The Importance of Climate Change and Land Use Patterns on Coastal Wetland Restoration Strategies

Kristen R. Keene
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THE IMPORTANCE OF CLIMATE CHANGE AND LAND USE PATTERNS ON COASTAL WETLAND RESTORATION STRATEGIES

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THE IMPORTANCE OF CLIMATE CHANGE AND LAND USE PATTERNS ON COASTAL WETLAND RESTORATION STRATEGIES

A Master Thesis

Submitted to the Faculty

of

American Public University

by

Kristen Rheann Keene

In Partial Fulfillment of the

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of

Master of Science

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DEDICATION

I dedicate this thesis to my family, and most importantly, my husband. The completion of this work would not have been possible without the love and support from my family.
ACKNOWLEDGEMENTS

I wish to thank my professor, Dr. Molly Whitworth, for her support, patience, attentiveness, and guidance in completing my final degree requirement. My experience throughout the Master of Science Environmental Policy and Management program has been quite an adventure, one that I will always be grateful for. I am thankful for the opportunity to have worked with exceptional educators throughout my coursework, who have provided me with the tools to advance my educational and professional career.
Climate change and land use patterns in coastal regions can have a significant impact on adjoining ecosystems, such as coastal wetlands, and the selection of restoration strategies used to restore a degraded system is likewise influenced by these factors. Determining how climate change and surrounding land use impacts coastal wetland restoration decisions was investigated in the Chesapeake Bay region of the United States using three case studies which exhibited different surrounding land use patterns: urban, commercial agricultural production, and recreational. The study addresses the following: the impacts surrounding land use practices have on adjacent coastal wetland systems; the relationship between surrounding land use patterns and selected coastal wetland restoration strategies; the types of restoration strategies that can be applied to account for climate change impacts, based on surrounding land use patterns; and whether or not current wetland restoration techniques exhibit long-term effectiveness considering climate change impacts. Study findings highlight how surrounding land use patterns influenced the selection of coastal wetland restoration strategies and the ability of a wetland system to
account for climate change impacts. Recommendations related to localized approaches, landscape-level approaches, and targeted adaptation measures are discussed in an effort to provide guidance to natural resource managers and urban planners.
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I. INTRODUCTION

Climate change and land use patterns in coastal regions can have a significant impact on adjoining ecosystems, such as coastal wetlands, and the selection of restoration strategies used to restore degraded systems. The connections between landscape patterns and adjacent wetlands affect many parameters of restoration such as hydrogeological function, biogeochemical pathways, and ecological processes (White & Fennessy, 2005). In this study, climate change and surrounding land use impacts to coastal wetland restoration decisions are investigated in the Chesapeake Bay region of the United States.

The Chesapeake Bay is the largest estuary in the United States with a watershed that drains an area of approximately 166,000 squared kilometers (km²) and encompasses six states including Maryland, New York, Virginia, Delaware, Pennsylvania, and the District of Columbia (Horton, 2003). The Bay has a large number of tributaries and over 11,400 km² of waters that experience tidal influence (Horton, 2003). Additionally, the Bay contains approximately 12,870 km of shoreline, making the estuary vulnerable to impacts from runoff, freshwater inputs, and anthropogenic activities (Horton, 2003). The Chesapeake Bay watershed exhibits a diverse set of land use practices including but not limited to: urban, industrial, agricultural, recreational, rural, commercial, and military (Boesch, 2006).

Three case studies, exhibiting varying land use practices, are assessed in terms of how surrounding land use influences coastal wetland restoration strategies and the ability of those restoration sites to account for climate change. The study addresses the following uncertainties:

1. The positive and/or negative impacts surrounding land use practices have on adjacent coastal wetland systems;
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2. The relationship between surrounding land use patterns and selected coastal wetland restoration strategies;

3. The types of restoration strategies that can be applied to account for climate change impacts, based on surrounding land use patterns; and

4. Whether or not current wetland restoration techniques exhibit long-term effectiveness considering climate change impacts.

It is important to consider climate change impacts and land use patterns in the selection of coastal wetland restoration designs to ensure that restoration efforts are successful. The assumption is that climate change and surrounding land use patterns significantly impact coastal wetland restoration decisions. This study will contribute to existing knowledge regarding coastal wetland restoration by providing guidance to resource managers relative to how surrounding land use patterns influence restoration objectives and identifying strategies that can be used to account for climate change in restored wetland systems.

