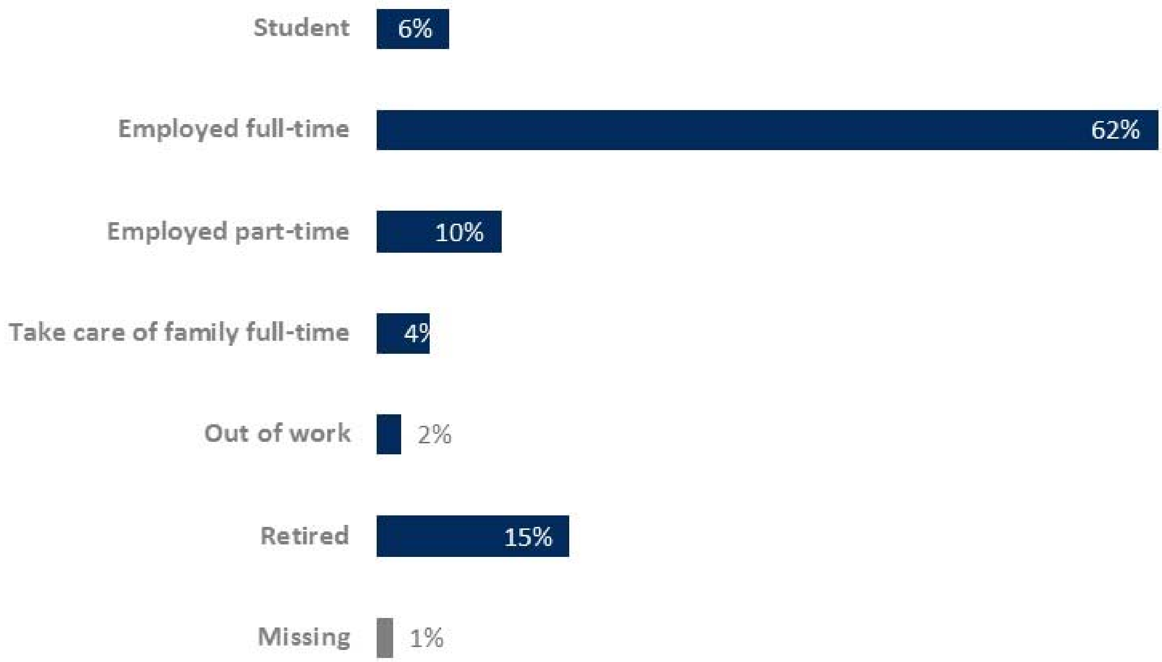


FIGURE 33. Employment status

Which of the following categories best represents your total household income over the past 12 months?

