Potential Impacts of Sea-Level Rise in Massachusetts

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INTRODUCTION

The contrasting features of the Massachusetts coast are often depicted in vacation brochures and photographs: the north shore with its rocky coasts and isolated barrier beaches, the south shore boasting sandy beaches and offshore shoals such as Georges Bank and Nantucket Shoals, and Cape Cod and the islands of Martha's Vineyard and Nantucket offering a combination of sea cliffs, sandy beaches, and barrier beaches.

These coastal features result, primarily, from submergence produced by Holocene relative sea-level rise, and secondarily, from wind-generated waves and tides that erode, transport and deposit coastal sediment.

The way the New England coast responded to the encroaching Holocene sea was dependent upon the postglacial characteristics left by the Pleistocene glaciation: While some parts of the northern Massachusetts coast had been stripped of sediment, the retreating glacier left isolated deposits of till—frequently with drumlins—or hummocky, stratified glacial drift in other areas. Submergence of the northern Massachusetts coast produced drowned bays with drumlin islands, flooded valleys with salt marshes, rocky headlands, and isolated barrier beaches.

Much of the southern Massachusetts coast had been overlain with thick glacial deposits in the form of outwash plains and moraines. Typically, this terrain had low slopes and consisted of easily erodable, unconsolidated sediment. The advancing seas submerged vast portions of it, producing large, offshore shoal areas such as George's Bank and Nantucket Shoals. Steeper regions, such as the eastern coast of Cape Cod, were eroded by a combination of wave action and sea-level rise to produce coastal sea cliffs with broad offshore wave-cut platforms. Sediment that eroded from these shores produced sandy beaches fronting the sea cliffs and barrier beaches downdrift from them. Behind the barrier beaches extensive salt marshes developed in the protected lagoons and bays.

PRESENT IMPACTS OF SEA LEVEL RISE

Today, relative sea level is rising in Massachusetts, as it has been for thousands of years. An overall value of 3 mm/yr (0.01 ft/yr) is frequently used as an estimate of the "present" relative sea-level rise rate throughout the state. As in the past, the primary result of this rise is submergence of the coastal upland. Of course, the rate of upland submergence depends upon regional topography and, in general, is considerably higher along the outwash plains of the south than along the rocky shores of the north. Giese, Aubrey, and Zeeb (1986) have calculated upland loss due to submergence for each of the 72 coastal towns of Massachusetts and found that the state as a whole loses an average of 26.5 hectares (65 acres) of upland each year due to this process. Half of this total is lost by only 10 towns, all but one of which are along the south coast. It is likely that a large percentage of this submerged upland is converted to fringing marshland. Such areas of new marsh development along the inner marsh margin tend to offset losses due to erosion at the outer marsh boundary and to overwash deposition at the marsh/barrier beach boundary.

Relative sea-level rise in Massachusetts also contributes to upland loss through active coastal erosion of Pleistocene glacial deposits along exposed sea cliffs. These losses are particularly large along the open-sea facing cliffs of outer Cape Cod, Martha's Vineyard and Nantucket, where the long-term cliff retreat is frequently on the order of 1 m/yr and in some locations exceeds that rate. Despite the dramatic appearance of wave-eroded cliffs throughout Massachusetts, upland loss due to active erosion is considerably less than that due to passive submergence. As an example, it has been estimated that of the total of approximately 13.3 hectares (33 acres) of upland lost each year on Cape Cod, 9.7 hectares, or 73 percent, is the result of passive submergence, and only 3.6 hectares (27 percent) results from active erosion.

Wave erosion of upland material is the only significant source of sediment for the beaches and

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barrier beaches of Massachusetts. As has been widely reported for this area and many other parts of the world, Massachusetts' barrier beaches maintain themselves in the face of rising relative sea level by "rolling-over" themselves, i.e., by migrating landward through a combination of dune movement, storm wave overwash and tidal inlet deposition. Present barrier beach migration rates vary from very little to as much as several meters per year (in long-term average) at some locations such as along sections of Cape Cod's Nauset Beach system.

POTENTIAL IMPACTS OF SEA LEVEL RISE

How will the Massachusetts coast respond to different rates of relative sea-level rise in the future? In particular, how would the coast respond to increasing sea-level rise rates?

