resulting in a relative sea level change in parts of the North Atlantic. Investigators modeled several scenarios for the eastern seaboard of the United States and demonstrated that if these currents are weakened relative sea level rise could increase between 0.15 – 0.21 m along the eastern seaboard, which would be superimposed upon the global sea level rise (Yin, et al., 2009).

During the 20th Century, relative sea level in southern New England rose at a long-term rate of about 2.6 – 3 mm/year (e.g., Fig. 20) or approximately 0.3 m (one foot) , and this represented an almost three-fold acceleration of the rate that the region had experienced for many centuries (Donnelly, 2004; Fig. 21).

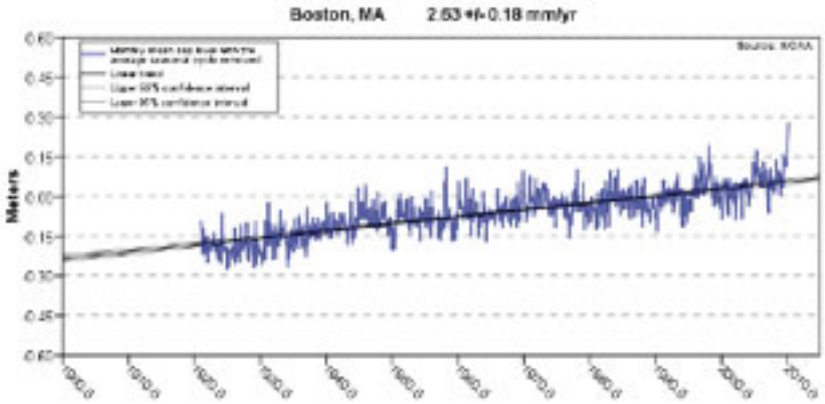


**FIGURE 20**

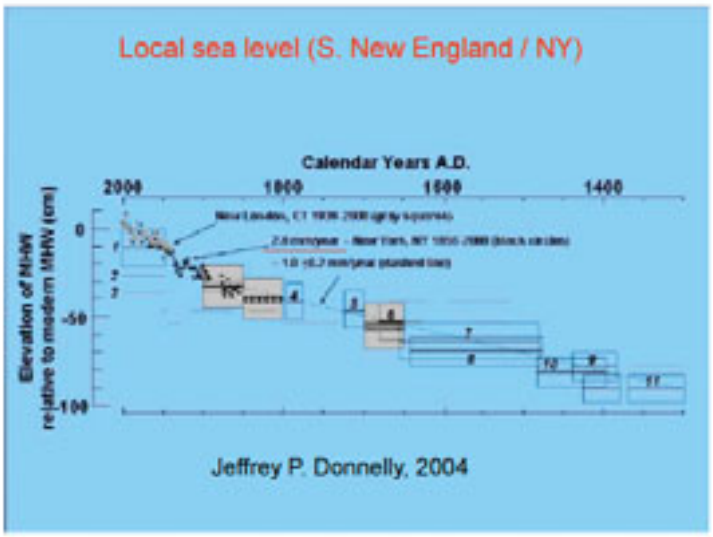


**FIGURE 21**

The global component of the southern New England 20th Century relative sea level rise of 0.3 m is close to the 0.18 m "low" IPCC estimate (IPCC, 2007) for the 21st Century. Therefore, under this scenario, we would expect 21st Century changes at Monomoy to follow the general patterns observed over the past century as follows:

During the 2nd and 3rd decades (2010-2030), South Beach overwashes more frequently producing washover fans on its inner (western) side; South Beach sediment moves southward along the South Monomoy outer shore; Monomoy Point grows southward/southwestward. In the 4th and 5th decades (2030-2050), South Beach overwashes thoughout its length; washover shoals reach Morris Island ending Outermost Harbor navigation; a re-curved spit, or hook, develops on southwestern side of Monomoy Point, sweeping northward. In the 3rd quarter-century (2050-2075), shoals from former South Beach end all "inside" navigation and finally connect Morris Island to South Monomoy; the Monomoy Point hook almost joins the western shore of South Monomoy. During the final quarter-century (2075-2100), Monomoy exists as peninsula for most of period, but thins south of Morris Island by close of century; Monomoy

Point extends southwestward onto nearby section of Handkerchief Shoal; and an enclosed pond forms on western shore of South Monomoy inside former re-curved spit.

This scenario for the 21st Century assumes that the major forcing factors for the period will be similar to those of the recent past, but this assumption would not be valid if global sea levels rise a half-meter or meter or more by century-end. The magnitude of relative sea level rise in that eventuality would significantly modify a number of factors affecting the evolution Monomoy, such as regional wave climate, Nantucket Sound tides, and the elevation of the ground water table.