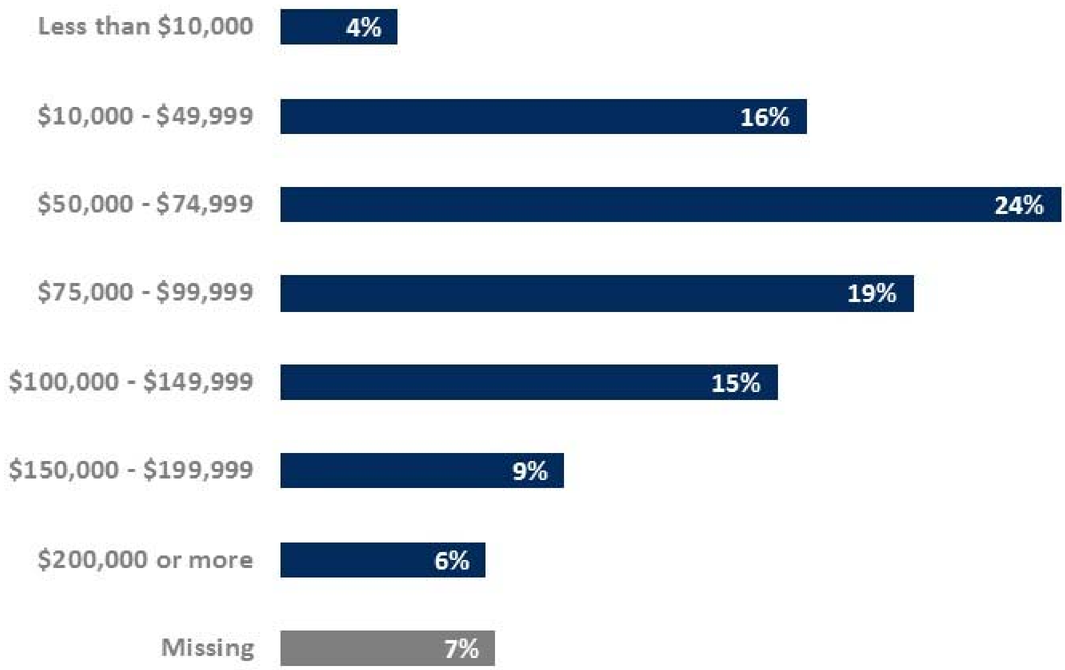


FIGURE 34. Income distribution of survey respondents

Feedback on the Survey

Is there anything else you would like to share today?

FIGURE 35. Feedback on the survey (n=100)

Image source: Word cloud created using Wordle. Relative size of text reflects the relative frequency of the word.

THANK YOU FOR COMPLETING THIS SURVEY. WE VALUE YOUR OPINIONS & TIME.

Results of initial statistical analyses

Inferential statistics (Tabachnick, Fidell and Osterlind, 2001) and regression analysis (Greene 2012, Vaske 2008, Griffiths et al, 1993) can improve our understanding of survey responses. This section contains results of regression analysis, and we begin with an explanation of data variables that may be used in this analysis.

Table 1. Description of variables used in the regression analyses

Survey Question	Variable Name	Description
Have you noticed any changes in the width, size or shape of the beach and shoreline at Popham Beach State Park?	Notice Change	1 if Yes 0 if No
In your opinion, are there impacts of erosion happening at Popham Beach State Park?	Erosion Impact	1 if Yes 0 if No
Is today your first visit to Popham Beach State Park?	First Visit	1 if Yes 0 if No
For how many years have you been visiting Popham?	Years Visiting	Number of years reported (0-84 years)
About how many days have you visited Popham Beach State Park this summer?	Frequent Visitor	Number of days reported (1-40 days)
Which of the following categories best describes your current employment status?	Education	1 if college graduate or postgraduate 0 if no college or postgraduate degree
Which of the following categories best represents you total household income?	Income	1 if respondent household income greater than $100,000; 0 if less
What is the zipcode of your primary residence?	Maine Resident	1 if a Maine zipcode 0 if non-Maine zipcode
What is the zipcode of your primary residence?	Out of State, U.S. Resident	1 if non-Maine, in U.S. zipcode 0 if non-U.S. zipcode
Have you seen signs posted at Popham Beach about erosion?	Erosion Signs	1 if Yes 0 if No
Are there children under age 18 in your household?	Children	1 if Yes 0 if No

In what year were you born?	Age (Age Squared)	18-86 years
Did you look for information about the tides before coming to Popham today?	Sought Tidal	1 if Yes 0 if No
If a future erosion event caused Popham to be on average one half its current width….would this make your experience….	Future erosion impact visit	1 if Worse 0 if better or no effect Visitor Worse =1 if indicated worse experience; 0 otherwise Visitor Neither =1 if indicated neither improve or worsen; 0 otherwise
Overall, do you think the state should take actions to address changing shorelines or choose to let nature take its course at Popham?	Management Action Choice	1 if 'Take Management Action' 0 if 'Let Nature Take Its Course'
Building a seawall to harden the shoreline	Building seawall	1 if Low Priority 2 if Medium Priority 3 if High Priority
Altering the channel of the nearby Morse River	Altering Morse River	1 if Low Priority 2 if Medium Priority 3 if High Priority
Moving sand from one area of the beach to another	Moving sand	1 if Low Priority 2 if Medium Priority 3 if High Priority
Bringing in sand from other areas to widen beach	Bring in sand- widen	1 if Low Priority 2 if Medium Priority 3 if High Priority
Relocating bathhouses to more inland areas	Relocation bathhouses	1 if Low Priority 2 if Medium Priority 3 if High Priority
Relocating parking to more inland areas	Relocating parking lot	1 if Low Priority 2 if Medium Priority 3 if High Priority
What additional information, if any, would you like to have about changing shorelines at Popham Beach State Park or the options above?	Information Wanted	1 if wanted any type of information 0 if no information wanted

