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Coastal Erosion in Cape Cod, Massachusetts: Finding Sustainable Solutions

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ABSTRACT

The Massachusetts Office of Coastal Zone Management (CZM) and the Cape Cod Planning Commission have identified coastal erosion, flooding, and shoreline change as the number one risk affecting the heavily populated 1,068 square kilometers that constitute Cape Cod (CZM, 2013 and Cape Cod Commission 2010). This paper investigates natural and anthropogenic causes for coastal erosion and their relationship with established social and economic systems. Sea level rise, climate change, and other anthropogenic changes increase the rate of coastal erosion. The impacts associated with coastal erosion include habitat loss, property loss, infrastructure damage, and beach loss. These impacts will affect economic, ecological, and social systems in Cape Cod. We explore the relationships between socio-ecological systems in Cape Cod. There are structural and non-structural solutions that will help communities in Cape Cod adapt to challenges posed by coastal erosion. Structural solutions include coastal landscaping, beach nourishment, and soft infrastructure. Non-structural solutions include policy, economic compensation, education, and community involvement. In the future, Cape Cod should search for sustainable solutions to the problems associated with coastal erosion.

Introduction

According to a 2014 report by the Intergovernmental Panel on Climate Change (IPCC), the number one risk resulting from increasing global temperatures driving climate change is coastal storm surges, sea level rise and coastal erosion. Global mean sea levels are expected to rise between .2 and 2.0 meters by the year 2100 (Massachusetts Office of Coastal Zone Management, 2013). While thermal expansion of water and melting ice caps (the main drivers of rising sea levels) are expected to increase in the coming decades, spatial variations in land use history, pollution, and coastal development (i.e. anthropogenic drivers) as well as variations in geologic features, weather, and circulation patterns will contribute to differences in rates of erosion and coastal flooding (IPPC, 2014). The social, economic, and ecological costs (e.g. loss of life, injury, loss of livelihood, and habitat degradation) associated with sea level rise and coastal erosion far outweigh the costs of adapting coastal regions to increasing sea levels.

Global sea level rise has already produced observable impacts. For example, sand dunes, beaches, and barriers have experienced net erosion in places as far apart as the mid-Atlantic to the south Pacific (IPCC, 2014). Additionally, coastal vegetation such as sea grass meadows have declined in the Mediterranean, the Atlantic, and Australia. Along with declines in vegetation, pole-ward migration of coastal vegetation has been observed and is expected to continue in the coming decades as plant communities adapt to changing conditions. Likewise, rising sea levels have caused saltwater intrusion, negatively impacting freshwater aquifers in islands and low-lying regions in the Pacific, Indian, and Atlantic Ocean (IPCC, 2014). In the United States alone, between 2001-2006 almost half of all land use changes have occurred on the coast due at least partly to sea level rise. The majority of available research has focused on the ecological impacts with little attention paid to the social and economic impacts to the approximately 150 million people living within 1 meter of high tide (Grinsted, Moore and Jevrejeva, 2012; Felsenstein and Lichter, 2013). We believe there is a need to examine the relationships between the ecological, economic, and societal systems in order to understand the breadth of the possible impacts of sea level rise and coastal erosion.

In order to examine the complexity of socio-ecological systems, we need to apply a systems approach. Systems analysis is often used in order to understand the inter-relatedness of integrated systems and is a keystone concept in sustainability science. Downing et al. (2014) applied a systems approach in order to understand the feedback loops between fisheries decline in Lake Victoria, East Africa and the social and economic systems that are embedded within the ecosystem. Using a qualitative loop model, Downing et al. (2014) showed conceptually how disturbances in one part of the system affected the other subsystems, which they were able to use to inform management decisions. Mavrommati, Baustian, and Dreelin (2014) used a similar systems analysis to study the inter-relatedness of socio-ecological systems in the Great Lakes region of North America. By looking at the system holistically, they showed how tourism, land use, and other industry impact water use. In this paper, we will apply systems analysis in order to better understand the inter-relatedness of socio-ecological systems in Cape Cod, Massachusetts.

Background

Cape Cod beaches are dynamic ecosystems that are consistently being altered by wave energy and winds. The original Cape Cod shoreline of the late Holocene approximately 3,000-4,000 years ago, was formed by sea level rise and had highly irregular topography and coastlines, a product of their glacial creation (USGS, 2013). The most recent advancement and retreat of the glaciers occurred approximately between 18,000 to 25,000 years ago. The final retreat of the glacier produced moraines, outwash plains, glacial sediments, and drift—the ingredients which make up the Cape Cod we know today, a truly unique landscape containing many critical ecosystems with diverse hydrologic characteristics. These historic glacial deposits are the principal source of beach material: sand and gravel. These original sources have been eliminated over time due the construction of coastal structures (i.e. jetties, groins and revetments) along the shoreline (USGS, 2013).