To answer these questions, it is important to understand that relative sea-level rise has two components: one due to global, or "eustatic," sea-level rise, and the other due to local crustal subsidence. Considering the present relative sea-level rise rate in Massachusetts of approximately 3 mm/yr, we will assume that half of that rate, or 1.5 mm/yr, is the result of eustatic sea-level rise, and that the other half results from crustal subsidence. Global climate changes, of course, affect only the eustatic component. Therefore, in order to achieve a doubling of the relative sea-level rise rate from 3 mm/yr to 6 mm/yr, eustatic sea level must triple (increasing 1.5 mm/yr to 3.5 mm/yr). Hence the ratio of future rates of submergence to present rates would approximately equal the ratio of future relative sea level rise rates to present relative sea-level rise rates.

In the case of unconsolidated cliff retreat (active erosion) and barrier beach retreat, we assume a similar linear increase in retreat rate with respect to increases in relative sea level rise depending on sediment dynamics.

Total salt marsh area probably would not be significantly reduced by increased relative sea-level rise. New marsh would form at the marsh/upland boundary, even as existing areas would be lost at the outer margins of the marshes. This assumes that new marsh growth would be able to keep pace with sea-level rise because, in Massachusetts, marsh development depends primarily on sediment supply. This is an area of much uncertainty and it is the subject of intensive research at the present time.

The projections presented above have not taken into account the critical factor of societal responses to future sea-level rise. While we do not know what those responses will be, present practices in Massachusetts give cause for concern. The state's coastal wetlands regulations make it possible for coastal property owners—especially those whose homes predate the 1978 enactment of the regulations—to construct sea walls on actively eroding cliffs. In addition, there are presently no regulations prohibiting barriers to the encroachment of fringing salt marsh on low-lying inner upland slopes.

The long-term cumulate impact of these practices, together with the impacts of existing jetties and groins in reducing the alongshore movement of sediment, could be devastating for the Massachusetts coast. By preventing cliff erosion, sea walls reduce the supply of sediment to beaches. This leads to the reduction of alongshore movement of beach sand. Jetties and groins similarly "starve" beaches downdrift of them: These structures disrupt the stability of beaches and barrier beaches by decreasing the sediment supply. They also destabilize the shore by preventing it from adjusting its form to long-term changes of wave exposure. Finally, marsh development is threatened by these structures since new marsh areas are produced by coastal submergence. New marsh area tends to balance areas lost at outer marsh boundaries. Interference with their development would be expected to lead to overall long-term salt marsh loss.

SUMMARY/CONCLUSIONS

Along the Massachusetts coast:

1. Relative sea level has risen, is rising, and probably will continue to rise.
2. As a result, coastal upland has been, is being, and probably will continue to be submerged.
3. At the present rate of relative sea-level rise (c. 3 mm/yr), about 26.5 hectares (65 acres) of upland are lost each year due to submergence.
4. Geographically, the rate of upland submergence depends upon local topography, and therefore upon local geological history.
5. Ten towns account for 50% of annual upland submergence. Nine of the 10 are on southeastern outwash plains.
6. Much of the submerged upland is converted to upland-fringing salt marsh.
7. This new marsh serves to offset seaward salt marsh losses due to erosion and barrier beach roll-over.

8. Along exposed sandy coasts, storm waves erode upland. On Cape Cod, about 1/4 of total upland loss is due to active erosion, 3/4 to passive submergence.
9. Upland erosion provides sand for beaches and barrier beaches which, in turn, moderate the erosion process and provide storm and flood protection for associated upland.
10. Coastal engineering structures designed to control shore submergence and erosion at specific sites are having a detrimental effect on the shoreline as a whole.
11. As a result of such efforts to reduce the impacts of relative sea-level rise, Massachusetts is now experiencing:
    a. Loss of salt marsh due to engineering structures designed to control upland submergence, and
    b. Loss of beaches and barrier beaches due to engineering structures designed to control upland erosion or alongshore sediment transport. It is likely that these adverse impacts will continue to occur in the future, perhaps at an increased rate.

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