Visitor perceptions of erosion and shoreline change

Table 2. Binary Logistic regression results, modeling probability of Notice Change

Explanatory Variables	Parameter Estimate
Intercept	-2.063
First Visit	**-1.389****
Years Visiting	**0.068*****
Frequent Visitor	0.058
Education	0.372
Income	-0.0123
Maine Resident	0.144
Erosion Signs	0.103
Children	0.032
Age	0.025
Age Squared	-0.000

*, **, *** indicates statistically significant at the 10%, 5% and 1% levels respectively
AIC = 294.79656

Table 3. Binary Logistic regression results, modeling probability of Erosion Impacts

Explanatory Variables	Parameter Estimate
Intercept	0.606
First Visit	0.021
Years Visiting	**0.036****
Frequent Visitor	0.012
Education	**1.476*****
Income	0.094
Maine Resident	-0.066
Erosion Signs	**0.708****
Children	-0.425
Age	-0.022
Age Squared	0.000

*, **, *** indicates statistically significant at the 10%, 5% and 1% levels respectively;
AIC =242.89733

Visitor opinions about adaptation strategies.

Table 4. Binary Logistic regression results, modeling probability of Management Action Choice

Explanatory Variables	Parameter Estimate
Intercept	-2.569
Notice Change	0.384
Erosion Impact	0.277
First Visit	-0.507
Years Visiting	-0.005
Frequent Visitor	**-0.062****
Education	0.468
Income	-0.248
Maine Resident	1.457
Out of State, U.S. resident	**2.118****
Erosion Signs	0.487
Children	**0.661***
Age (years)	-0.007
Sought Tidal	-0.508
Future erosion impact visit	**1.779*****

*, **, *** indicates statistically significant at the 10%, 5% and 1% levels respectively
AIC= 268.351

Table 5. Relative ratings of management actions, in terms of priority. Percent of all respondents (percent of those respondents who preferred 'Take Management Action' /respondents who preferred 'Let Nature Take Its Course).

	Low Priority	Medium Priority	High Priority
Building a seawall to harden the shoreline*	57 (48/74)	23.0 (26/16)	12.0 (18/4)
Altering the channel of the nearby Morse River*	66.0 (56/78)	19.0 (23/11)	4.0 (9/0)
Moving sand from one area of the beach to another*	49 (36/67)	34 (41/25)	11 (18/3)
Bringing in sand from other areas to widen the beach*	66 (59/79)	20 (23/13)	9 (14/4)
Relocating bath-houses to more inland areas	40 (42/39)	27 (27/28)	27 (26/27)
Relocating parking to more inland areas	42 (42/44)	25 (26/23)	27 (27/25)

*indicates responses were statistically different between individuals who chose 'Take Management Actions' and 'Let Nature Take Its Course'.

Table 6. Limited Dependent Variable Regression results, modeling choice of ranking different management actions.

