8 — Coastal Zone and Ocean

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Introduction

Massachusetts' coastline and ocean are tremendous resources that have shaped the state's economy, history, and way of life. Today, unfortunately, these resources are threatened by a host of issues, including erosion of public beaches, costly storm damage of homes and businesses, habitat loss, pollution of waterways from land runoff, and the spread of invasive species. While work is underway to address these challenges, the focus is often based on a historic view of coastal and ocean environments. Climate change—with its resulting acceleration of sea level rise, potential increased frequency and intensity of storms, and shifts in ocean temperature, currents and chemistry—is altering these already dynamic environments, exacerbating coastal management challenges.

Through efforts in coastal hazards management, ocean planning, habitat restoration, fisheries assessment and management, and land protection, Massachusetts has taken many important steps and is poised to become a national leader in coastal climate change adaptation. To reduce and mitigate severe climate change threats to public safety, local and regional economies, marine and terrestrial habitats, and public and private infrastructure, a new focus is needed.

This chapter provides a general overview of the climate change vulnerabilities within the coastal zone and ocean "sector" in Massachusetts. It then focuses on three categories: (1) residential and commercial development, ports, and infrastructure; (2) coastal engineering for shoreline stabilization and flood protection, and; (3) coastal, estuarine, and marine habitats, resources, and ecosystem services. For each of these three categories, the chapter summarizes the existing resources and climate change adaptation efforts currently underway; discusses the vulnerabilities of these resources to climate change; and offers potential strategies for reducing risk and vulnerability and improving resilience to the evolving impacts of a changing climate.


AP Photo/Michael Dwyer

Overview of Vulnerabilities

Unaddressed, climate change will result in significant impacts to Massachusetts' coast and ocean waters. On the coast, modest changes in temperature can have major impacts on sensitive ecosystems, threatening biodiversity and ecosystem-based economies, such as fisheries, tourism, and recreation. Sea level rise will exacerbate impacts to development, infrastructure, and natural systems from erosion and storm damage. Impacts could include loss of life; extensive property damage; destruction of public infrastructure; release of sewage, oil, debris, and other contaminants; and loss of commercial and marine-related businesses critical to local, regional, and state economies.

Coastal salt marshes, barrier beaches, and floodplains are particularly vulnerable to rising sea levels because they are generally within a few feet of existing sea elevations. These areas also provide extensive recreational opportunities and significant environmental services, including providing habitat for many species, playing a key role in nutrient uptake, and protecting inland areas from flooding. In the ocean, temperature changes can influence ocean current strength, stratification of the water column, temperature and salinity levels, and nutrient and mineral transport—affecting the ecosystems and economically important species that depend on them. In addition, increased marine acidity levels will impact shell formation for certain species. The overall result of these changes for ecosystem and fisheries health will be significant.

Adaptation Strategies

Today, Massachusetts is already facing and endeavoring to manage the impacts of sea level rise, including increased erosion and storm damage. The resiliency of Massachusetts coastal and ocean ecosystems and economies—that is, their ability to accommodate impacts from both existing natural hazards and future climate change—requires planning, collaboration, and action. With the many economic and environmental issues facing the state, addressing the additional challenges posed by climate change can seem a daunting, complicated, and expensive endeavor. However, by incorporating climate change projections into existing strategic, management, and fiscal plans, resiliency can improve. The result will be forward-thinking climate change strategies that could be built into land use plans, financial budgets and capital investments, regulatory processes, and similar implementation mechanisms. The following section contains possible strategies aimed at improving resiliency of Massachusetts' coasts and oceans. To more effectively convey a wide range of issues and suggestions, recommendations are organized under three categories within the Coastal Zone and Ocean sector. Strategies with similar elements have been consolidated.

Residential and Commercial Development, Ports, and Infrastructure

The coastal zone is densely developed with homes, businesses, roadways, docks, ports, and other infrastructure and facilities critical to local, regional, and state economies, but also highly vulnerable to storm damage and other impacts of climate change such as sea level rise. The built environment in the coastal zone, which constantly changes due to new development and redevelopment, presents a significant challenge for climate change adaptation.

Existing Resources

Massachusetts' coastal cities and towns are home to one third of the State's population and its coastal counties have more than three-quarters of the state's population. According to a U. S. Census Bureau estimate in 2007, coastal cities and towns with significant populations (>45,000 people) include Boston, New Bedford, Quincy, Fall River, Lynn, Revere, Plymouth, Weymouth, Peabody, and Barnstable. Within these and other coastal communities are an extensive number of residences, businesses, shopping centers and malls, industrial operations and the critical public and private infrastructure that supports this development.

