Beach, 2) southwest migration of the southern barrier island (i.e., detached south end of Nauset Beach), 3) Nauset Beach elongation to the south, followed by, 4) a new breach.

Champlain, 1607

FIGURE 4

It is the second step of this pattern that concerns us here because an analysis of historical shoreline changes in the Monomoy region indicates that the detached end of Nauset Beach is the major sediment source for landforms in that region. As can be seen in Figure 5, adopted from a recent report by (Giese et al., 2009), following initiation of a new inlet referred to as "North Inlet" (Fig. 5b,) the former inlet ("South Inlet") closes (Fig. 5c) enabling littoral transport of sediment southward from the barrier island ("South Beach") to Monomoy.

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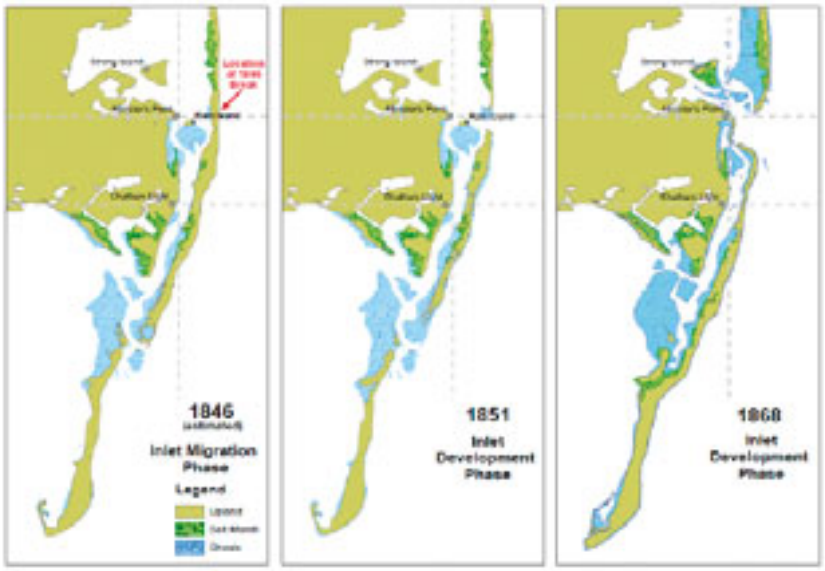

FIGURE 5 (a, b, c)

As the result of southward and westward sediment transport over the following decades (Figs. 6 and 7), Monomoy shifts westward, widens, attaches to Morris Island, and grows southward. After about a century, southward-growing Nauset Beach overlaps North Monomoy, which is deprived of incoming sediment, and begins to break-up into a group of islets and shoals. Finally, when Nauset Beach breaches again, and a new "South Beach" attaches to South Monomoy Island, a renewed sediment supply is available to nourish South Monomoy (Fig. 8c).

11

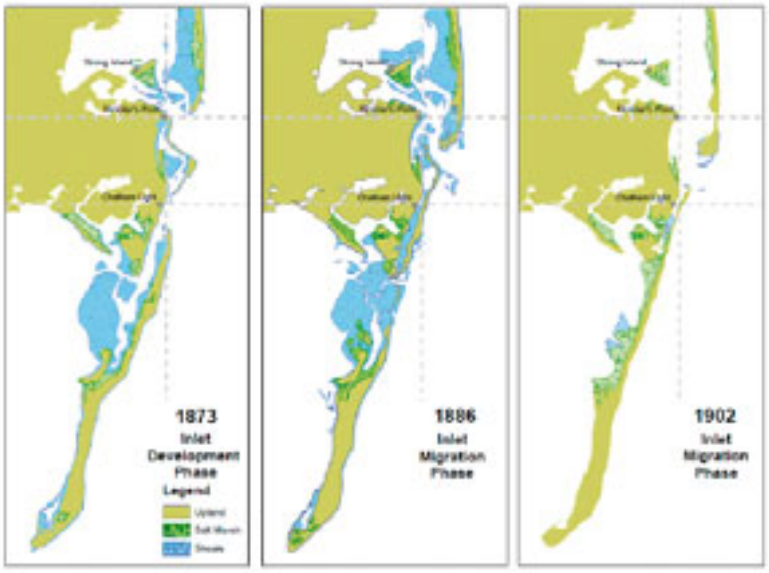

FIGURE 6 (a, b, c)