Oceanic factors affecting shoreline stability and sediment transport are: waves, tides, and currents associated with the respective forcings. The major influence on shoreline change in the Cape is longshore sediment transport which occurs when winds are not perfectly perpendicular to the shoreline, causing waves which are wind generated to run up the beach at an oblique angle. At the maximum of wave run-up, gravity pulls the water downslope creating a parabolic pattern (Berman, 2011). Sediments are then directly transported by oscillatory wave action within the swash zone causing a net movement in a parallel direction. The second component of longshore transport involves the movement of sediment by the currents generated by this wave action. This is how erosion at one shoreline can transport material for beach and dune formation downdrift of the previous position (Berman, 2011). Water serves as the vehicle to transport sediments, and wind provides the energy for movement. The geologic processes of accretion and erosion are natural and vital to beach formation. They are occurring on beaches at any given time supplying and removing sediment to the area parallel to the shoreline. Without these processes there would be no beaches, no dunes, no barrier islands or spits, no sea cliffs as well as fewer saltmarshes, lagoons, bays, and sheltered harbors (Berman, 2011).

Echoing the IPCC's risk assessment findings, the Massachusetts Office of Coastal Zone Management (CZM) and the Cape Cod Planning Commission have identified coastal erosion, flooding, and shoreline change as the number one risk affecting the heavily populated 1068 square km that constitute Cape Cod (CZM, 2013 and Cape Cod Commission, 2010). While erosion and shoreline change are natural processes that have always occurred along the northeast coast, the rates of these processes have increased from a 1.9 m over the last 2,000 years to .3 m in just one year (Cape Cod Commission, 2010). These observed increases are believed to be due to sea level rise and human activities such as the interruption of sediment flow and long-shore sediment transport. Along with coastal development, these drivers have contributed greatly to the loss of salt marshes, beaches, dune systems and floodplains. Besides filtering pollutants, these important habitats create natural buffer systems that help protect shorelines from extreme flooding events (e.g. storm surge) (CZM, 2013 and Cape Cod Commission, 2010).

In 1972 the United States passed the Coastal Zone Management Act (CZMA). The CZMA delineated two programs, the National Coastal Zone Management Program and the National Estuarine Research Reserve, to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone" (NOAA, 2012). In the United States, thirty-four coastal management programs were created to reconcile land and water issues in coastal zones using estuarine reserves as research sites to obtain a deeper understanding of estuarine systems and human impacts. Through the CZMA states are eligible to receive federal funding to implement coastal zone management programs that seek to protect, restore, and or, enhance existing coastal regions while considering, and seeking to limit the risk and incidence of death and the “destruction of property by eliminating development and redevelopment in high-hazard areas, managing development in other hazard areas, and anticipating and managing the effects of potential sea level rise" (NOAA, 2012).

The Massachusetts Office of Coastal Zone Management (CZM), a product of the 1972 Coastal Zone Management Act, seeks to protect the ecological, economic, and social values of “coastal and marine resources.” The CZM is part of a network of state, federal, local, academic, and nonprofit organizations that, in conjunction with the participation of the general public, seek to sustainably manage the coastal regions of Massachusetts (CZM, 2014). Since 2002, CZM has run the Coastal Estuarine Land Conservation Program (CELCP). Established by Congress, the program functions to conserve coastal and estuarine regions that are ecologically, economically, and socially valuable. In 2007, CELP developed a statewide conservation plan to address issues of coastal erosion in an era characterized by the human degradation of ecosystems (CZM, 2014).

Despite the formation of the CZM and the delineation of the statewide CELCP, management of Massachusetts’ coastal regions have proved to be more than difficult with climate change leading to increased rates of shoreline change and coastal erosion due to sea level rise. To compound the challenges of management, the majority of the shoreline, and land in general, in Massachusetts is privately owned limiting the scope of state or federal initiatives to protect coastal regions. In light of this the CZM has created StormSmart Coasts, a program to educate and empower coastal communities “to address the challenges of erosion, flooding, storms, sea level rise, and other climate change impacts” (StormSmart Coasts, 2014). Through this program the CZM finances a Coastal Community Resilience Grant to cities and towns that are involved in action to address the impacts of climate change and sea level rise in their communities, and the Green Infrastructure for Coastal Resilience Pilot Grant Program, which gives financial support to communities that seek to mitigate “or eliminate risks associated with coastal storms, erosion, and sea level rise through natural and nonstructural approaches, called green infrastructure” (StormSmart Coasts, 2014). In spite of the severity of the effects associated with sea level rise and coastal erosion there are initiatives that seek to improve climate change resiliency and mitigate the impacts in coastal regions in Massachusetts.

Study Area

Size and Location:

Massachusetts has a total area of 21,456 square kilometers, 20,265 square kilometers of which is land and 1,191 square kilometers which is occupied by inland water. Massachusetts is bordered by Vermont and New Hampshire to the north and to the east by the Atlantic. To the south of Massachusetts is the Atlantic Ocean, Rhode Island and Connecticut and to the west is New York. Massachusetts extends 306 kilometers from the east to the west and is a total of 177 kilometers from the northern reaches to the southern reaches. The total boundary length of Massachusetts is 829 kilometers which includes 309 kilometers of coastline.

Figure 1- The diverse habitats of Cape Cod (Cohn,2011).

Land Use:

From 1971 to the present, more than 50,000 acres have been developed in Cape Cod, resulting in more than a 20% reduction in forestland. Currently, about 40% of land cover is developed. The largest percentage of land in Cape Cod (60%) is undeveloped. Twenty-nine percent of that undeveloped land is protected by federal, state and private landowners. Of the protected land, 13% is wetland or water bodies. The remaining 31% is unprotected and undeveloped. The majority of the undeveloped and unprotected land is broken into small plots. There are many important habitats in Cape Cod including: dune/beach systems, salt marshes, swamps, bogs, sand plain grasslands and pitch pine forests (Figure 1). There are 15 towns in Cape Cod of which the town of Barnstable is the largest.