A significant economic sector is coastal and marine tourism and recreation—which includes recreational fishing and boating—with an annual output of $8.7 billion in 2004. Another important sector to the marine economy is the commercial seafood sector—comprised of fishing and fishing supplies, marine aquaculture, seafood processing and wholesaling, and retail and food service seafood sales—whose value in 2004 was $1.6 billion (Donahue Institute, 2006).

Massachusetts Coastal Economy

The total output of the Massachusetts coastal economy is approximately $117 billion, or 37 percent of annual gross state product. The coastal zone economy directly employs over 1 million people, representing close to 37 percent of employment in the state.

Many resources already exist to reduce risks to development in the coastal zone. Massachusetts has statutory and regulatory programs that govern the siting and design of new construction and redevelopment, including the Massachusetts Environmental Policy Act (MEPA), The Public Waterfront Act (MGL chapter 91) and the Wetlands Protection Act. Environmental variation driven by a changing climate may necessitate modifications to these policy tools. Certain Massachusetts General Laws (e.g., Zoning Enabling Act, Wetlands Protection Act, Subdivision Control Law, and the Septic System Regulation-Title V) grant powers to municipalities to guide siting and design for growth. Local officials rely on Flood Insurance Rate Maps, the state Smart Growth/Smart Energy Toolkit, and funding via the Community Preservation Act to help guide siting and development.

Vulnerabilities

Development in the coastal zone is highly vulnerable to current and future impacts of climate change. Without adaptation, one can expect more extensive damage and loss of development associated with infrastructure and critical facilities due to severe erosion of coastal shorelines, overwash and

The Cost of Coastal Storms

The Massachusetts Hazard Mitigation Plan (2007) illustrates two significant coastal storms that hit Massachusetts in 1991, Hurricane Bob and the October nor'easter. These two events caused $49 million in damages to uninsured property and infrastructure (e.g., roads, bridges, public facilities, and public utilities). An additional $125 million was paid out by the National Flood Insurance Program (NFIP) in flood insurance claims. The following year saw another coastal storm that caused more than $12.6 million in damages to public infrastructure and 1,874 NFIP claims at a cost of nearly $12.7 million.

breeching of barrier beaches, inundation of coastal floodplains from sea level rise, increased storm surge, and flooding. Coastal communities that have been densely developed for decades already experience frequent and expensive flood damages. From 1978 to 2009, Scituate property owners received more than $49.6 million in National Flood Insurance Program (NFIP) claims. Scituate ranks number one in terms of flood damages and accounts for 17.6 percent of NFIP payments to policyholders in Massachusetts. The town of Scituate and other communities, including the city of Quincy, are actively working to help property owners elevate utilities and entire homes to reduce flood damages (Massachusetts Office of Coastal Zone Management, 2009). Other vulnerabilities include:

- Widespread damage of public and private development with limited or no relocation options;
- Impassable roadways and constrained access for emergency vehicles and personnel resulting in significant risk to public safety; and
- Inoperable wastewater and stormwater systems and associated public health concerns.

The funding and other incentives outlined in the previous section, while effective for short-term planning purposes, may not adequately consider longer-term of sea level rise or an increase in the intensity and frequency of storm events. Recent revisions to the State Building Code (780 CMR 120.G) strengthened existing standards for construction in floodplains and coastal dunes. Since many designs still do not address future inundation or migration of resource areas such as wetlands, however, new construction and redevelopment are likely occurring in areas that will erode and flood within the lifespan of these projects.

Potential Strategies

Adaptation strategies are necessary to reduce risk along Massachusetts' highly populated coast. An important and highly effective way to minimize threats to human health and safety, damage to public and private property, and preventable expenditure of scarce resources is to site new development and major redevelopment away from current and future vulnerable areas, including floodplains, zones subject to storm surges and wind-driven waves, and areas with high erosion rates. Additionally, by planning development to account for the future migration of important resource areas such as salt marshes, dunes, and areas subject to storm flow, the ability of natural systems to respond to changing conditions can be maintained. A proposed project located in an area that might be considered buildable today, may be undevelopable after weighing the projected costs against projected risk, factors such as increased sea level and flood frequency.

Climate change will result in greater storm damages to existing development and an increase in recurring storm damage to individual properties (referred to as "repetitive losses"). Difficult choices face Massachusetts regarding options for protecting the built environment and their potential conflict with existing property rights. Now is the time to start a public dialogue about the benefits, costs, risks, and resources needed to make informed decisions about where to target major investments to protect existing development. The analysis and assessment of risk management needs to be done at several scales and within different socioeconomic contexts, including state, regional, and local levels. In urban areas with large populations—especially those that are environmental justice communities—implementation of highly engineered structural protection measures will likely be a high priority for extensive public infrastructure and private development. Other areas may be able to reduce risk through approaches involving less engineered

Coastal Zone Management's StormSmart Coasts

Like other New England states with "home rule" government, many land-use decisions in Massachusetts are made at the local level. For coastal communities, this means grappling with the impacts and effects of erosion, storm surge, and flooding problems, which are being exacerbated and accelerated by global climate change. To help communities address these challenges, the Massachusetts Office of Coastal Zone Management (CZM) launched its StormSmart Coasts program in 2008. CZM developed user-friendly tools such as fact sheets, case studies, smart growth planning strategies, legal and regulatory tools, and extensive technical materials. CZM also held a series of regional workshops to connect local officials directly with the program.

