Appendix I


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View of refuge

A Geomorphological Analysis of the Monomoy Barrier System

Provincetown
Center for Coastal Studies

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the Monomoy Barrier System

by

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1. PREFACE

This report is submitted at the request of the Eastern Massachusetts National Wildlife Refuge Complex for geomorphological research and report preparation in support of a comprehensive conservation plan for Monomoy National Wildlife Refuge. Areas of interest specified include a summary of the present understanding of outer Cape Cod coastal processes; a chronology of southeastern Chatham coastal forms using aerial photographs to illustrate changes at Monomoy; a general overview of climate change and associated sea level rise with respect to the study area; discussion of the potential benefits and problems associated with dredging around Monomoy; and discussion of potential future research to benefit Refuge management.

2 . INTRODUCTION

"Monomoy" as seen on regional maps appears as an appendage to the bended arm of Cape Cod, extending southward some 15 km. from the Cape's sharp elbow at Morris Island in Chatham (e.g., Fig. 1). Depending on the map's date, Monomoy may have the form of a continuous peninsula – a barrier spit consisting of dunes, marshes and beaches with a bulbous terminus at Monomoy Point, or it may appear as a series of isolated and small barrier islands and shoals in the north leading southward to a larger island, "South Monomoy Island". However, the marine setting is similar at all dates: Monomoy is bordered on the southeast by a northeast-southwest trending channel, "Pollock Rip Channel"; on the southwest by a string on shoals known collectively as "Handkerchief Shoal" parts of which are sometimes exposed at extreme low water; and on the west by a broad shallow triangular platform, "Monomoy Flats" (Fig. 1).

3. METHODOLOGY

Cartography. Studies of the Monomoy Barrier Beach System using comparative cartographic sources began in earnest in 1871 with the work of Henry Mitchell. Mitchell, a prominent scientist and accomplished topographer with the Coast Survey, relied on the accurate field work and charts of the Coast Survey to document the movement and growth of the Monomoy

Spit and its offshore shoals and to investigate the potential effect of this movement on maritime commerce (Mitchell, 1871; Mitchell, 1873; Mitchell, 1874; Mitchell, 1886; and Mitchell, 1887). This present study, employing a similar methodology of chronological cartographic and aerial photograph comparisons, continues work undertaken for the Chatham Conservation Commission more than 30 years ago on the Nauset Beach System (Giese, 1978, Giese et al., 1989).

A major goal of the present study was to develop and document a chronology of the changing form of the Monomoy barrier beach system. To help achieve this goal, methodology from the Massachusetts Office of Coastal Zone Management (CZM) Historical Shoreline Mapping Project (Mapping Project) was adapted to meet the specific requirements of the current work. The Mapping Project, completed in 2007, evaluated historical cartographic documents from the 17th century through the present to establish presumptive lines of state tidelands jurisdiction for the entire coast of Massachusetts (Mague & Foster, 2008) and the methodology used to assess and apply historical cartographic documents in a contemporary mapping context is well-documented (BSC, 2007).

The methodology of this current study is based on a six-step approach: (1) research of cartographic and archival information depicting onshore and offshore historical configurations of the Monomoy barrier beach system; (2) qualitative assessment of historical information, including maps, charts, plans and narratives, to identify documents for further consideration; (3) registration of cartographic information to the North American Datum of 1983 (NAD83); (4) analysis and assessment of registered maps and charts with verifiable spatial accuracies; (5) digitization of topographic and bathymetric barrier beach features representing the location of salt marsh, mean high water (MHW) lines, mean low water (MLW) lines, and 1-, 2-, and 3-fathom lines for the following time frames: 1853-54, 1873-74, 1886-89, 1902, 1931, 1979, and 1996; and (6) compilation of figures depicting the location of these barrier beach features for each period to facilitate a comparative analysis.

As a recognized authority for the location of historical coastal features (Shalowitz, 1964), the work of the U.S. Coast Survey and in particular the information recorded on its topographic (T-sheets) and hydrographic (H-sheets) field sheets form the basis of the chronological series of figures and cartographic comparisons considered in this study.[1] Period-specific nautical charts, where necessary, were used to clarify cartographic symbology on T- and H-sheets and to fill in gaps in spatial coverage.