Water Resources:

The Cape Cod watershed reaches beyond the landmass of the Cape and 70 miles into the Atlantic Ocean. Four bodies of salt water border Cape Cod: Buzzards Bay, Cape Cod Bay, the Atlantic Ocean and the Nantucket Sound. The watershed covers a drainage area of approximately 1140 sqare kilometers, and is composed of approximately 900 km. of coastline, 360 ponds, 145 wells that supply public water, 300 square kilometers of protected open space, and 8 areas that have been designated as critical ecological concerns by the Massachusetts Office of Energy and Environmental affairs (EEA). Of the 15 towns sharing the Cape Cod watershed four of them have the greatest number of rare species listed by the state of Massachusetts. Cape Cod's aquifer is the only source of water for the, approximately 250,000 year-round residents, and 500,000 people during peak travel time in the summer (Massachusetts Executive Office of Energy and Environmental Affairs, 2014 and USGS, 2013).

Critical Areas:

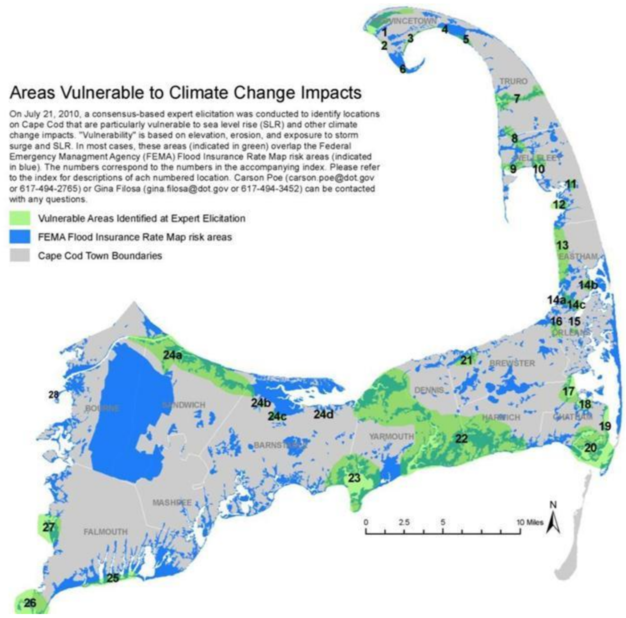

Figure 2- Areas vulnerable to impacts associated with climate change (USDOT, 2010).

Some areas in Cape Cod are more prone to damages due to sea level rise. The Federal Highway Administration published a study that assessed areas at risk in Cape Cod due to sea level rise, coastal erosion, and storms, which are notated by the green areas in Figure 2 (U.S. Department of Transportation: Federal Highway Administration, 2010, Fig. 2). Many of the areas were along the coast of the Cape. Some beaches, such as Sandy Neck, are susceptible to erosion (U.S. Department of Transportation: Federal Highway Administration, 2010). Water sources, such as Mayo Creek and those in Harwich (highlighted by the large green area, #22, in Fig. 2), are also at risk (U.S. Department of Transportation: Federal Highway Administration, 2010). Roads in these areas are susceptible to being lost through erosion, especially those in Provincetown, and including such roads as Route 6, Route 6A, Blackfish Creek Highway, Route 28, and Chapoquoit Road in Falmouth (U.S. Department of Transportation: Federal Highway Administration, 2010). Areas at high risk of flooding include the following Woods Hole and Hyannisport, a major area of transportation (U.S. Department of Transportation: Federal Highway Administration, 2010). Chatham Fish Pier will also be affected, which will affect the economy (U.S. Department of Transportation: Federal Highway Administration, 2010).

Demographics:

Cape Cod contains Barnstable County, which consists of fifteen towns: Provincetown, Truro, Wellfleet, Eastham, Orleans, Brewster, Harwich, Chatham, Dennis, Yarmouth, Barnstable, Sandwich, Mashpee, Bourne, and Falmouth. Barnstable is the county's only metropolitan area (US Census Bureau, 2014). Cape Cod has experienced a 400% increase in its population from 1950 until the present (Woods Hole Research Center, 2014). However, recently the population has begun to stabilize (Woods Hole Research Center, 2014). Over a third of the population consists of individuals 55 and older, and individuals 17 and under make up another 20% of the population. Cape Cod is predominantly Caucasian (~94%) (US Census Bureau, 2014). Economically, tourism brings in the most capital (43%), followed by retirement (15.3%) (Cape Cod Chamber of Commerce, 2006). There are approximately 160,978 housing units, and there is an 80% homeownership rate (US Census Bureau, 2014).

Modelling the Impacts of Coastal Erosion

Due to sea level rise, climate change, and other anthropogenic changes, Cape Cod is facing an increasing rate of coastal erosion (Figure 3). Sea level rise causes a decrease in shoreline. Sea level rise is a large contribution to an increasing rate of coastal erosion, because, according to the Bruun Rule, for every 1 cm of the sea level rise, there is a corresponding 1 meter of coastal erosion, due to the ability of waves to move farther upland (Phillips & Jones, 2006). Climate change causes an increase in precipitation, which in turn causes an increase in Hortonian Overland Flow (HOF). Anthropogenic changes, such as an increasing population that creates more development, causes changes in the plant vegetation. There may be a decrease in total land vegetation because of footfall or vehicle traffic, or there may be a decrease in the natural land vegetation and an increase in invasive species (Woods Hole Research Center, 2014; Coverdale et al., 2013). This increase in HOF and decrease in natural land vegetation promotes coastal erosion at an increased speed and/or magnitude.