Then, in 2009, CZM began five StormSmart Coasts pilot projects with seven communities—Boston, Falmouth, Hull, Oak Bluffs, and the three-town team of Duxbury, Kingston, and Plymouth—to test drive local, proactive implementation of StormSmart Coasts tools. The results are successful, transferable coast-wide models and enhanced partnerships with regional, state, and federal agencies; conservation organizations; academia; and the private sector to better serve coastal communities in Massachusetts. For more information, see the StormSmart Coasts website (www.mass.gov/czm/stormsmart).

structural measures, such as Low Impact Development, or some combination thereof.

1. Analyze strategies for siting new development and redevelopment outside of projected vulnerable and future resource areas. Design new development and redevelopment projects according to risk projected over the project lifespan. This may be achieved by the following means:
   a. Continue to discourage and avoid siting in current and future vulnerable areas, such as floodplains, velocity zones, and areas with high erosion rates. Additionally, by planning development to account for the future locations of important resource areas such as salt marshes, dunes, and areas subject to storm flowage, the ability of natural systems to respond to changing conditions can be protected;
   b. Consider building on Executive Orders 149 and 181 (intended to reduce vulnerability and damage costs in floodplains and on barrier beaches); explore issuing an Executive Order that specifically directs state development and significant redevelopment, as well as state-funded projects, out of vulnerable coastal areas;
   c. Strengthen the alternatives analysis for

Figure 10: ***Projected Inundation at High Tide, East Boston—2100***
Shading indicates current areas of East Boston, Massachusetts, inundated at high tide in the year 2100 under low and high sea level rise (SLR) scenarios. The future elevation of high tide is based on the current elevation of Mean Higher High Water (MHHW) plus projected SLR. The low SLR scenario at 2 m (A) includes both regional SLR due to land subsidence and the low end of the range of eustatic (global) SLR projected by Rahmstorf (2007). The high SLR scenario at 3 m (B) includes both subsidence and the high end of the range of eustatic SLR projected by Rahmstorf (2007). On the right, the top inset shows areas near Constitution Beach and the bottom inset shows areas near Central Square, under the high scenario. Highest confidence in the delineation of the elevation exists for blue-shaded areas. Areas shaded with red and orange contain minor uncertainty (5%) due to the vertical resolution of the topography
Source: Map developed by Chris Watson and Ellen Douglas, UMass-Boston; Paul Kirshen, Battelle

development siting and design standards to identify, characterize, and avoid project risk and adverse effects associated with climate change impacts;

d. Develop Chapter 91 policy guidance to fully implement 310 CMR 9.37(2)(b)(2), which states "[In the case of a project within a flood zone]…new buildings for non-water-dependent use intended for human occupancy shall be designed and constructed to…incorporate projected sea level rise during the design life of buildings", in a manner consistent with predicted sea level rise stated in this report. Consider a change to the regulation to include all new development and any redevelopment considered significantly vulnerable;

e. Examine Wetlands Protection Act rules and/or policies for potential revisions that address predicted changes in spatial extent of coastal wetlands;

f. Promote the nationally recognized "No Adverse Impact" approach—advanced by the Association of State Floodplain Managers (2007) and underlying the Massachusetts Office of Coastal Zone Management's StormSmart Coasts program—that calls for the design and construction of projects to have no adverse or cumulative impacts on surrounding properties;

g. Consider expanding recent revisions to the State Building Code, with provisions that strengthen requirements for storm-resistant building designs, materials, and features;

h. Update coastal erosion and flood-hazard zones delineations, especially in areas that experience high velocity floodwaters and breaking waves, so that they incorporate projected rather than historic rates of sea level rise; and

i. Consider whether a rise in water table levels warrants changes to the Massachusetts Septic System regulations (known as Title V) to provide for additional protective separation distances for septic systems.