Explanatory Variables	Building Seawall	Altering Morse River	Moving Sand	Bringing in Sand	Relocating Bathhouses	Relocating Parking Lot
Intercept3	-2.157**	-3.391***	-2.174***	-1.864**	-1.978**	-1.19
Intercept2	-.0468	-2.031**	0.187	-0.731	-0.688	-0.529
Mgmt Action Choice	**1.545*** **	**1.166*** **	**1.404*** **	**1.612*** **	-0.244	0.083
Notice Change	-0.358	-0.025	**-0.629* **	**-1.484*** **	-0.475	-0.286
Erosion Impact	0.461	-0.112	-0.007	0.586	**1.806*** **	**1.779*** **
First Visit	**1.035* **	-0.614	0.529	-0.217	-0.085	0.129
Years Visiting	0.019	0.0132	0.006	0.007	-0.011	-0.009
Frequent Visitor	-0.012	-0.016	0.007	-0.005	-0.008	-0.002
Education	0.225	-0.429	0.279	0.089	0.250	0.017
Income	0.344	0.257	-0.269	**0.985** **	-0.052	0.138
Maine Resident	0.151	0.077	-0.099	-0.184	-0.220	-0.269
Erosion Signs	-0.161	0.386	-0.081	**-1.337*** **	-0.348	0-.284
Children	-0.546	-0.013	0.406	-0.022	0.257	0.180
Age (years)	**-0.073** **	-0.006	**-0.025** **	**-0.031** **	-0.001	0-.010
Sought Tidal	**0.607* **	0.486	-0.299	0.001	0.204	0.308

Explanatory Variables	Building Seawall	Altering Morse River	Moving Sand	Bringing in Sand	Relocating Bathhouses	Relocating Parking Lot
Future erosion impact visit	0.459	**0.8927****	**0.565***	**0.816****	0.285	0.248
	AIC= 334.514	AIC= 271.830	AIC= 370.551	AIC= 282.591	AIC= 443.489	AIC= 437.298

*, **, *** indicates statistically significant at the 10%, 5% and 1% levels respectively

Impacts of erosion events on visitor experiences.

Table 7. Binary logistic regression results, impact of beach changes on future visits

Explanatory Variables	Visitor Worse	Visitor Neither
Intercept	-0.281	-0.048
First Visit	-0.540	0.362
Years Visiting	-0.009	0.009
Frequent Visitor	0.038	-0.031
Education	-0.258	0.272
Income	0.398	-0.415
Maine Resident	0.009	-0.115
Erosion Signs	-0.096	-0.014
Children	-0.239	0.019
Age (years)	-0.003	0.024
Age (squared)	0.000	-0.000
Management Action Choice	**1.467*** **	**-1.395*** **

*, **, *** indicates statistically significant at the 10%, 5% and 1% levels respectively
AIC= 374.38835; AIC= 377.76831

Information and adaptation.

Table 8. Binary Logistic Regression results, probability of requesting additional information

Explanatory Variables	Parameter Estimates
Intercept	-0.377
Management Action Choice	0.017
Notice Change	**0.679***
Erosion Impact	**0.949****
First Visit	0.400
Years Visiting	-0.006
Frequent Visitor	0.014
Education	0.225
Income	**-0.762****
Maine Resident	-0.025
Erosion Signs	0.108
Children	0.150
Age (years)	0.002
Sought Tidal	-0.043
Future erosion impact visit	0.491

*, **, *** indicates statistically significant at the 10%, 5% and 1% levels respectively
AIC=300.396

Table 9. Binary Logistic regression results, modeling probability of searching for tidal information (Sought Tidal)

Explanatory Variables	Parameter Estimates
Intercept	1.413
Notice Change	-.045
Erosion Impact	-0.177
First Visit	**-1.536****
Years Visiting	-0.007
Frequent Visitor	**.061****
Education	-0.302
Income	-0.076
Maine Resident	**-1.329***
Out of State, U.S. resident	-1.135
Erosion Signs	-.244
Children	-.058
Age (years)	.011
Future erosion impact visit	.248

*, **, *** indicates statistically significant at the 10%, 5% and 1% levels respectively
AIC=336.052

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