II. LITERATURE REVIEW

Coastal Wetland Characteristics and Values

Coastal wetlands exist at the interface between land and water and include both tidal and non-tidal freshwater systems, among others. Coastal wetland systems provide a variety of environmental, economic, and recreational benefits to coastal regions. An extensive amount of data has been collected relative to coastal wetlands in the United States, which includes information regarding wetland classification and functions. For instance, the U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) is a database that has been used to map and classify wetlands of the United States for over two decades; information from the NWI has since been used to determine wetland functions based on the characteristics identified by the database.
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(Tiner, 2003). The correlation between NWI data and wetland functions in the northeastern United States has resulted in the identification of a variety of beneficial wetland functions including, but not limited to: the storage of surface and storm-generated waters; streamflow maintenance; sediment and nutrient retention; shoreline stabilization; the provision of terrestrial and aquatic habitat; and biodiversity conservation (Tiner, 2003).

The ability for a coastal wetland system to temporarily store surface and storm-generated waters aids in the reduction of flooding frequency and intensity, along with erosion, which helps to minimize both property and personal damages in coastal regions (Environmental Protection Agency [EPA], 1995). The hydrologic regime, which can be maintained by streamflow is critical for the persistence of vegetation patterns, biogeochemical processes, waterfowl abundance, and aquatic species, among others (Neubauer & Craft, 2009). Coastal wetlands are especially proficient in their ability to retain sediments and nutrients, which is accomplished in coordination with vegetative patterns, and serves to improve water quality by reducing sedimentation rates (EPA, 1995). The presence of vegetation plays an important role in the ability of a wetland to reduce sedimentation via plant uptake and soil absorption, which allows coastal wetland systems to function as a filter for excess nutrients and contaminants as a result of adjacent land use practices (Johnston, 2009).

The provision of terrestrial and aquatic habitat is another important function of coastal wetland systems. Due to their location at land-water interfaces, coastal wetlands serve as an appropriate habitat for fish, shellfish, waterfowl (including migratory birds), terrestrial species, and aquatic-dependent species (EPA, 1995). Coastal wetland systems are capable of providing a suitable habitat for a wide variety of species considering that the ecosystem is utilized for nesting, breeding, feeding, and as a stopover site (EPA, 1995). Considering the ecological and
environmental components of coastal wetland systems, a variety of recreational values are associated with wetlands including, but not limited to: hunting, boating, fishing, wildlife photography, and bird watching (United States Fish and Wildlife Service [USFWS], 2011). In terms of biodiversity conservation, coastal wetlands are capable of sustaining a wide variety of species, which can be primarily attributed to the presence of diverse plant communities that support a large number of wildlife (Tiner, 2003). Overall, coastal wetland ecosystems are critical to the persistence of many species.

In addition to providing critical habitat, the composition, distribution, and diversity of wetland vegetation offers significant benefits to coastal regions. The configuration of wetland vegetation contributes to the geomorphological engineering of coastlines, which supports the wave attenuation and shoreline stabilization properties of coastal wetlands as a means of direct and indirect shoreline protection against erosional forces such as storm events (Gedan, Kirwan, Wolanski, Barbier, & Silliman, 2011). For instance, the presence and density of wetland vegetation has the capacity to attenuate waves, while the accretion of sediments functions as a stabilizing mechanism (Wardle et al., 2004). Vegetation is a significant component of a coastal wetland system and will be especially important in the adaptation to conditions associated with climate change.

**Threats to Coastal Wetlands**

Coastal wetlands are vulnerable to a wide range of environmental disturbances, such as sea level rise, and local landscape alterations associated with anthropogenic land use practices (Neubauer & Craft, 2009). Coastal wetland loss and degradation is of important concern to coastal regions and according to the National Oceanic Atmospheric Administration’s (NOAA) Coastal Change Analysis Program data, approximately 40,000 acres of coastal wetlands have
been lost in the mid-Atlantic region from 1996 to 2006. Coastal wetland loss can often be attributed to direct and indirect causes such as urban development, agricultural land conversion, filling activities, the construction of dikes, and climate change (U.S. Department of Natural Resources [USDNR], 2008).