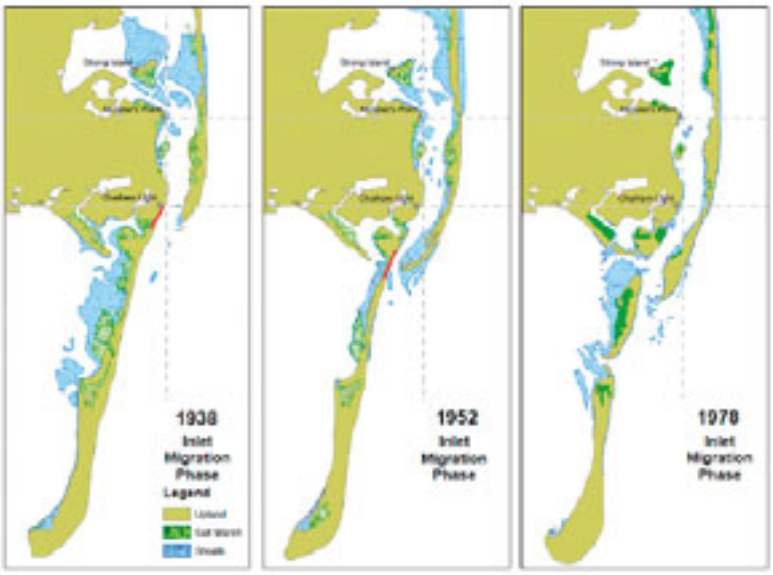

FIGURE 7 (a, b, c)

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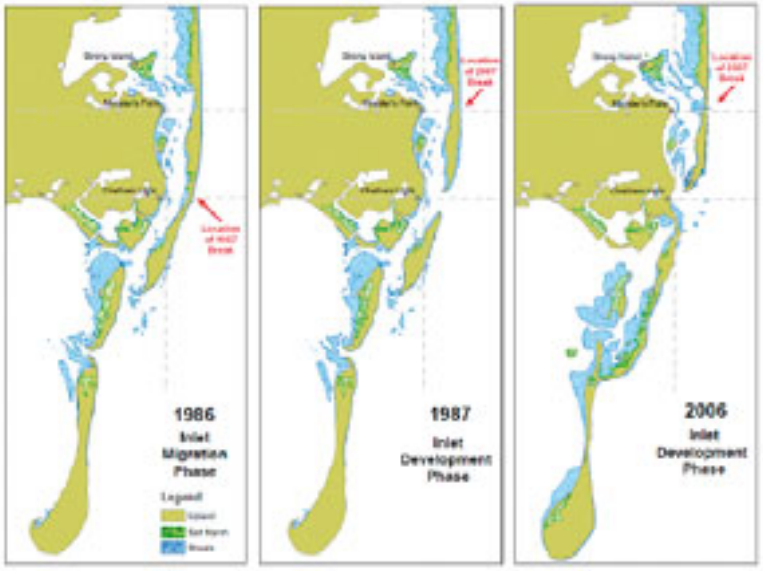

FIGURE 8 (a, b, c)

5. TIME SERIES OF MONOMOY CHANGES

The first two of the following three sub-sections present the results of cartographic and photographic research described in Section 3. The figures in *U.S Coast Survey Mapping* illustrate the general shape and position of the dominant landforms within the context of the surrounding shallow water features shown to a depth of 18 feet (3 fathoms) below mean low water. In contrast, the figures in *Aerial Photography* provide details of the changing landforms but little bathymetric information. In the third sub-section, *Discussion*, we call attention to the relationship between the landform changes and those of the surrounding bathymetry, as well as the distinction between the northern and southern sections of Monomoy.

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U.S. Coast Survey Mapping.