2. Decrease risk and repetitive losses to existing development by implementing the following strategies:

a. Consider additional revisions to the State Building Code to expand the requirement for elevating new and substantially improved buildings above the base flood elevation in hazard areas beyond the "V" zone (velocity flood zone with wave heights >3 feet) in order to accommodate sea level rise. Examine expansion of this standard to Federal Emergency Management Agency designated "A" zones (wave heights <3 feet) in coastal areas.

b. Consider incentives such as insurance cost reduction and hazard mitigation grants for communities that embrace climate change adaptation measures.

c. Seek to reduce the number of vulnerable coastal properties through land acquisition from willing sellers in fee, or by conservation restrictions. Evaluate the use of Transfer of Development Rights, a smart growth technique that is currently in use, to direct coastal redevelopment inland. A potential scenario may include several components for further consideration such as:

i. to promote the transfer, existing homeowners who agree to sell their rights and abandon a storm-damaged property could receive state and local tax breaks for rebuilding in an upland area, or could purchase municipally owned land appropriate for development at a below-market rate;

ii. additional funding could be realized by encouraging coastal communities to adopt the Community Preservation Act and use the Community Preservation Fund for acquisition of properties at risk of storm events and sea level rise (high risk for development) that also have preservation or recreation value; and

iii. pool resources of the state and other partners, such as non-profit land trusts, to acquire land and conservation restrictions in perpetuity within vulnerable coastal areas.

Freeboard is the height of watertight surface between a body of water and the lowest point of entry. The expense of incorporating increased freeboard into new structures is low, generally adding only about 0.25 to 1.5 percent to the total construction costs for each foot of added height.

d. Consider a statewide rolling easements policy for existing development along the shoreline. These rolling easements are typically coupled with policies that prevent armoring of the coast. Similarly, require that reconstruction of buildings significantly damaged by storm events comply with new standards and delineations of erosion and flood-hazard zones.

e. Evaluate and update hazard mitigation, evacuation, and emergency response plans to address the changing conditions associated with new development and climate change, especially related to sea level rise and increased storm intensity and frequency. Make updates to these plans as refinements are made to climate change projections and development patterns change within a community, or at a minimum of every five years.

Hull Freeboard Incentive

The Town of Hull offers a freeboard incentive to protect the health and safety of its citizens, prevent property damage, and reduce the need for costly emergency services during storm events. For residential and commercial building elevation, or new construction projects, building department permit fees will be reduced by $500 (or by the cost of the permit, if lower than $500) if an elevation certificate is provided to verify the building is elevated a minimum of two feet above the highest federal or state requirement for the flood zone. If the base-flood elevation on the FEMA November 2008 draft map is higher than the current map, eligibility for the permit fee reduction will be based on the draft map.

Coastal Engineering for Shoreline Stabilization and Flood Protection

Public and private coastal engineering structures are designed to protect buildings, infrastructure, and other uses in the coastal zone by controlling shifts in shoreline positions and blocking floodwaters. Engineered beaches and dunes that introduce sediment into starved beach systems are also considered in this section. Future permitting of coastal engineering projects could include consideration of local and regional processes and conditions to better eliminate or reduce impacts from erosion, flooding, and long-term inundation.

Existing Resources

A variety of structures exists along the coast of Massachusetts to stabilize the shoreline and protect buildings and infrastructure from erosion and flooding. Coastal structures include bulkheads, seawalls, revetments, groins, jetties, and breakwaters, as well as hurricane barriers, and flood and tide gates. The State conducted a comprehensive inventory of publicly owned or managed coastal structures along the shoreline (Massachusetts Coastal Hazards Commission, 2007). Visual inspections by civil engineers resulted in the rating of bulkheads, seawalls, revetments, groins, jetties, and breakwaters according to their condition using a letter system, from excellent (A) to critical (F). Structures with critical levels of deterioration exhibit conditions such as section loss, cracking and undermining. These structures provide little or no protection from major coastal storms and require complete reconstruction to regain functionality. Each structure was also assigned a priority rating based on its condition and ability to protect buildings from erosion and flooding. Structures with a high priority rating may warrant emergency stabilization due to the presence of high-density residential dwellings or other critical structures and the potential for loss of life or property. The inventory provides critical information required to better manage these structures. Similar assessments will need to be conducted for coastal structures that are in private ownership.

Vulnerabilities

Impacts of climate change will affect the ability of coastal structures to resist major storm events and prevent damage due to erosion and flooding. Structures placed along the shoreline, largely in the 1940s and 1950s and prior to enactment of coastal management policies and regulations, have interrupted the natural process of sediment transfer. Many of these structures, which were not designed for projected future conditions, remain standing landward of narrow beaches and other sediment starved resource areas. Potential overtopping, undermining, and collapse of coastal structures by storm surge combined with higher sea levels are serious concerns. Because of limited functionality and these potential impacts, residential and commercial development, ports, and infrastructure will likely be more vulnerable in the future. Maintenance and future plans for coastal structures challenge the state, municipalities, and residents of the coastal zone and require new strategies.