The horizontal accuracies of T- and H-sheets are well documented and quantifiable, making them well-suited for historical studies (Mague, 2009). When T-sheets and H-sheets are registered using archived coordinate values for Coast Survey triangulation stations (Coast Survey, 1851; Coast and Geodetic Survey, 1894) or sheet graticules translated to the project datum in accordance with accepted procedures (BSC, 2007), they have been shown to meet or exceed National Map Accuracy Standards at their respective compilation scales (BSC, 2007; Daniels & Huxford, 2001; Crowell et al, 1991). Estimates of H-sheet accuracies, with horizontal and vertical components, are more difficult to quantify. Referenced to local MLW datums frequently defined relatively short series of tidal measurements, H-sheet sounding accuracies have been estimated to range from 3 to 4± feet for 1800s to early 1900s surveys, 2 to 3± feet for mid-1900s surveys, and 0.5 to 1.0± feet for modern surveys (Byrnes, 2002; Johnston, 2003; and U.S. Coast Survey, 1878). For shallow depths (± 15 feet), small tidal ranges, and regular bottoms with minimal relief, such as much of the area surrounding Monomoy, these estimates would appear to be conservative. Future work that includes refining these uncertainties is necessary for a detailed assessment of the sediment transport systems, nearshore and offshore processes, and the calculation of sediment budgets and volumes that contribute to the formation of the extensive shoals surrounding Monomoy, particularly the triangular area extending approximately 2 miles to the west, characterized by flat relief, a tidal range of 3 ± feet, and a significant shoal area defined by the 1-, 2-, and 3-fathom lines. (Note: 1 fathom = 6 feet).

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[1] The official name of the U.S. Coast Survey has evolved over time. Reference to the Coast Survey throughout this report is meant to include the U.S. Coast Survey and its successor agencies the U.S. Coast & Geodetic Survey and the current Office of Coast Survey.

Copies of the historical plans of the U.S. Coast Survey were obtained from the digital database of the Mapping Project, which contains in excess of 2,600 historical plans, maps, and charts of the Massachusetts coast (BSC, 2007). Historical charts were obtained from the Historical Map & Chart Project website of the National Oceanic & Atmospheric Administration (NOAA) Office of Coast Survey. Contemporary charts of the area were obtained from the NOAA Office of Coast Survey Nautical Charts website. A list of all historical and contemporary cartographic information considered for this study is contained in Section 11.

Information from historical and contemporary maps, charts, sketches, and orthophotos were incorporated into a project Geographic Information System (GIS), created in ArcGIS 9.3 with MassGIS, 1:5,000 scale, 2005 orthophotos as the base map, to develop figures depicting the shape and orientation of Monomoy Spit and its nearshore bathymetry out to a depth of three fathoms (18 feet), local MLW datum. Historical cartographic manuscripts were registered to the North American Datum of 1983 (NAD83) using the ESRI, ArcGIS 9.3 georeferencing extension, set for a First Order Polynomial (Affine) Transformation. Registration points consisted of Coast Survey triangulation stations or map graticules with a minimum of six points retained for each registration with the goal of minimizing the root mean square (rms) of the error associated with the registration or control points. To the extent possible, registration points were distributed equally across each manuscript to account for potential unequal distortion of the source document.

Finally, similar to the approach of Mitchell, figures depicting the historical positions and spatial orientation of Monomoy and its offshore shoals were compiled at the same scale to facilitate qualitative comparisons of geomorphic changes over the past 160 years. These figures are presented in Section 5.

Photography. A review of historic aerial photographs was completed at the Cape Cod National Seashore (CCNS) collection, and the Barnstable Service Center of the U.S. Department of Agriculture's Natural Resources Conservation Service (USDA/NRCS) office. Printed photos that cover Monomoy from 1938 and 1960 were located at the CCNS. The 1938 set does not extend northward to the southeastern shore of Chatham. A set of 1978 aerial photos ends in Chatham; it does not extend southward to include Monomoy. A set of 1947 photos also stopped in Chatham for the printed copies of the CCNS collection, however, additional photos in this series are available and could be incorporated in to future analyses.

Black and white aerial photos available from USDA/NRCS are 1938, 1951, 1971 and 1980. A set of color infrared photos are available for 1984. Orthorectified aerial photographs were available in digital format for 2009 from the Town of Chatham. A 2002 orthophoto was provided by the Town of Chatham, which was acquired by the National Fish and Wildlife Service. Additional orthorectified aerial photos were available for 1994, 2001 and 2005 from the Massachusetts state office of Geographic Information Systems (MassGIS).

Year	Description	Source Location	Comments
1938	B & W	NPS and NRCS/USDA	scanned and mosaiced, used for interpretation
1947	B & W	NPS/Aerial Viewpoint	available for purchase, may be useful for future study
1951	B & W	NRCS/USDA	reviewed, may be useful for future study
1960	B & W	NPS Highland Lab	scanned and mosaiced, used for interpretation
1971	B & W	NRCS/USDA	reviewed, may be useful for future study
1980	B & W	NRCS/USDA	reviewed, very small scale probably not useful
1984	CIR	NRCS/USDA	reviewed, may be useful for future study
1991	B & W paper	Town of Chatham	scanned and mosaiced
1994	Orthophoto	MassGIS	digital files used for interpretation
1997	B & W paper	Town of Chatham	scanned and mosaiced
2001	Orthophoto	MassGIS	digital files used for interpretation
2002	Orthophoto	DFW/Town of Chatham	digital files used for interpretation
2005	Orthophoto	MassGIS - Coastal	digital files used for interpretation
2009	Orthophoto	Town of Chatham	digital files used for interpretation

Table 1 Summary of Aerial Photo Review

Blue text denotes aerial photos used in this report. Aerial photos in green text were acquired but not utilized for this study. Black text denotes other photos that are available for the study area.