In such a case, the resulting increase in water depths over inner- and outer continental shelf shoals, including George's Bank, could increase ocean wave energy reaching Nauset Beach and Monomoy sufficiently to markedly increase southward net sediment transport – perhaps to the extent that Chatham upland south of Minister's Point becomes directly exposed to wave action (Giese, et al., 2009). In such a case, the large amount of sediment made available between the coast and upper shoreface (c. 10 m depth) could be sufficient to maintain a permanent barrier connection between Morris Island and South Monomoy.

A marked increase in Nantucket Sound water depths could increase tidal range and currents in the eastern sound, increasing the scour of Pollock Rip Channel – an erosional trough (Uchupi, et al., 1996) – thereby adding to the bulk of Handkerchief Shoal. This, in turn, coupled with an increased supply of sediment from the north, could enhance the southwestern growth of Monomoy Point.

A large and rapid relative sea level rise would be accompanied by a similar rise in the South Momonoy water table, flooding low-lying areas and enlarging existing ponds and wetlands. Prevailing southwesterly wind waves coupled with higher sea levels could markedly increase erosion of sound-side Monomoy, narrowing the peninsula. At the same time, higher sea levels and reduced sediment supply could be expected to deepen Monomoy Flats.

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In summary, while the IPCC "low" global sea level rise projection might be expected to produce patterns of change over the 21st Century that are basically similar to those of the recent past, patterns accompanying the much higher sea level rise projections would be strikingly different. As stated above, there is a general consensus in the earth science community that global sea level rise rates are increasing and will continue to increase during the 21st Century, but there is much uncertainty regarding the magnitude of that increase within the ranges discussed. Accordingly, it seems reasonable to assume that the patterns of coastal change at Monomoy during the 21st Century will follow the general trends of those experienced over the recent past, but at an accelerated pace.

## 7. DREDGING

Bottom sediment dredging in the vicinity of Monomoy raises question with respect to the potential negative and positive impacts of this activity on the Sanctuary. Dredging in the region is not uncommon. The entrance channel to Stage Harbor, which lies north and west of Morris Island, is a federally maintained waterway and regularly dredged. In addition, the Town of Chatham dredges to maintain safe navigation of its waters for both commercial (especially fishing) and private vessels. Past history has shown these operations to be benign with respect to local environmental impacts on water quality (e.g., turbidity, nutrients, toxins), but the need for suitable sites for dredge spoil deposition has been recognized, and the possibility of depositing such sediment within the Sanctuary has been discussed.

Such biological questions as effects of dredging activities on benthic infauna are beyond the scope of this report, but potential impacts on the physical environment can be addressed within the context of its findings. Given the history of high-energy sediment transport at North Monomoy and Monomoy Flats, the addition of suitably-sized sediment there would not appear to present difficulties. Since the potential sediment volumes involved would be small in comparison to those contributed annually by natural processes, the major impact would be to slightly increase the rate of growth of the barrier complex.

However, the suggestion of using Stage Harbor dredge spoil to create an islet, similar to "Minimoy", that would provide a suitable environment for beach nesting birds raises several concerns. First, although a northerly location on Monomoy Flats would be preferred for economic reasons, it could have negative impacts on nearby navigation channels. Second, there is the question of the lifespan of such an islet. Unlike Minimoy, which developed slowly as a flood tidal shoal over an extended period under natural conditions, a single, quickly-deposited islet would soon be reworked by waves and tides, and lacking a extended source of additional sediment, could be transformed to an inter-tidal shoal sooner than expected.

A possible alternative plan could locate a Stage Harbor dredge spoil deposition site immediately adjacent to the western shore of North Monomoy. While not providing the advantages of a separate islet, such a deposit would increase the bird nesting area and could be could be designed to be compatible in form with the existing wave-dominated shoreline.

## 8. FUTURE RESEARCH

*Coastal Change Monitoring*. Historical data discussed in this report confirm earlier suggestions that evolution of the Monomoy barrier system is closely linked to that of the Nauset Beach barrier system. Since the formation in 1987 of a new tidal inlet (now known as "South Inlet") opposite Chatham Light, the Town of Chatham has been recording annual changes in Nauset Beach using high-resolution vertical aerial photography. It would be prudent for the Sanctuary to partner with Chatham in this effort, thereby by extending the annual coverage to include all of Monomoy. Interpretation of the resulting time series of photographic images would provide invaluable guidance for Sanctuary management decision-making.

*Bathymetric Analysis*. The historical bathymetric data depicted on the H-sheets of the U.S. Coast Survey and its successor agencies can be an important source of information for assessing large-scale and long term coastal change in response to natural processes and human activity. When used appropriately, comparisons of H-sheets prepared at different points in time can yield important insights into changes in regional sediment transport systems, estimates of