Coastal shorelines shift continuously in response to a variety of factors. Wind, waves, tides, seasonal variations, human alterations, and sea level rise influence the movement of sand and gravel within shoreline systems. Developed coastlines that face east or northeast are particularly vulnerable to nor’easters, which are common winter storms in Massachusetts. These coastlines are typically dominated by erosion and flooding. Erosion rates often increase as a result of coastal structures such as seawalls and revetments, which cut off the supply of sediment to adjacent beaches and decrease their widths and volumes. Barrier islands in Massachusetts actively erode because of decreased sediment supply as well as inlet dynamics, changes in nearshore shoaling patterns, location and size of coastal structures, and other human alterations. Climate change will exacerbate these issues—higher sea levels and future storm events will result in greater erosion and flooding impacts over time.

Potential Strategies

The assessment of vulnerable coastal areas will require a better understanding of sediment resources and transport. By incorporating current shoreline change rates and trends as well as additional wave run-up analyses, the delineation of flood and erosion -hazard areas can be strengthened. The armoring of the coast has interrupted natural processes that build and maintain beaches, and has contributed to sand deficits that exist on many Massachusetts' beaches today. There are limits to the effectiveness and availability of beach nourishment and there are difficult decisions to make regarding holding the line or retreating. Protection of individual properties will need to be balanced against other local concerns such as effects to abutting properties, safety of emergency responders, and community resource values. In some cases, large-scale approaches may be considered to preserve uses (such as water-dependent and marine industrial) that cannot be relocated or protected using traditional structures. Overall, it is important to evaluate the application, design, and placement of coastal engineering approaches. Strategies for consideration include:

1. Institute policies and regulations to improve assessment of local erosion and flooding, and evaluate design and placement of engineered approaches to manage these coastal hazards. New or revised state policies and regulations that address coastal erosion and flooding, particularly related to coastal engineering practices, would improve assessment and management of these hazards.
   a. Strengthen the delineation of erosion and flood-hazard areas by incorporating current rates and trends of shoreline change as well as additional analyses of the maximum vertical extent of wave run-up on beaches or structures. With additional resources, state agencies could acquire and update this information every five to ten years for effective management of risk, especially in a changing climate.
   b. Continue to advance use of soft engineering approaches that supply sediment to resource areas such as beaches and dunes in order to manage the risk to existing coastal development. Periodic nourishment with sand is essential to maintaining dry recreational beaches along many developed coasts.
   c. Adhering to provisions of the Massachusetts Ocean Management Plan, examine issuing a state policy regarding the mining of sediment from the seafloor to guide the use of sand and gravel resources from Massachusetts' tidelands, especially for nourishment of private beaches.
   d. Consider prioritizing placement of sediment on public beaches over offshore disposal. Management of sediment resources is a necessary component of the overall resiliency approach that will allow competing interests to adapt and coexist in the dynamic coastal zone.
   e. Conduct an alternatives analysis when replacing failing public structures that pose an imminent danger, and ensure review of the analysis by local and state environmental agencies. Assessment of the analysis should consider cumulative impacts and the No Adverse Impact approach.
2. Plans to replace or construct new coastal engineered structures could better incorporate local conditions and higher sea levels. Analyses of benefits and costs may support large-scale engineered, structural protection of areas that are highly-developed urban centers or have significant water-dependent and marine industry that cannot be relocated.

Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services

Massachusetts coastal, estuarine, and marine habitats—such as beaches, salt marshes, and bays—provide valuable environmental, social, and economic benefits. Such benefits or "ecosystem services" are the wide range of conditions and processes through which natural systems help sustain and fulfill human life (Daily et al., 1997). These include maintenance of habitat for fish and shellfish, storm surge and flood protection, nutrient cycling and pollution prevention, atmospheric and climate regulation, renewable energy sources (wind, waves, and tides), and recreational opportunities.

While it is impossible to put an accurate dollar figure on the value of coastal and ocean systems, targeted economic analyses point to the tremendous value of this sector. For example, the National Marine

RESOURCE	AREA (ACRES)
Coastal bank	2,112
Barrier beach	11,840
Coastal beach	5,376
Coastal dunes	11,712
Rocky intertidal shore	1,024
Tidal flat	18,944
Salt marsh	45,376
Submerged aquatic vegetation	19,392

Table 7. ***Extent of coastal and estuarine habitats in MA***

Fisheries Service indicates that 32 percent of the commercial fish and shellfish collected in New England are directly dependent on estuaries and salt marshes (Stedman and Hanson, 1997). For New Bedford and Gloucester alone, value of the commercial fish and shellfish caught in 2010 was more than $346 million (MA DMF, 2011). In addition, the U.S. Army Corps of Engineers concluded that the flood control benefits of wetlands in the Charles River basin alone were estimated to be nearly $40 million per year in 2003 dollars (Schuyt and Brander, 2004).