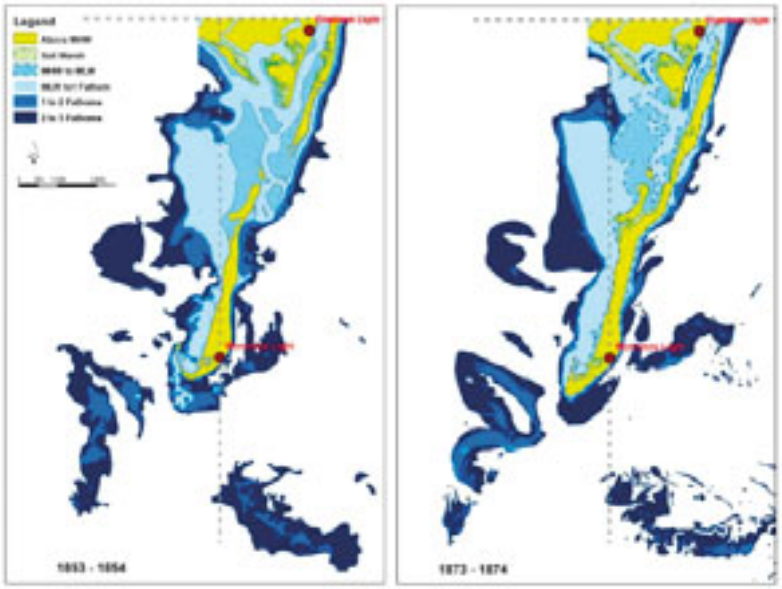

FIGURE 9 (a, b)

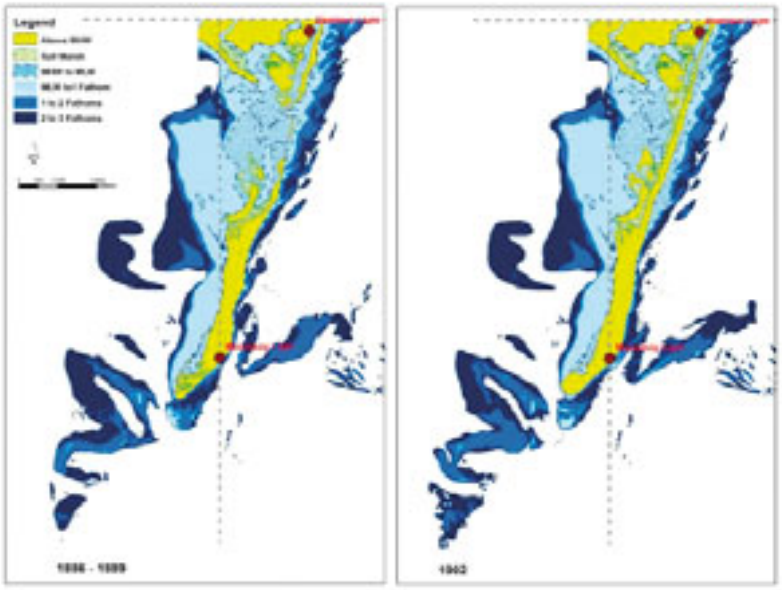

FIGURE 10 (a, b)

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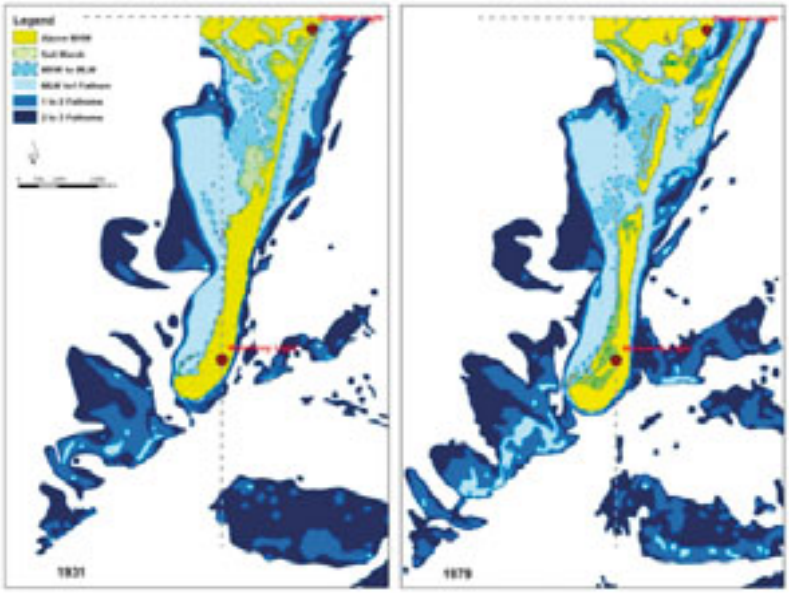

FIGURE 11 (a, b)