Sea level rise, as a result of global climate change, and population growth are two of the most significant threats to coastal wetland systems. According to the Environmental Protection Agency (n.d.), sea level rise in the mid-Atlantic region is expected to pose inundation risks to approximately one million acres of coastal wetlands over the next century. Specifically, climate change in the Chesapeake Bay region is expected to significantly impact coastal wetland systems and the ability of resource managers to effectively restore the functions of coastal wetlands. Additionally, human populations have a significant impact on surrounding wetland systems in terms of wetland area and distribution. Gibbs (2000) conducted an analysis on wetland loss and determined a direct correlation between human density and the concentration, proximity, and cumulative area of wetlands. For instance, as land use patterns are converted from rural to urban, wetland configurations shifted from abundant and clustered mosaics to a reduced number of isolated wetland areas (Gibbs, 2000). Cumulative wetland areas have declined in conjunction with the proliferation of human populations (Gibbs, 2000). In the Chesapeake Bay region, the population in urban and suburban areas has increased at a steady rate over the years; therefore, pressures on wetlands can also be expected to increase (Claggett, 2007). For instance, from 1950 to 2000, the population in the Chesapeake Bay watershed increased from 8.1 to 16 million (Claggett, 2007). Although climate change and increasing human populations pose a significant threat to wetland systems, restoration activities will hopefully conserve the remaining ecosystems in coordination with varying land use practices.
Climate Change Impacts

The accepted theory of climate change explains how the anthropogenic emission of carbon dioxide results in long-term significant changes in global climatic conditions (Najjar et al., 2010). Some of the anticipated climate change impacts include, but are not limited to: increases in storm frequency and intensity, sea level rise, salt water intrusion, increased temperatures, and shifts in plant community composition (Najjar et al., 2010). Of the predicted climate change impacts to coastal wetlands, sea level rise represents one of the most detrimental consequences. Specifically, the Intergovernmental Panel on Climate Change predicts that global sea level rise of 22-34 centimeters will occur between 1990 and the 2080s, which will intensify the risk of flooding and erosive forces and cause devastating environmental and economic effects such as the loss of coastal wetland systems, the degradation of coastal infrastructure, and diminished economic returns from coastal enterprises (Nicholls, 2004).

The Chesapeake Bay region is highly susceptible to the impacts of sea level rise; some locations have experienced approximately a twelve-inch increase in relative sea level rise during the 20th century due to a synergistic collaboration between global warming and natural land subsidence (National Wildlife Federation [NWF], 2008). Kearney et al. (2000) demonstrated via Landsat imagery that marshes are especially susceptible to sea level rise if they exhibit low tidal ranges and irregular flooding episodes, which is common in the Chesapeake Bay region due to the construction of dikes and berms for anthropogenic uses. The implications of sea level rise on coastal wetland systems in the Chesapeake Bay region could cause significant negative impacts to biogeochemical cycles, food webs, carbon sequestration, and water quality in the estuary (Kearney et al., 2000).
Sea level rise can impact coastal systems via increases in inundation frequency, increases in salinity, and exposure to erosive forces (NWF, 2008). For instance, prolonged periods of salinity, as a result of saltwater intrusion, can significantly reduce the community biomass, species richness, and productivity of coastal wetland vegetation (Sharpe & Baldwin, 2012). Sea level rise and subsequent saltwater intrusion may also alter the vegetative community causing shifts to more flood-tolerant plants and those capable of persisting in more saline conditions (Neubauer & Craft, 2009). Additionally, Neubauer and Craft (2009) explain that increased flooding frequency and intensity will impact seed germination and the development of seedlings considering that the emergence of seedlings will likely decrease as the degree of flooding increases in coastal wetlands.

In concert with sea level rise, increasing temperatures serve as another predominant consequence of global climate change and will have varying impacts on the biological components of coastal wetlands. A majority of the vegetative species that commonly exist in freshwater wetland systems have a broad geographic distribution, which indicates a high tolerance for certain environmental conditions, such as temperature; therefore, it is unlikely that shifts in temperature will result in any significant changes to the vegetative communities of freshwater coastal wetlands (Neubauer & Craft, 2009). In contrast, the geographic distribution and metabolic rates of many aquatic species are significantly influenced by temperature (Neubauer & Craft, 2009). Specifically in aquatic habitats, increases in temperature will result a reduction in the concentration of dissolved oxygen, which can lead to severely low oxygen conditions that are incapable of supporting the persistence of aquatic species (Neubauer & Craft, 2009). Relative to terrestrial species, a majority of mammals that utilize coastal wetland habitats exist in broad geographic ranges, making them less susceptible to temperatures increases
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(Neubauer & Craft, 2009). Some mammals, such as the invasive *Myocastor coypus* (nutria), are sensitive to colder temperatures; therefore, increases in global temperatures will allow for the species to increase their northward distribution, which could present potential problems with *M. coypus* invasion in the coastal wetlands of the northeastern United States (Neubauer & Craft, 2009). Lastly, global temperature increases will indirectly impact waterfowl species in terms of food resources considering the aforementioned reductions in aquatic species composition and availability (Neubauer & Craft, 2009). In general, plant and wildlife species will experience variable impacts from global temperature increases.