The scanned aerial photos for 1938, 1960, 1991 and 1997 were cropped and compiled in Adobe Photoshop, because there were not enough common features through time to georeference each photo frame given the dynamic nature of Monomoy. Once the photos were compiled into a montage for each year they were aligned generally in ArcView 9.3 using the georeferencing toolbar resizing and adjustment tools. There were not enough common points evenly

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distributed throughout the different time series to rectify the photos with common tie points. However, the general adjustment did allow for a basic alignment of the photos for comparison and scaling purposes.

4. REVIEW OF GEOMORPHOLOGICAL HISTORY

The genesis of Monomoy as the southern extremity of a 34 km deposition feature beginning at Coast Guard Beach in Eastham, the "Nauset-Monomoy Barrier System", has been treated in detail by Goldsmith (1972). In brief, the system is a complex of barrier beaches, barrier spits, barrier islands and associated tidal inlets consisting of sediment initially supplied by the erosion of glacial deposits exposed along the 32 km-long line of east-facing cliffs and nearshore sea bed that extends northward from Eastham to North Truro.

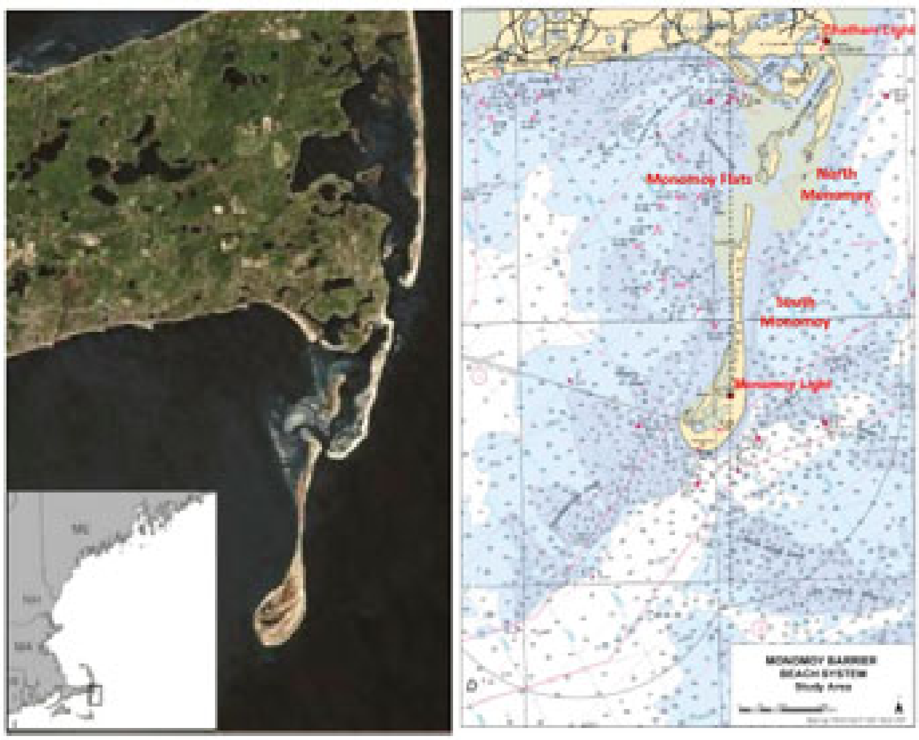

FIGURE 1

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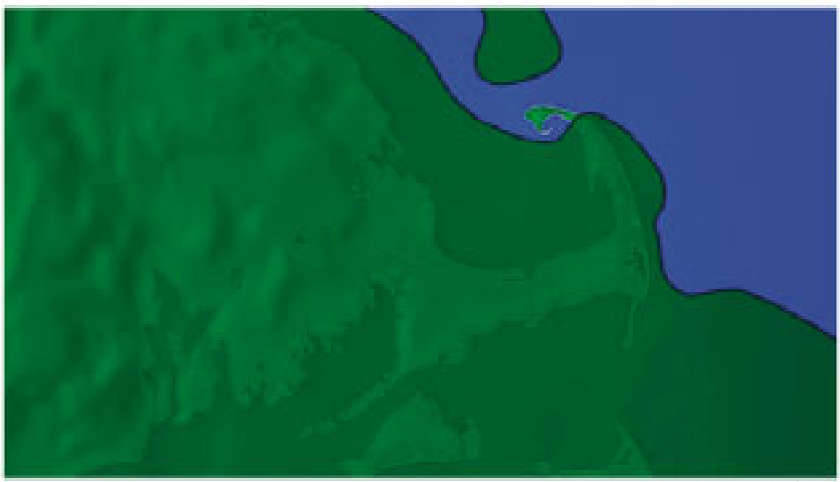
Early Holocene. As discussed in Section 5, historical geomorphic changes at Monomoy occur in step with those of Nauset Beach, however, before examining these processes in detail, let us review the broader scale development of the Cape Cod landmass during the Holocene Period – the approximately 12,000 year period following the most recent ("Wisconsin" stage) glaciation. At that time, sea level was some 55 m below its present level and most of the area comprising present-day Cape Cod Bay, Cape Cod, Nantucket Sound and Nantucket, and Vineyard Sound and Martha's Vineyard was part of the terrestrial borderland of the continental margin (Fig. 2).



Adapted from Uchupi, *et al.* 1996

FIGURE 2

The early Holocene was a period of rapid sea level rise. By 6,000 years B.P. (before present), sea level had risen some 45 m and was approximately 10 m below its present level. As a result of this submergence, the Cape and Islands, with their bays and sounds, became fully differentiated (Fig. 3), however, the major depositional features of outer Cape Cod, Provincetown Hook, Nauset Beach and Monomoy had not yet formed.

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Adapted from Uchupi, *et al.* 1996

FIGURE 3

Late Holocene. Wave-driven sediment transport became the major process controlling shoreline evolution during the past 6,000 years. At the beginning of this period, George's Bank - until that time a gradually shrinking landmass between Cape Cod and the open Atlantic basin – became fully submerged. As a result, higher energy, open ocean waves - previously highly damped by the time they reached the coast – were capable of transporting increased amounts of sediment. According to Uchupi et al. (1996), glacial sediments eroded from the sea cliffs and nearshore bottom between North Truro and Eastham during this time period were responsible for the construction of Provincetown Hook to the north and the Nauset-Monomoy barrier system and Handkerchief Shoals to the south.