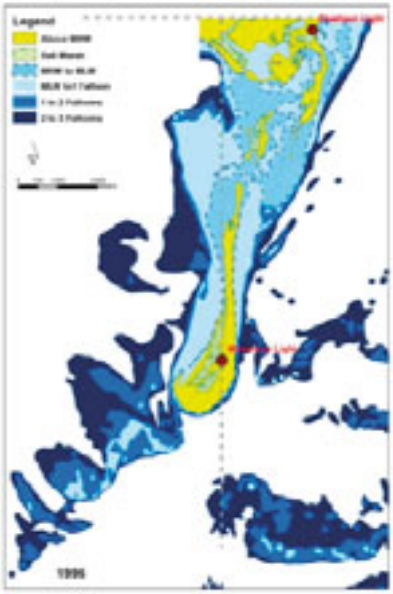

FIGURE 12

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Aerial Photography.

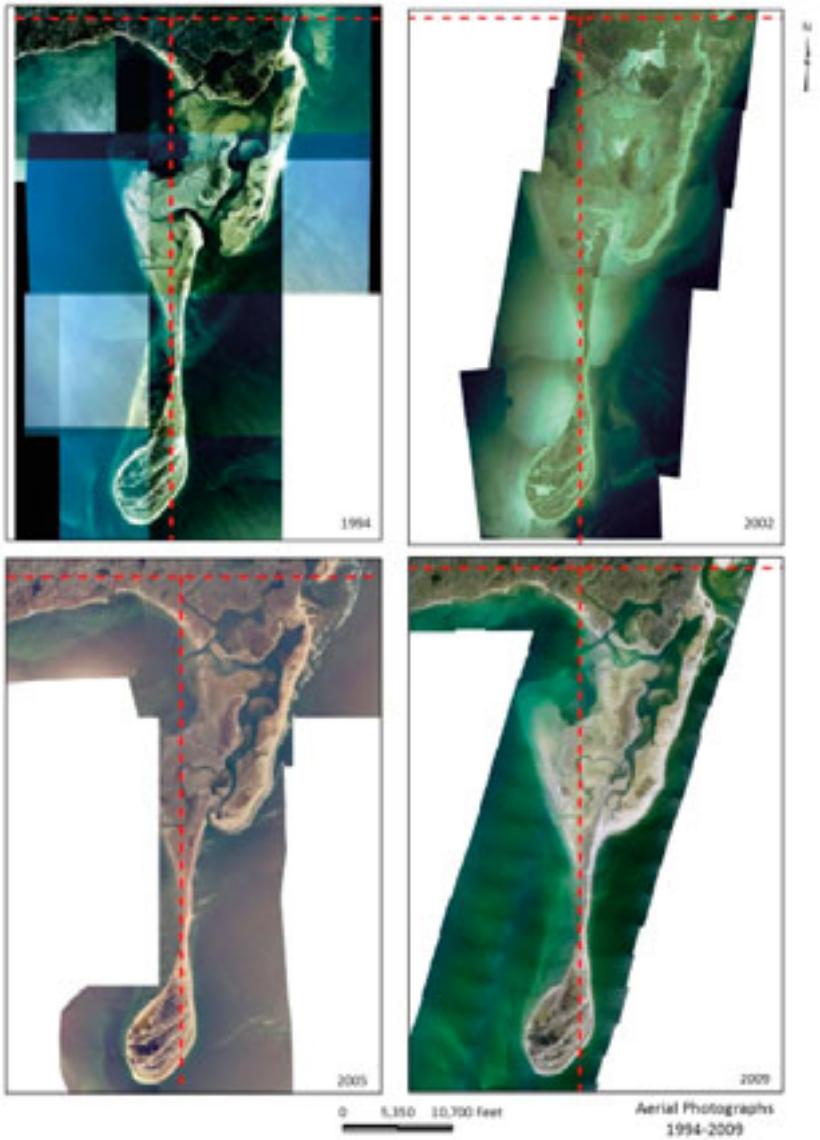

FIGURE 13

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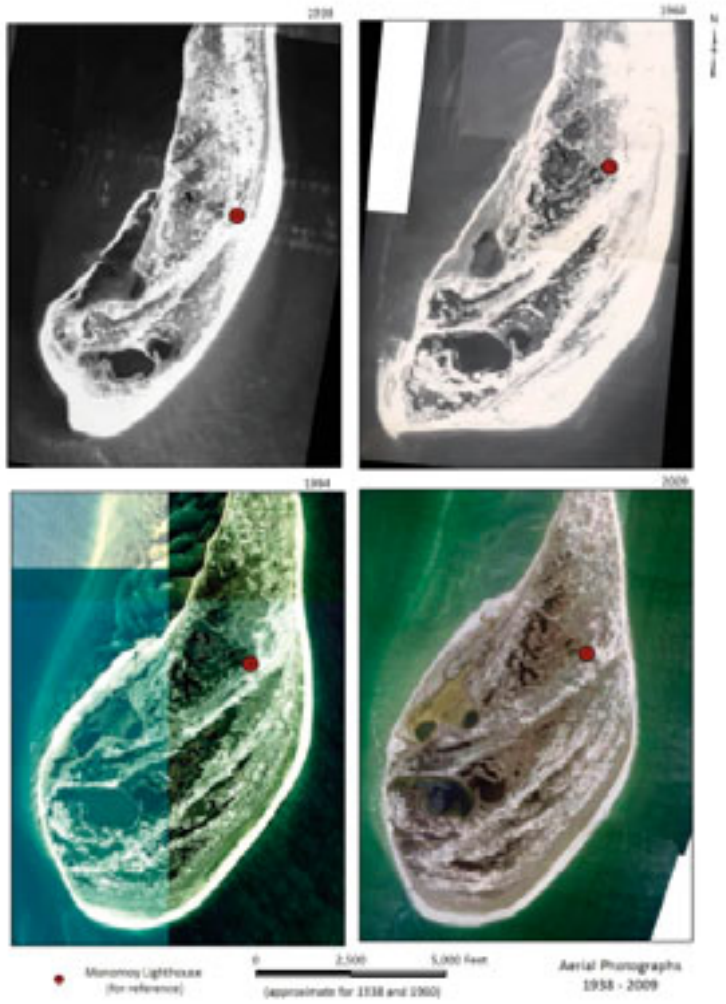

FIGURE 14

North Monomoy. Figures 9-12 reveal that Monomoy is comprised of two very distinct features. "North Monomoy" is a triangular shaped, mostly sub-tidal platform which widens northward. Subaerial landforms, when and where present, typically shift in position, size and shape. The margins of the North Monomoy Platform - well defined by the 6-foot (1 fathom) contour – appear remarkably similar in Figures 9-12 with the exception of Figure 9a, the earliest (1853-

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1854). It is likely that the somewhat irregular form of this figure's depth contours results from less accurate navigational techniques than those employed for the later surveys. The stability of the North Monomoy Platform is illustrated in Figure 15, which compares the location of the 6-foot contour in 1873-74 with its location in 1996. Both are superimposed on a 2009 photograph. The only apparent trend is on the western (Nantucket Sound) side, with a small retreat along the southwest-facing margin, and a small advance along the north-facing margin.