This increase in coastal erosion puts Cape Cod at an increased risk for habitat loss, property loss, and infrastructure damage. Habitat loss is an alarming effect because it can limit populations and increase the number of endangered species, as well as decrease biodiversity in the surrounding area. Property loss can cause displacement of people from their homes. This kind of change can be a traumatic experience and could even cause a decrease in ontological security among displaced people. The theory of ontological security explores the concept that people are tied to their familiar landscapes, and changes that occur to the landscape can disrupt a person's sense of well-being (Grenville, 2007). Property loss also ensues high costs, for either homeowners, renters, or insurance agencies. High costs are also associated with infrastructure damage. Infrastructure damage causes disruptions in the ability for travel within Cape Cod, which can cause some people to be stranded. Moreover, tourists will have a more difficult time coming to Cape Cod, which may cause a decrease in tourism, which causes a decrease in economic capital for the county.

People have also changed the landscape by building obstructions such as jetties, which interfere with the natural processes of coastal erosion and accretion (Figure 3). Although jetties may benefit the people on one side of it by protecting that coastal area from storm events and erosion processes, jetties also cause a decrease in accretion for the other side that receives the sand from those areas that normally eroded. This decrease of coastal accretion causes a loss of beaches, dunes, and barrier islands. Because of the loss of the protection provided by these sand structures, coastal regions become more vulnerable to storm impacts, which can cause infrastructure damage (Figure 3).

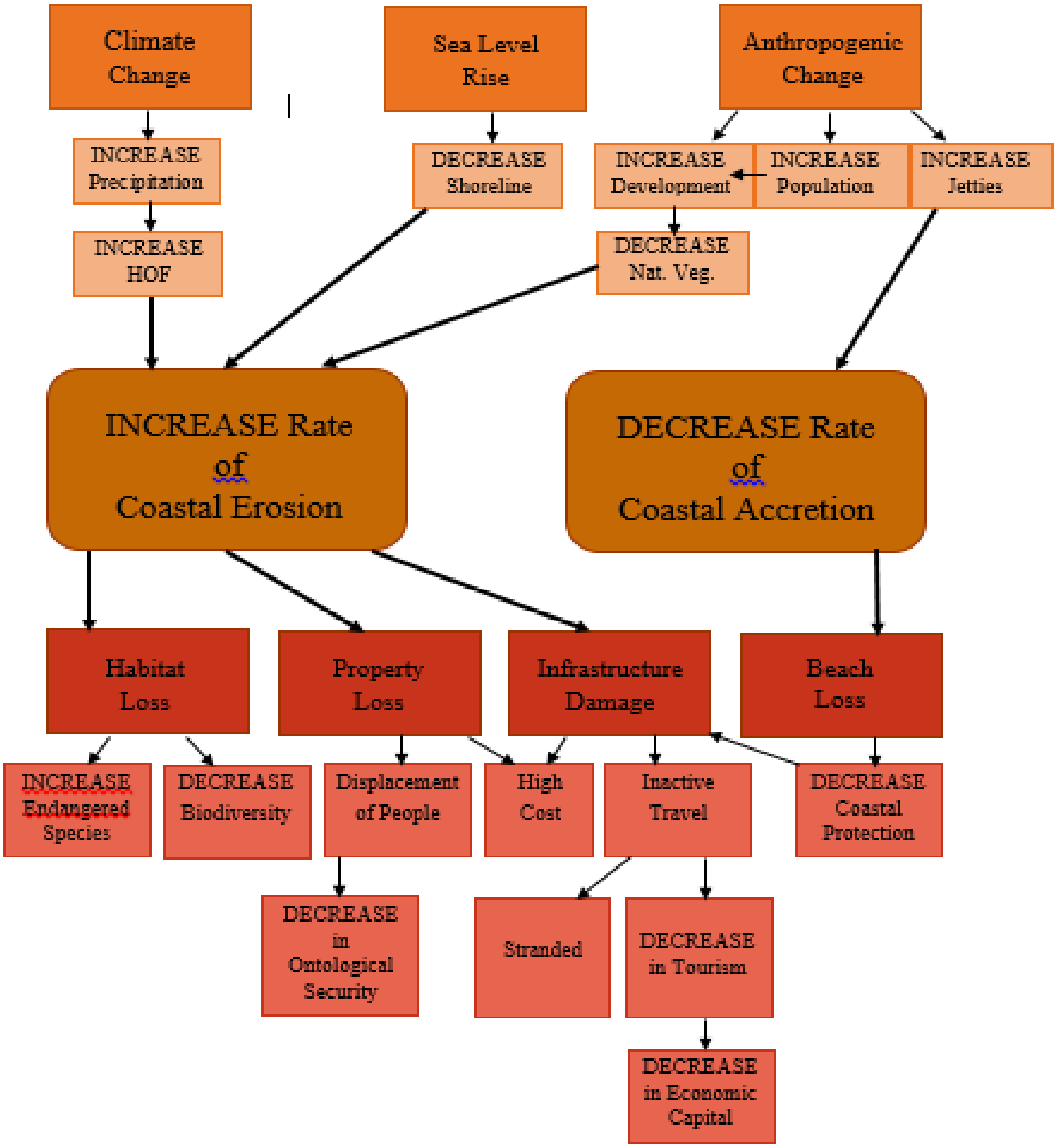

Figure 3-The interaction of socio-ecological systems in Cape Cod, MA.