Existing Resources

Massachusetts has over 4669 km. (2,900 miles) of varied coastline and over 5180 km^2 (2,000 $miles^2$) of estuarine and marine waters that include a vast array of habitats, flora, and fauna. Using digital wetland resource maps developed by the Department of Environmental Protection's Wetland Conservancy Program and distributed by MassGIS, an inventory of these resources was obtained, as shown in Table 7.

The State also has abundant bays, sounds, and other ocean habitats with various geologic settings, bottom types, depths, tide and current regimes, and biological interdependencies. For a comprehensive overview of the marine habitats in state waters, see the Baseline Assessment of the Massachusetts Ocean Management Plan (Massachusetts Executive Office of Energy and Environmental Affairs, 2009), which contains synopses of primary and secondary producers, benthic communities, fisheries resources, avifauna, marine mammals, and invasive species. Table 8 , taken from the plan's Baseline Assessment, lists some habitat features and their biological links.

Existing state regulatory programs have strong provisions to avoid, minimize, and—if necessary—mitigate the current, but not future, adverse effects of anthropogenic stressors. Recent advancements in protection include updates to the Massachusetts Wetlands Protection Act regulations and the state's Title V Sanitary Code, development of nitrogen loading standards through the Massachusetts Estuaries Project, and siting and performance standards that protect sensitive and unique habitats in the Massachusetts Ocean Management Plan (Massachusetts Executive Office of Energy and Environmental Affairs, 2009). State funding programs, including Coastal Pollution Remediation, Section 319 Nonpoint Source Pollution Competitive Grants, and the State Revolving Fund, provide significant state resources that leverage local funds to implement specific capital projects to address pollution from wastewater, stormwater, and nonpoint source runoff.

Vulnerabilities

Changes in air and sea temperature, precipitation, ocean circulation and flow dynamics, sea level, and storm patterns will have cascading effects on coastal, estuarine, and marine habitats and resources—affecting the ecosystem services they provide. The list below summarizes significant vulnerabilities that could have cascading effects throughout ocean and coastal habitats:

- increases in stratification (the separation in the water column into distinct layers by salinity and/ or temperature);
- changes in nutrient availability, and shifts in primary and secondary production due to changes in temperatures, precipitation, fresh water inputs, and currents/circulation;
- changes in, and potential loss of, suitable habitat and critical life-stage support for ecologically important marine and estuarine species;
- shifts in location and productivity of important marine and estuarine species, with a potential decrease and loss of significant commercial and recreational fisheries due to shifts in suitable habitat;
- loss of commercial fishing and aquaculture revenue due to shellfish impacts from reduced shell formation and reproduction and growth rates, and increased shellfish diseases, pathogens, and harmful algal blooms;
- loss of inter-tidal estuarine marsh habitat caused

Habitat Features	Characteristics
Non-living Structures (Cobble/rocky/boulder/ledge bottom [not shell] often called "rock piles")	Many species use these bottoms due to their 3-dimensional structures, which provide shelter. Some species' life histories require this type of habitat (e.g., juvenile cod and lobster)
Living Structures (Submerged Aquatic Vegetation, kelp, and structure-forming invertebrates)	Many species use these types of bottom due to their three-dimensional structure, which provide shelter. Some species' life histories require this type of habitat.
Areas of Upwelling	Important to driving productivity by bringing in nutrients; may not be a major feature in Massachusetts but could be important on a local scale
Deeper waters (channels, depressions)	Protected from the direct effects of storm-induced waves and warming waters
Estuaries, river mouths	Turbidity front at freshwater-saltwater interface can influence productivity.
Shell habitat	Settling habitat for invertebrates, may provide shelter
Shallow waters (<5 feet/1.5 meters) Mud flats, Salt marshes	Critical nursery areas; mud flats are of high value to marine animals that live and feed in this substrate
Frontal boundaries	Represent important "edge" habitat for a wide variety of resident and migratory pelagic species
Tide rips	Smaller frontal boundary features; sport fishing species; variety of species utilize these features and are popular fishing spots
Mud bottom	Has potential to provide abundant forage; lower resiliency to recurrent impacts in cold/deep mud bottom

Table 8. ***Marine habitat features and some important characteristics***

by an inability of marsh accretion and soil formation to keep pace with rapid sea level rise, further compounded by limitation of opportunities for landward migration;