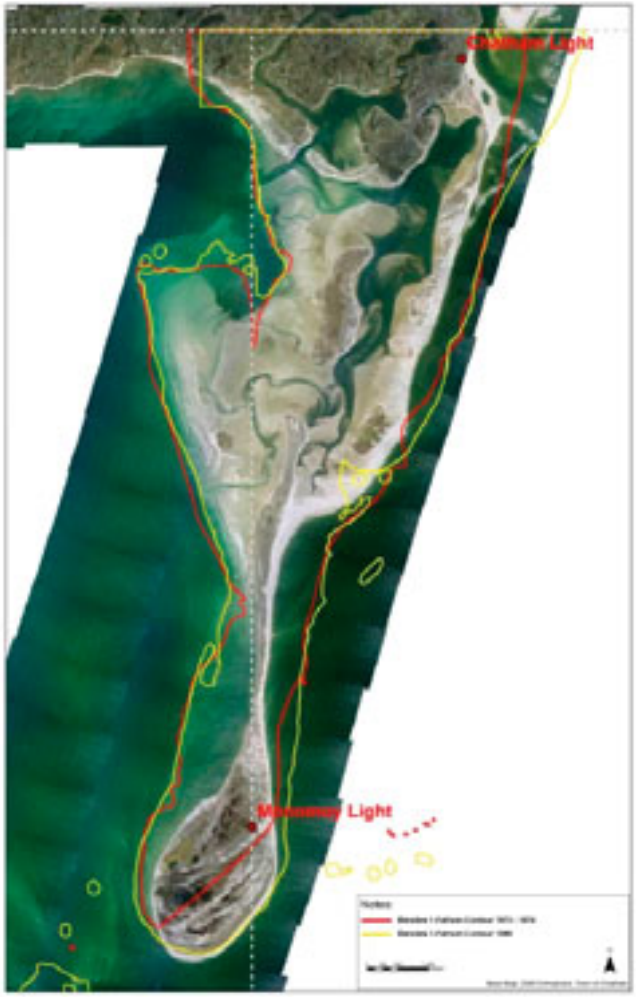

FIGURE 15

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Also apparent on Figures 9-12 is the mode of sediment transport from the eroding coast lying north of Monomoy (see Section 4), across North Monomoy Platform, to South Monomoy. A comparison of Figure 9 and Figure 5 illustrates the development of a second, more northerly tidal inlet in North Chatham that resulted in (1) closure of the inlet shown in Figure 9a, and (2) southward extension of the barrier spit to its north, leading to its welding onto South Monomoy (Figure 9b). Westward migration of the barrier across the platform is apparent in Figures 10a and b, leading to its eventual attachment to Morris Island (Figure 11a). At this stage, Monomoy was an unbroken peninsula connecting Monomoy Point to glacial upland in south Chatham.

This lasted only until southward extending Nauset Beach (Figures 6 and 7) reached the vicinity of Morris Island (Figure 11b) inhibiting wave-driven sediment transport along the Morris Island/North Monomoy coast. Deprived of a sediment supply, the peninsula broke down, first through a breach just south of Morris Island (1950's), then through a second breach (1978) (Figure 11b) separating North Monomoy from South Monomoy – each becoming a separate island. Tidal flow through the 1978 inlet produced a flood-tidal shoal near the western margin of the platform, which under the influence of the prevailing southwesterly wind waves, gave rise to the islet known as "Minimoy".

South Monomoy. "South Monomoy" is primarily a well-established and growing subaerial landform, consisting of dune, heathland, pond and marsh environments. It is a rare example of an actively accreting coastal landform along the exposed outer shore of Cape Cod, a distinction it shares only with the region near Race Point at the opposite extremity of the outer shore. Century-scale increase in area of the feature can be seen in the eastward and southward growth of the 6-foot (1 fathom) contour in Figure 15, and the southward extension of Monomoy Point since the mid-19th Century is clearly evident in Figures 9-12. Twentieth century change is shown in Figure 16 documenting a pattern of successive beach ridge development.