Impacts of Coastal Erosion: Ecological Thresholds

Cape Cod, like most of New England, is the product of land use history. Deforestation of Cape Cod began shortly after European colonists arrived in the 17th century and with them the worldview that landscapes needed to be tamed. At the time of the colonist's arrival, Cape Cod was densely forested; the soils in Provincetown were described by Europeans as dark and thick. As more and more forests were cut down, less water was returned to the atmosphere through evapotranspiration, exposing soils to the damaging effects of rainfall. As early as the mid-18th century, colonists in Cape Cod realized that deforestation was turning their home into a desert and began writing legislation to limit vegetation removal; however, a threshold of landscape stability had already been crossed (Forman et al., 2008).

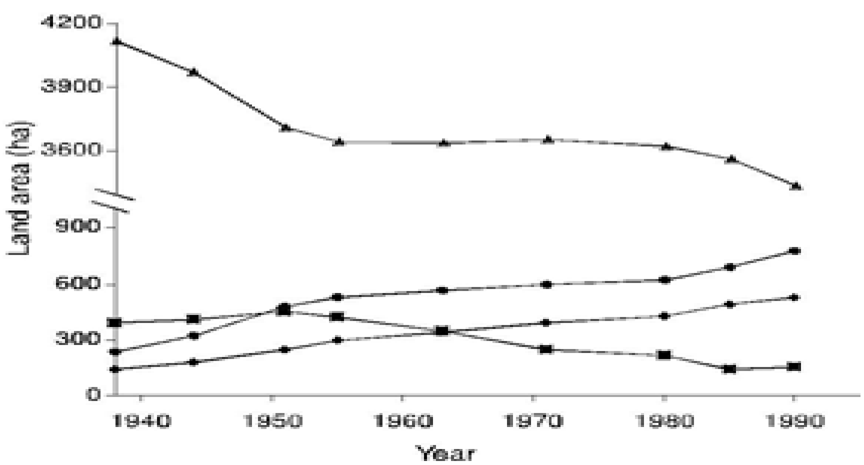

Figure 4- Changes in land use in Waquoit Bay watershed, Cape Cod, MA from 1938-1990. Triangles=natural vegetation, squares=agriculture,zeros=turf, diamonds= impervious (Valeila, 2011)

Increased urbanization of Cape Cod lead to the crossing of another important ecological threshold: impervious cover. Agricultural land use began to decrease in the late 19th through the early 20th century. Following the end of World War II, urbanization of Cape Cod began to increase rapidly (Forman et al., 2008, pp. 765-767). Figure 4 shows trends in land use change for the Waquoit Bay watershed in Falmouth, MA. Land that was previously used for agriculture was developed to accommodate the growing population.

As urbanization began to increase in the 20th century, more forest land and wetlands were removed. The urban development of the 20th and 21st century increased percentage of impervious surfaces such as roads and buildings as well as soils compacted as a result of development. The loss of permeability and storage capacity increases the risk of erosion as Hortonian overland flow (H.O.F.) becomes the dominant flow pathway (Crètaz and Barten, 2007). Increases in H.O.F. in urban areas are known to cause decreases in water quality as undiluted pollutants are transported along with sediment. Figure 5 combines groundwater flow, percentage of impervious cover, and current population for Cape Cod. The map shows an alarming trend in impervious cover. Studies have repeatedly shown total impervious area percentages greater than or equal to 10% on a landscape causes decreases in water quality due to urban run-off. (Cretaz and Barten, 2007, p. 218).

While coastal wetlands such as salt marshes have an amazing capacity to filter pollutants and trap sediment coming from urban runoff, their decrease throughout Cape Cod have made shorelines more vulnerable to erosion and coastal flooding. Smith (2009) quantifies salt marsh loss in Cape Cod and explains how these losses have occurred. Of the salt marshes Smith studied 65% experienced losses due to herbivory by *S. reticulatum*, a crab native to the northeast. Furthermore, Smith (2009) found salt marshes that did not exhibit damage from *S. reticulum* did not show signs of dieback. The recent increases in the population of *S. reticulum* is believed to be the result of overfishing of the crab's natural predators. Smith (2009) also found rates of high salt marsh retreat varied depending on marsh topography and elevation gradients. Specifically, he found large shifts occur when elevation gradient is low. He hypothesized the loss of high salt marsh was due to sea level rise (i.e. tidal inundation exceeded flood tolerance of salt marsh species). Smith (2009) suggests rising sea levels increase salt marsh dieback which decreases buffering capacity thereby increasing rates of erosion which increases impact of wave energy which further decreases salt marsh habitat. Since development limits the migration of salt marshes in response to sea level rise, Smith (2009) hypothesizes an increase in salt marsh losses over the next several decades (Smith, 2009, pp. 183-205).