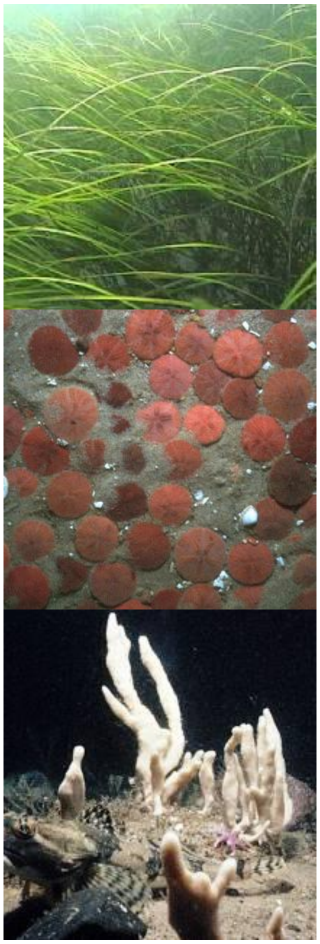
- degradation and loss of freshwater drinking water supplies through increased saltwater intrusion into groundwater aquifers;
- increase in adverse human health effects and degraded estuarine water quality due to increases in polluted run-off and combined sewer overflow events; and
- shell thinning due to increased ocean acidity in organisms with calcium carbonate shells (e.g., snails, clams, mussels, crabs, and lobsters), impacting both the ecosystem and economy.

Potential Strategies

The protection of land from future development through direct acquisition or conservation restrictions is one of the most straightforward and effective tools for climate change resiliency. To maximize the climate resiliency benefits from land conservation efforts by state agencies, evaluation and prioritization criteria for potential acquisition or restriction could include factors that examine the predicted future changes to the project area in terms of landscape, community, and habitat changes.

"Green" infrastructure—where habitat enhancements and natural systems are used instead of hard engineering for storm-damage prevention and other purposes—also promotes resiliency. The green infrastructure concept has strong connections to stormwater management and nonpoint pollution source control, where natural systems (such as vegetated swales, bio-retention cells, and green roofs) perform the water management functions of traditional engineered curbs, gutters, and pipes, but with significant natural benefits and less cost. Habitat enhancement projects that would serve as green infrastructure include: oyster or mussel reefs for storm surge attenuation, constructed wetlands for floodwater control and storm surge attenuation, planted coir fiber sills for erosion control and storm surge protection, and beach or dune nourishment for erosion control and storm surge protection. Shellfish aquaculture also provides ancillary benefits including nutrient (especially nitrogen) reduction when the cultured product is harvested.

As the marine and estuarine waters of the U.S. East Coast increase in temperature in response to global climate change, coldwater species are expected to move farther northward and species whose ranges have historically been farther south of Massachusetts will shift into Massachusetts waters and north of



Cape Cod. Fisheries managers will need the ability, tools, and information to change management measures in response to the redistribution of species. This will need to be accomplished at the interstate level involving the Atlantic States Marine Fisheries Commission, New England and Mid-Atlantic Fisheries Management Councils, and the National Oceanic and Atmospheric Administration. Future productivity of individual stocks may be significantly increased or decreased in response to climate change, habitat, secondary productivity, or ecosystems.

Historic harmful algal blooms, along with emerging data, suggest decadal cycles of occurrence. Climate change has the potential to alter abundance and distribution, disrupting natural, established cycles. At present, models focus on offshore waters. Higher model resolution in the nearshore will aid in the management of highly productive coastal and estuarine shellfish growing areas. As described above, while the general vulnerabilities of the coastal zone and ocean can be identified, the specific impacts and effects of changing estuarine and marine conditions are not well-known at this time.

Effective management requires sufficient and accurate information. Through this recommended strategy, the scope and focus of current monitoring, assessment and modeling efforts could be expanded to ensure that adequate ocean monitoring and observation capabilities exist in Massachusetts. This would provide sustained, high-resolution information at key locations for sea level, storm frequency and magnitude, salinity, pH, temperature, nutrients, biological community structure and size, currents, chlorophyll, and other parameters that will inform management of climate change impacts and trends. Strategies to be considered for implementation include the following:

1. Bolster land conservation efforts and account for changing landscape and natural communities, protect valuable ecological resources, and provide zones for migration:
   a. Protect land from future development through direct acquisition or conservation restrictions.
   b. Include factors that examine the predicted future changes to the project area in terms of landscape, community, and habitat changes in the evaluation and prioritization criteria for potential acquisition or restriction. Also, include tracts/habitat complexes at varying scales and geographic distribution in preservation targets. The ability of prospective areas to accommodate shifting natural communities and features like floodplains and seasonal wetlands will enhance natural resiliency.
   c. Identify the location of future habitats (and resource areas) through the implementation of predictive mapping and modeling, as a necessary step in the protection of these evolving ecosystems.
2. Improve resiliency of natural habitats, communities, and populations to climate change through habitat restoration, green infrastructure, and invasive species management efforts; design projects for future conditions. Healthier natural systems are better able to absorb and rebound from the impacts from weather extremes and climate variability.
   a. Ensure that projects account for future changes in the ecosystem, investments are justified given those predicted changes, and the project is designed and engineered for sea level rise and changes in hydrology.
   b. Promote resiliency through use of habitat enhancements such as constructed wetlands, oyster or mussel reefs (or other types of shellfish aquaculture), and for storm-damage prevention and floodwater control in lieu hard engineering solutions, where feasible.
3. Increase natural resiliency and reduce anthropogenic stressors through directed improvements in estuarine and marine water quality that minimize unavoidable impacts to habitat. This could be achieved via the following methods:
   a. Consider retreating and migrating wetlands, expanding floodplains, rising sea level and water tables, and increased inundation and flooding through program specific criteria, guidance, policies, or performance standards.
   b. Strengthen consideration of cumulative impacts as influenced by climate change at project planning levels, whether through MEPA review or the State Revolving Fund Loan Program Project Intended Use Plans.

Low Impact Development at Caldwell Farm—Building Smarter to Protect Natural Areas

Low Impact Development (LID) projects are designed to maintain natural drainage flow paths, minimize land clearance, and reduce impervious surfaces—all of which reduce stress on habitats and promote natural resiliency. The Caldwell Farm development in Newbury is an excellent example of how the interests of developers, realtors, and local officials can be brought together to create a "low impact development" that benefits all—including the homeowner.

A 66-unit housing project on a 125-acre site, Caldwell Farm was developed by C.P. Berry Construction Company, which incorporated LID techniques and the protection of open space to maintain 100 acres of the site as fields, forest, freshwater, and saltwater wetlands adjacent to the Parker River National Wildlife Refuge and an Area of Critical Environmental Concern (ACEC). LID techniques used in Caldwell Farm were cluster buildings, reduced road pavement width, and natural buffers to resource areas and grass swales for drainage. Caldwell Farms has received several national awards, including "the Best Overall Community" by the National Association of Home Builders in May 2007.

c. Consider use of the No Adverse Impact approach, which calls for the design and completion of projects so that they will not have adverse or cumulative impacts.

d. Consider development of No Net Increase approaches such as the nitrogen cap policy implemented by the Cape Cod Commission, which requires an offset of each increment of additional nitrogen load with some means of nitrogen removal for other nitrogen loads in the watershed.

e. Maximize incentives, training opportunities, and requirements for Low Impact Development natural design and stormwater best management practices in local planning and regulatory processes to enable routine implementation of these proven smart growth tools, improving water quality and stormwater absorption and reducing flooding impacts.

4. Evaluate incorporating flexibility into fisheries management systems to accommodate species shifts. Expand biological surveys into estuaries, which is where climate change effects are anticipated to be especially pronounced. To avoid unnecessary burdens on recreational and commercial fisheries, fisheries managers could consider a move to a management system that incorporates more contemporary estimates of productivity and ecosystem processes, ensuring that targets are realistic and achievable. Ecosystem-based approaches that address cumulative impacts, establish cross-jurisdictional management mechanisms, and incorporate triggers and methods for adjustments based on evolving knowledge and information will provide significant institutional resilience to climate change.

5. Improve shellfish management and aquaculture by incorporating predictions of harmful algal blooms, marine pathogens, and rainfall. Obtain higher model resolution in the nearshore to aid in managing highly productive coastal and estuarine shellfish growing areas.

6. Increase monitoring, observations, and assessments to better manage resources and respond to critical shifts in conditions. Expand the scope and focus of current monitoring, assessment and modeling efforts including:

   a. Use acoustic mapping to provide base information necessary for determining bathymetry and seafloor hardness and roughness.

   b. Develop a better understanding of the spatial and temporal distribution and habitat needs of marine animals and plants.

   c. Track other important biotic components, especially endangered sea turtles, seabirds, major avifauna and bat migratory pathways, benthic communities of flora and fauna, certain pelagic fish, and areas of high trophic support (primary and secondary productivity and forage fish).

   d. Contribute to and support the development and operation of regional and local 'ocean observing system' infrastructure. Support and augment the few existing efforts that routinely collect such data, including the ocean observation system, whose buoys provide a range of information essential for navigation, safety, and oceanographic modeling and forecasting.

   e. Develop models of coastal hydrodynamics and inundation (coupled with biological and chemical models) to support scenario analyses of future conditions and to test hypotheses.

   f. Continue and augment other high priority baseline datasets, such as seafloor and water column temperature and salinity measurements, which can be used to track decadal, annual, and seasonal trends in salinity, temperature, and water column stratification. Improved measurements of waves and chlorophyll are also important for providing baseline information for modeling.

The symbol signifies adaptation strategies that are also climate change mitigation actions.

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