Notably, the rate of shoreline retreat accompanying these changes increased southward. Between about 6,000 and 1,000 years ago, the eroding bluff section retreated at an average rate of approximately 0.3 m/year at the northern end and 0.6 m/year in the south (Uchupi et al., 1996). A recent study (Giese and Adams, 2007) reports that contemporary century-scale bluff retreat rates continue to increase north-to-south by a factor of two, but the contemporary rates (ranging from 0.5 m/year to 1.0 m/year) are greater in magnitude, perhaps a response to acceleration in the rate of sea level rise. Presently on-going research indicates that the southward increase in coastal retreat continues southward, past the end of the bluff section and along the length of Nauset Beach at least as far south as North Chatham. There, the century-scale average retreat exceeds 1.5 m/year, 3 times the retreat rate of the north end of the bluff section (Vaux, in press). Many local anecdotal reports confirm continual westward migration of Nauset Beach during the historical period (e.g., Nickerson, 1988).

If we assume, based on these rates of coastal retreat, that Nauset Beach lay 1 to 2 km offshore of its present location a thousand years ago, it seems unlikely that the origin of Monomoy predates that time. Geological maps of Cape Cod (e.g., Oldale and Barlow, 1986) indicate "ice contact" glacial deposits west of the northern section of Nauset Beach, and Uchupi et al. (1997) propose that the original eastern boundary of glacial Cape Cod lay just eastward of the present upland coasts of Nauset Harbor, Pleasant Bay, and Chatham Harbor. In that case, a long marine embayment lay inside Nauset Beach at 1,000 years BP, extending from the Eastham upland southward to the vicinity of Chatham.

Presently restricted basins such as Pleasant Bay, Little Pleasant Bay, and Nauset Harbor would have had free access to the embayment, while the embayment would have had a relatively unrestricted connection with the sea. Given this configuration, southward moving littoral sediment would not have reached the upland coast of south Chatham as it does today.

Recent history. By the time that accurate maps of the coast became available (e.g., Des Barres, 1764), Nauset Beach had migrated far enough westward to severely restrict tidal flow in the narrowing embayment. Even earlier (17^{th} Century) sketches and notes by Champlain (1607) (Fig. 4) suggest that Nauset Harbor was already largely tidally-separated from the Pleasant Bay system to the south. The restriction of tidal flow between the Pleasant Bay basins and the open sea produced by changes in Nauset Beach have produced a quasi-cyclic pattern of tidal inlet/barrier island formation and barrier spit development (e.g., Mitchell, 1873; Goldsmith, 1972; Giese, 1978). In brief, this pattern consists of the following steps: 1) a breach in Nauset