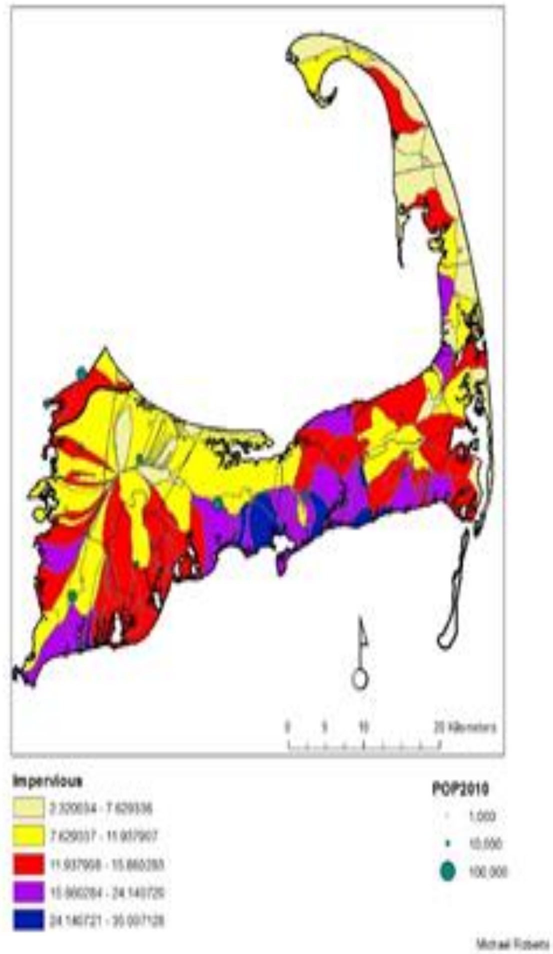

Figure 5-Impervious cover (%) and groundwater flow along with 2010 population numbers. Data source: USGS and MassGIS

Social and Economic Impacts of Coastal Erosion: Damage Potential and Exposure

Building resilience in Cape Cod, MA requires an ecosystem approach to conservation and management practices. The Intergovernmental Panel on Climate Change has stated that the main risk associated with the increase of global mean temperatures are coastal storm surges, sea level rise, and coastal erosion. However, the growing disparity in income worldwide means that the ability of communities to build climate change resiliency is tied to economics. The loss of life, incidence of injury, destruction of infrastructure, and population displacement resulting from coastal storm surges, sea level rise, and coastal erosion are some of the major challenges facing communities that must be mitigated by proactive coastal resource management, but are also dependent on ability to acquire, or produce, adequate funding for the development of green infrastructure, and the implementation of coastal resource management plans. Although the costs associated with coastal zone management can be high, the socio-economic costs associated with coastal erosion are far greater.

Figure 6- Housing Units on Cape Cod (Figure source: Ellison, 'Seasonal Housing Units,' 2010).

Reports by the Massachusetts Office of Coastal Zone Management (CZM) and the Cape Cod Commission (CCC) have reflected findings of the IPCC and identified coastal erosion and flooding as the main risks facing the inhabitants of Cape Cod. In the 2010 Multi-Hazard Mitigation Plan (MHM) for Barnstable County, the Cape Cod Commission (CCC) developed a risk management plan based on the identification of regional vulnerabilities "to reduce the loss of, or damage to life, property, infrastructure, and natural, cultural, and economic resources from natural disasters" (Cape Cod Commission, 2010). The MHM defines regional risk and vulnerability using the spatial hazard zones SLOSH (potential zones for Sea, Lake, and Overland Surges from Hurricanes as developed by the National Weather Service) and FIRM (Flood Insurance Rate Map developed by the Federal Emergency Management Agency). As a result, the CCC found that of Cape Cod's total 1,068.16 square kilometers, 186.99 square kilometers, or 17.51% of the total area, are in potential SLOSH zones, while 186.38 square kilometers, or

17.45% of the total area, are in a FIRM zone (Cape Cod Commission, 2010). According to the Cape Cod Commission, seasonal fluctuations in population, an accurate number of people that would be impacted by a hazard event is unknown (Cape Cod Commission, 2010). However, by analyzing census data from the same year we are able to see that 46.7 % of housing units on Cape Cod are owner occupied, 13.6% are renter occupied, 35.8% are seasonally occupied, and 3.8% are listed as other or vacant. Figure 6 shows the distribution of seasonally occupied housing units on Cape Cod. In analyzing this distribution it becomes clear that the majority of housing units on the coastline are seasonally occupied, especially in the Outer and Lower regions of the Cape.