Overall, the major assumptions of climate change highlight how the hydrological, biological, and physical characteristics of coastal wetland systems are impacted. The anticipated impacts of climate change should also be considered in the selection of coastal wetland restoration strategies in an effort to account for potential impacts in the planning, design, and implementation of restoration projects.

**Defining Ecological Restoration**

Government agencies and peer-reviewed literature provide numerous definitions of ecological restoration and despite the varying descriptions, a common theme among them includes the concept that a successful restoration translates into a scenario in which an ecosystem is stable, or independently persistent over time (Palmer, Ambrose, & Poff, 1997). For instance, Kentula (2000) defines wetland restoration success in terms of compliance, functionality, and landscape. Compliance success refers to the ability of a restoration project to meet the parameters outlined in an agreement, such as permit; functional success represents the capacity for restoration strategies to reestablish ecological functions and maintain stability; and landscape success quantifies how the restoration of a site influences the integrity of a regional area or
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landscape (Kentula, 2000). In simpler terms, the National Research Council (1992) defines ecological restoration as “returning a system to a close approximation of its condition prior to disturbance, with both the structure and function of the system recreated.” For the purposes of this study, the National Research Council’s definition of ecological restoration will be used as the foundation for restoration criteria and qualification of a successful restoration.

Common Restoration Strategies

Despite the loss and degradation of coastal wetland systems, a variety of restoration strategies are used by federal, state, and local agencies to restore ecosystem functions in affected coastal wetland systems (USDNR, 2008). The objective of coastal wetland restoration involves the reestablishment of preceding ecological conditions. A few of the common coastal wetland restoration strategies utilized by resource managers include, but are not limited to: planting efforts; invasive plant species control; the installation of artificial structures; and the use of dredged material.

Vegetating a wetland area via planting events can restore a wetland system suffering from exposed and/or eroding soils (U.S. Department of Agriculture [USDA], 2008). Additionally, planting events can aid in the restoration of a coastal wetland system experiencing subsistence via the selection of species that are more tolerant of a deeper hydrologic regime (USDA, 2008). In conjunction with planting events, plant protection structures, such as tubing and screens, are often used to prevent extensive herbivory in the early successional stages of a restored marsh (Maryland Department of Natural Resources [MD DNR], 2007). Enhancing plant diversity is a common objective associated with coastal wetland restoration; however, invasive plant species often pose significant threats to newly established vegetative communities in coastal wetlands. In an effort to maintain the natural vegetation patterns associated with a
coastal wetland, the control of invasive plant species via herbicide applications and/or mechanical removal is a common restoration tactic utilized by resource managers (Alliance for the Chesapeake Bay, 2003).

Another innovative strategy that is being implemented in coastal wetland restoration efforts involves the installation of artificial structures, such as reef balls, in an attempt to attenuate wind-generated waves, reduce erosion rates, and provide a habitat network that can be utilized by aquatic organisms in nearshore waters (Gedan et al., 2011). According to the U.S. Department of Agriculture (2008), the installation of structures can also be used to block channels, which can help to restore coastal wetlands experiencing issues associated with saltwater intrusion by limiting the influx of saltwater. In addition to the installation of artificial structures, the use of dredged material is also a common restoration strategy used to help reestablish coastal wetland systems. Depositing thin layers of dredged material provides a variety of benefits to coastal wetland systems such as increasing marsh elevation and promoting vegetative colonization (Ford, Cahoon, & Lynch, 1999).

Overall, a wide variety of restoration strategies are currently used to reestablish the functions of coastal wetlands to preexisting conditions. Implementation of the aforementioned restoration strategies, among others, is designed to meet restoration objectives in an effort to promote restoration success.