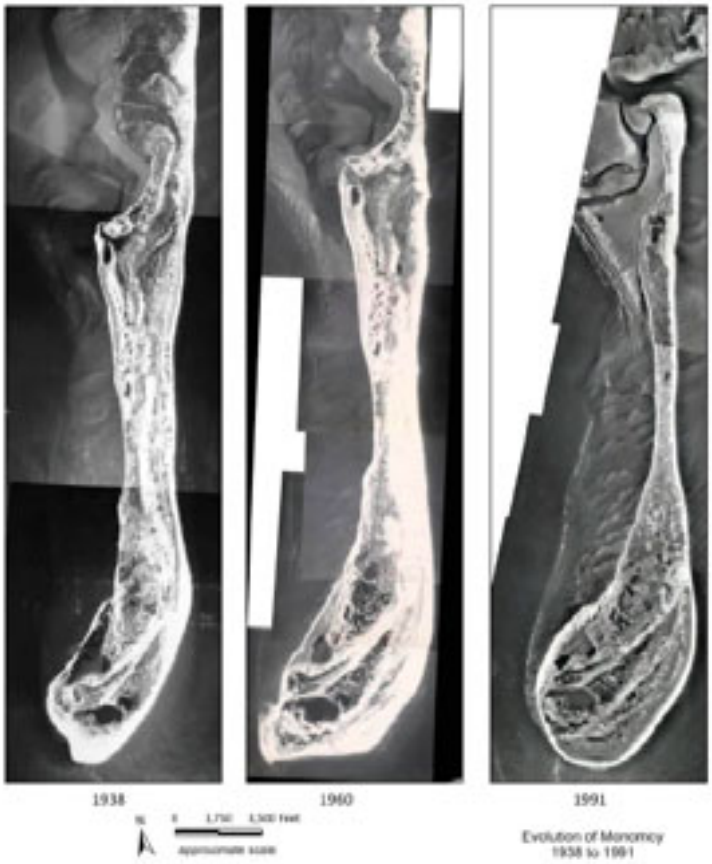

FIGURE 16

Change in location of the southern-most extremity of Monomoy Point is shown by the red vectors in Figure 17. The blue vectors in Figure 17 illustrate the change in location of the southern-most extremity of Handkerchief Shoal over the same time period. Evidently the evolution of South Monomoy is interdependent with that of Pollock Rip Channel and Handkerchief Shoal, which forms the channel's western boundary south of Butler Hole. Figure 18 shows historical locations of Monomoy Point for the years 1853, 1931, 1967, 1952 1979, and 1996, as defined by former ridge lines visible on the 2009 orthophoto.

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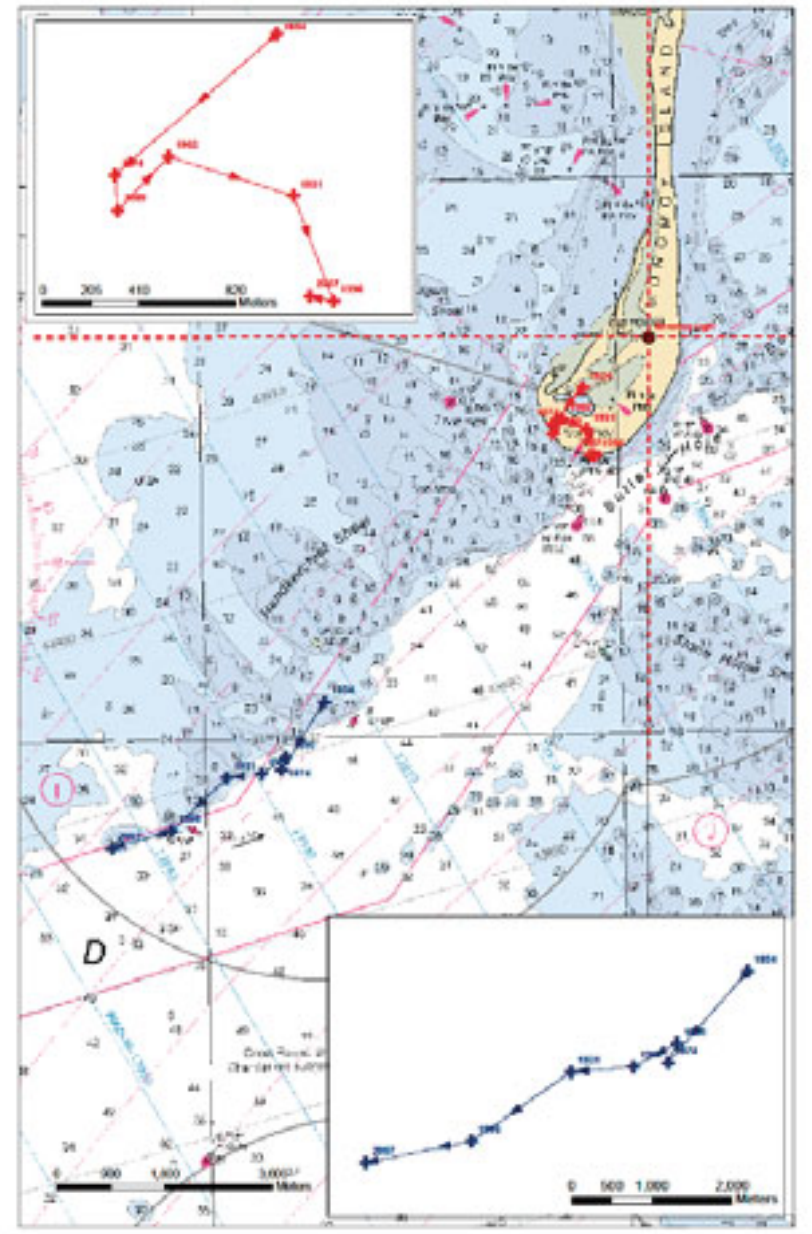

FIGURE 17

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FIGURE 18

It is interesting to note in Figures 9-12 that Monomoy Point appears to have grown southward directly onto an adjacent portion of Handkerchief Shoal, and that at present, for the first time,– it directly abuts on the margin of Butler Hole. However, the figures also indicate that

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Handkerchief Shoal has developed considerably over the same time period. Together these observations suggest that future growth of Monomoy Point may follow a more southwesterly trajectory.