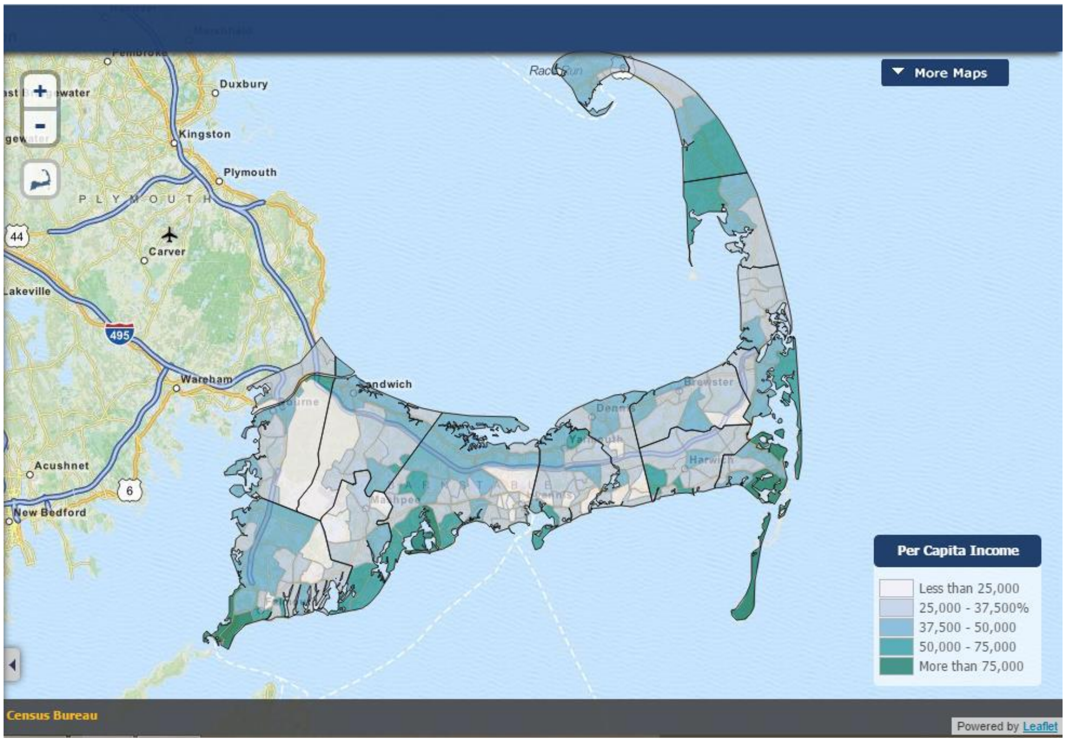

Figure 7-Per Capita Income Distribution of Cape Cod (Figure source: Ellison, 'Per Capita Income,' 2010).

Social justice issues will occur because of at-risk areas corresponding to areas with low per-capita income. With the increase in storms and the decrease in protection areas, there comes an increase in floods. Unfortunately, the people most likely to experience flooding are people who have smaller incomes. According to the Federal Emergency Management Agency (FEMA), the critical areas that are likely to experience increased flooding closely match areas with per capita income less than $25,000 (Figure 7).

Building Resiliency

Technology Solutions

There are many technologic solutions that could be implemented. Beach nourishment is said to be one of the most important long term solutions (Peabody, 2010). Through the StormSmartCoasts Program, the Massachusetts Office of Coastal Zone Management (CZM) provides a wealth of information that can be used as a tool to effect coastal resource management and mitigate the impacts of coastal erosion through beach nourishment.

One of the main strategies is to replace natural coastal vegetation in areas where vegetation has been lost or replaced by invasive species (Coverdale et al., 2013; O'Connell, 2002). Coastal landscaping is a viable and relatively low-cost solution for managing coastal erosion through the re-development of natural coastal buffer zones (StormSmartCoasts, 2014). When choosing plant species for coastal areas it is important to consider the requirements of the species and landscape in which they are being planted (e.g. intertidal areas, dry beaches, coastal dune areas, and more sheltered dune areas). Some suggestions of native plants to be used in intertidal areas are Switchgrass, Black grass, and Marsh Elder; for dry beach, American Beach grass, Beach pea, and Sea Rocket; in coastal dune areas, American Dune grass and Beach Heather; in more sheltered areas of coastal dunes, Sea Lavender, Red Chokecherry (edible), Large Cranberry (edible), Black Cherry, and Eastern Red Cedar (StormSmartCoasts, 2014).

Another solution is to address infrastructural causes of erosion. One way is to take down the jetties that are causing problems; however, this alternative will probably cause political problems (Peabody, 2010). Hard infrastructure often causes associated erosional problems, while soft infrastructure works more with natural processes (Phillips & Jones, 2006). Beach nourishment is considered a soft infrastructure alternative; another alternative are submerged breakwaters, which target the waves, with the object of decreasing wave power (Phillips & Jones, 2006).

Policy & Economic Solutions

In 2002, CZM established the Coastal and Estuarine Land Conservation Program (CELCP) to manage the anthropogenic causes of coastal erosion throughout Massachusetts. Many towns have understood the importance of planning for coastal erosion and have developed management plans (Woods Hole Group, 2014). These plans address different strategies that the town will take in combating the negative effects of coastal erosion, including a cost and benefit analysis. Towns can apply for grants from donors or federal funding in order to implement their chosen alternative (Massachusetts Energy and Environmental Affairs, 2014; O'Connell, 2002). The StormSmartCoasts Program provides grants to cities and towns "to advance new and innovative efforts to address climate change and sea level rise impacts" through the Coastal Community Resilience Grant Program, and provided support to communities engaged in efforts to reduce the impacts and "risks associated with coastal storms, erosion, and sea level rise" through using nonstructual approaches (StormSmartCoasts, 2014). Individuals can also seek financial help by applying for grants. For instance, homeowners can apply for FEMA grants in order to pay to raise their homes, which helps protect against flooding (Massachusetts Energy and Environmental Affairs, 2014). Raising homes also serves as an economic incentive; those people who have raised their homes using freeboard, surpassing the minimum requirement, are likely to receive lower insurance bills (Massachusetts Energy and Environmental Affairs, 2014).