**Wetland Protection Measures**

Growing concerns over the loss and degradation of wetland systems in the United States over the past few decades has prompted the establishment of federal legislation aimed at protecting wetlands. Some of the most significant federal regulations established to protect wetland systems include, but are not limited to: the Clean Water Act (CWA) of 1972; the Coastal
Zone Management Act (CZMA) of 1972; the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990; the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991; the National Environmental Policy Act (NEPA) of 1970; and the Endangered Species Act (ESA) of 1973.

One of the most influential laws that have been developed to protect wetlands includes the CWA. The CWA of 1972 Section 404 was established to regulate the discharge of fill and dredged material into waters of the United States, which includes wetlands (EPA, 2010). Additionally, Section 401 of the CWA provides directives regarding water quality standards for wetland systems (USFWS, 2005). The United States Army Corps of Engineers (USACE) and the EPA are the regulatory entities responsible for reviewing individual and general permits, as well as enforcing the CWA (USFWS, 2005). In addition to the CWA, the CZMA of 1972 and the CZARA of 1990 were also developed in an effort to provide protection for wetlands while balancing the need for sensible growth in coastal zones (USFWS, 2005). The regulatory agencies responsible for enforcing the CZMA and CZARA include Maryland Department of the Environment (MDE) and the NOAA Office of Ocean and Coastal Resource Management (USFWS, 2005).

Coastal wetland systems are highly subject to transportation decisions considering that transportation infrastructure, such as highways, often intersect with wetlands causing direct physical impacts, but also indirect impacts via growth stimulation, which can lead to increased sources of pollution (USFWS, 2005). As a result of the potential impacts that transportation infrastructure can have on wetland systems, the ISTEA of 1991 was established in an effort to impose comprehensive planning requirements relative to transportation decisions to ensure that the integrity of wetland ecosystems are maintained (USFWS, 2005). For instance, of the
transportation funding provided to state and local governments by ISTEA, 20 percent of the funds can be used for transportation-related enhancements, while the other 80 percent must be utilized for mitigation efforts to account for impacts to coastal wetlands (USFWS, 2005).

In 1970, the NEPA was established in an effort to determine goals for the protection, conservation, and enhancement of environmental resources, including wetlands; the Council on Environmental Quality is responsible for overseeing the regulation (USFWS, 2005). The NEPA also requires government agencies to generate an Environmental Impact Statement or Environmental Assessment, which are used to analyze the potential environmental effects of proposed actions and develop alternatives to the proposed actions in an effort to maintain environmental compliance (USFWS, 2005). Wetland protection measures can also be achieved indirectly through regulations directed towards wildlife. For example, the ESA of 1973 contributes to the federal protection of wetlands by requiring agencies to implement measures to protect endangered and threatened species (USFWS, 2005). Of the species protected under the ESA, approximately 35 percent exist exclusively in wetland habitats, or are dependent on wetland systems during a portion of their life cycle; therefore, the ESA contributes to the protection of wetlands via the species that utilize the ecosystem (USFWS, 2005). The USFWS and the National Marine Fisheries Service are the federal agencies responsible for administering the ESA (USFWS, 2005).

In addition to federal regulations that apply to wetland systems, the protection of coastal wetlands in the Chesapeake Bay region is also achieved though a variety of regional partnerships, such as the Chesapeake Bay Program, which aims to increase scientific knowledge and enhance decision-making tools in an effort to maintain existing coastal wetland systems and associated natural resources (EPA, n.d.). Generally, a considerable foundation exists for the
protection of coastal wetlands; however, targeted restoration activities continue to serve as an important proponent used to facilitate the continued existence and enhancement of coastal wetland systems.

Existing Studies

The existing literature relative to climate change and wetland restoration strategies primarily focus on how wetland systems will be impacted by climate change and provide associated recommendations for wetland restoration. For instance, Fu, Pollino, Cuddy, and Andrews (2015) evaluated the impacts of streamflow management in wetland systems, based on varying climate change scenarios, which provided useful information relative to how climate-induced hydrology will affect wetland ecosystems. Additionally, Bellisario, Cerfolli, and Nascetti (2014) investigated how the distribution and connectivity of wetland systems are influenced by climate change. Results of the study demonstrated that climate change impacts are capable of altering the distribution and connectivity of wetland habitats and recommend the use of models to prioritize land areas critical for the persistence of habitat corridors (Bellisario et al., 2014). In another study, Day Jr. et al. (2005) demonstrated how climate change could impact hydrologic regimes and concluded that hydrological management should be included in coastal wetland restoration strategies in an effort to control saltwater intrusion and maintain sediment retention properties. Despite the extent of existing studies, the ways in which surrounding land use practices influence restoration approaches and the ability to account for climate change is not widely discussed. Overall, this study will help to advance the practice of coastal wetland restoration by fostering a better understanding of how surrounding land use patterns influence restoration objectives and identifying strategies that can be used to account for climate change in restored wetland systems.
III. METHODOLOGY