Figures 9 -12 also illustrate that some of the Nauset Beach-derived sediment that nourishes the growth of the eastern and southern South Monomoy continues around the point and forms the northward-trending spits that characterize the western shore of South Monomoy. The manner in which such spits develop into recurved spits that can eventually enclose ponds has been described by Zeigler, et al. (1965), who refer to Mitchell's (1886) account of the development of Powder Hole on South Monomoy:

> In my boyhood the Powder Hole was considered to be a very valuable harbor of refuge, but when I ran into it ... in 1856, forty fishing vessels ... packed it nearly full. Three fathoms at low water could be carried into this snug little place when our chart of 1854 was issued, but Mr. Chapin found but two feet at the time of his recent visit.

Wind waves from the southwest dominate sediment transport along the western coast of South Monomoy because of the extensive distance of fetch across Nantucket Sound. Winter prevailing northwesterly winds, in contrast, have a very limited fetch and, as a result, net sediment transport is directed to northward.

6. CLIMATE, SEA LEVEL AND 21st CENTURY MONOMOY

Small islands are particularly vulnerable to sea level rise (IPCC, 2007). However, this report shows that at the current rate of sea level rise, sediment supply from Nauset Beach to Monomoy is not only capable of maintaining the barrier complex, but of supporting ongoing accretion along the southern portion of South Monomoy Island.

Recent changes in global, or eustatic, sea level rise are largely driven by two phenomena: the thermal expansion of seawater as a result of increasing sea surface temperatures and the

melting of glacial ice (Williams and Gutierrez, 2009). The most recent report of the Intergovernmental Panel on Climate Change (IPCC) predicted future rises in sea level of 0.18 – 0.59 m by the year 2100 (Fig. 19; IPCC, 2007). However, some more recent studies include higher contributions from melting ice and suggest a global sea level rise by 2100 of 1 m or more (Rahmstorf, 2007; Rahmstorf, et al., 2007; Vermeer and Rahmstorf, 2009).

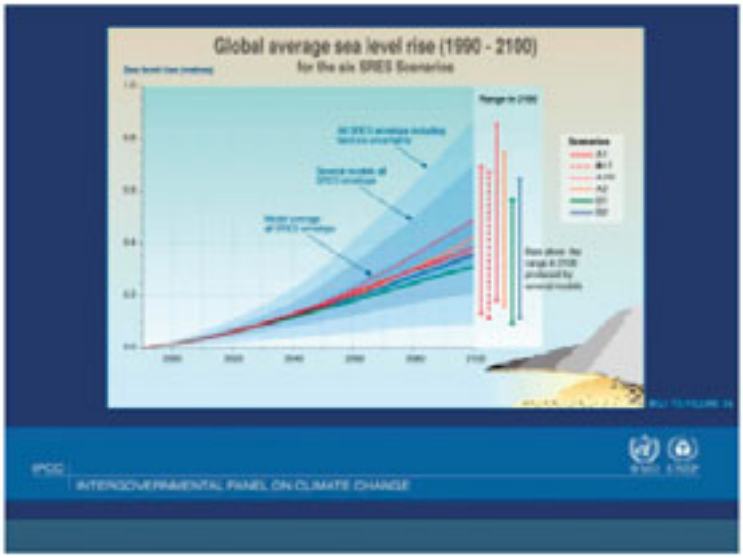

FIGURE 19

"Relative" sea level includes the augmentation or diminution by local phenomena on global sea level. Some of these phenomena include subsidence, post-glacial rebound, tectonic processes and oceanographic currents. For instance, in much of Scandinavia relative sea level is falling due to the rapid uplift of the land resulting from deglaciation since the Late Pleistocene.

Along the eastern seaboard of the U.S. researchers have identified a sea level trough maintained by the Gulf Stream and the North Atlantic Current that has kept the sea level anomalously low (Gregory, 2005; Meehl et al., 2007). Sea level in this area is 0.6 m lower than the global average and it has been shown that climate change will weaken those currents

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