Whether through state or federal policy, one solution is to purchase critical areas and setting them aside as reserves (Macadangdang & Newmons, 2010). This solution is likely to meet with opposition, especially from local towns. However, coastal erosion in the future is inevitable, and Cape Cod’s shoreline will recede. Buying the critical areas would prevent development in those areas and could enable the restoration of the protection areas through adding coastal landscaping and other conservation practices.

The Massachusetts 2014 Fiscal Year (FY) Budget Bill created a Coastal Erosion Commission whose function is to investigate and document the effects of coastal erosion in Massachusetts and develop strategies “to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes” (Massachusetts Energy and Environmental Affairs, 2014). This commission not only functions as a governing body but as a regulatory entity and educational coordinator. Education is a key solution. Conservation methods can be taught in the school system in Cape Cod. In fact, Safe Harbor, a local group practicing environmental education, offers internships for high school teachers to learn conservation practices that they can teach to students (Safe Harbor, 2014). Including conservation methods into the curriculum, in such classes as earth science, would ensure that approximately 20% of the population in Cape Cod, those individuals 17 and under, would understand conservation practices that combat problems caused by erosion (Barnstable County Human Services, 2002). Education can also be extended through community programs. The Massachusetts Coastal Erosion Commission has extended some workshops for the Cape Cod community (Massachusetts Energy and Environmental Affairs, 2014). In a study in Scotland, it was noted that the community did implement what they learned from community education outreach attempts (Young et al., 2014).

Involving the community is an important part of planning, especially as the community is a key stakeholder in the outcomes of coastal erosion. Although involving the community is important, policy may be need to be formed so that environmental impacts are also addressed. In Scotland, a local community initiated the call for a coastal management plan, illustrating a bottom-up movement (Young et al., 2014). However, the community chose the alternative that kept erosion from causing a changed shoreline by choosing to erect a crushed rock bund, which was identified by experts as the least sustainable and environmentally problematic alternative (Young et al., 2014).

Implications for Further Research:
Sustainability Thresholds

The next step in analyzing the relationships between socio-ecological systems is to look at the relationships between system thresholds. Thresholds are defined (Folke et al., 2010) as “A level or amount of a controlling, often slowly changing variable in which a change occurs in a critical feedback causing the system to self-organize along a different trajectory, that is, towards a different attractor (para 8).” Uehara (2013) studied the link between economic and ecological-economic thresholds and found that ecological-economic thresholds often occur before economic thresholds. The predictive ability of thresholds is important in understanding the impact one system’s collapse may have on other related systems, giving scientists, policy makers, and planners the ability to adapt. One of the goals of understanding thresholds in complex systems is understanding the resilience capacity of the systems. Resilience is defined as the ability of a system to maintain its structure and function while undergoing shock (Folke et al., 2010). Vulnerability of communities and ecosystems varies on spatial and temporal scales. According to Felsenstein and Lichter (2013), social welfare is the most important determinant of resilience to vulnerability due to sea level rise. Figure 8 is a visualization of the relationship between economic, ecological, and social system thresholds. There are well-documented ecological thresholds with known, quantifiable values. For example, impervious cover >10% is known to cause decreases in water quality. Carbon dioxide concentrations > 350 ppm is a threshold believed to have global atmospheric impacts. Social thresholds may be harder to quantify but access to healthcare, social unrest, instances of conflict, rates of disease are all metrics that could be investigated. Economic thresholds include income levels, income distribution, and levels of development. Any research in this area should also focus on the temporal and spatial characteristics of thresholds. Future research in systems thresholds and their application to sustainability science could also compare socio-ecological systems in different geographic locations (e.g. developed vs. developing) to see if there are discernable patterns.

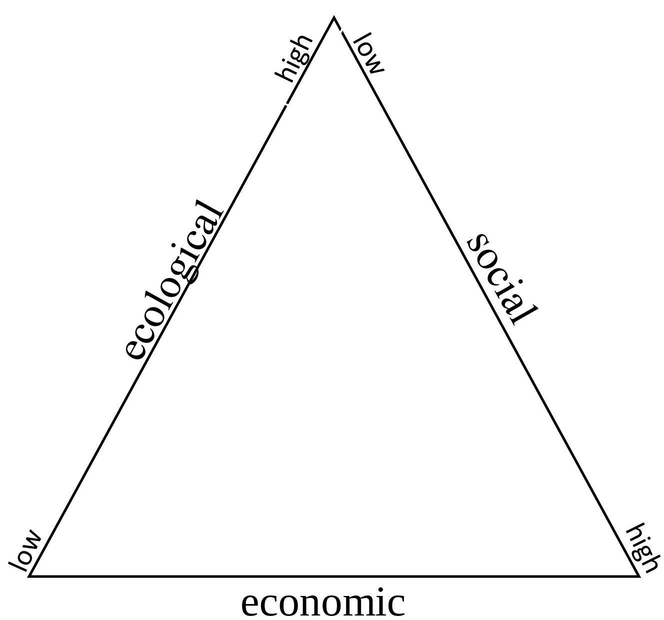

Figure 8- A conceptual model showing the relationship between socio-ecological thresholds.

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