This study addresses how climate change and adjoining land use practices influence the selection of coastal wetland restoration strategies through the investigation of three applicable case studies in the Chesapeake Bay region (Figure 1) that exhibit different surrounding land use patterns including urban, commercial agricultural production, and recreational. The following case studies were analyzed:

1. Case Study #1: The Anacostia River fringe wetland restoration project in Washington D.C.;
2. Case Study #2: The Mudford Farm wetland restoration activities in Sudlersville, MD; and
3. Case Study #3: The Blackwater National Wildlife Refuge wetland restoration efforts in Cambridge, MD.

Figure 1. Map indicating the locations of the coastal wetland restoration case studies (Google Earth).
Case Study #1 involves a coastal wetland restoration project surrounded by urban land use practices; Case Study #2 discusses restoration activities with consideration for commercial agricultural adjacent land use practices; and Case Study #3 includes restoration efforts surrounded by recreational land use practices.

Information regarding surrounding land use practices and selected restoration strategies relative to each case study was obtained through the review of federal, state, and local government reports; peer-reviewed journal articles; online books; personal phone and email correspondence; and site-specific technical documents. Specific information relative to climate change, including corresponding statistics, and federal wetland protection legislation was obtained from government websites, technical documents, and peer-reviewed journal articles. The tables included in the study were generated using Microsoft Word and the figures were derived from Internet resources.

A majority of the information included in the study was obtained via internet-based search engines, which included Google and the journal article databases available through the American Public University System Library. Throughout the investigation, key words and phrases were used in conjunction with the search engines and included, but were not limited to: “coastal wetland restoration,” “surrounding land use,” “urban,” “agricultural,” “recreational,” “climate change,” “sea level rise,” “Chesapeake Bay,” “restoration strategies,” and “federal legislation,” among others. In addition to case study investigations using Internet resources, phone and email correspondence was conducted with John E. Gerber, Director/Wildlife Habitat Ecologist, at the Chesapeake Wildlife Heritage in an effort to obtain specific information regarding the Mudford Farm wetland restoration project.
Overall, the information obtained from the various sources was used to provide a foundation for the study and investigate the restoration strategies utilized in each of the case studies. The ability to account for climate change in the coastal wetland restoration scenarios was evaluated based on the capacity of the wetland systems to adjust to sea level rise and associated impacts such as saltwater intrusion and increased flooding frequency and duration.

**Site Selection**

The coastal wetland restoration case study sites were selected based on their geographical location in the Chesapeake Bay region. The following background investigations for each study include information such as a description of the land use practices surrounding the restoration site; the entities responsible for conducting the restoration efforts; property ownership; and the causes of degradation and/or loss to the affected coastal wetland system.

*Case Study #1 Background*

The Anacostia River fringe wetland restoration project was conducted in 2003 in an area surrounded by the urban land use patterns of Washington D.C. and was performed as a coordinated effort between the USACE Baltimore District, the District Department of the Environment, the U.S. Geological Survey, the National Park Service, the University of Maryland, and the Anacostia Watershed Society (District Department of the Environment [DDOE], 2009). The National Park Service owns the lands selected for the coastal wetland restoration project and funding for the project was obtained through multiple partner contributions (EPA, 2006). The total project cost was $4M, which included the development of feasibility studies, permitting requirements, project design and construction, and the implementation of a five-year monitoring program (EPA, 2012). Funding for the project was obtained from the following contributions: the EPA Clean Water Act Section 319 Nonpoint
Source Management Program provided a $200,000 grant to assist with project implementation; the USACE Baltimore District contributed 75 percent of the total project cost and managed the project contract and associated restoration activities; and, the DDOE provided 25 percent of the total project cost, which aided in the implementation of restoration activities and staffing needs (EPA, 2012). The central objective of the restoration effort involved the reestablishment of the historical structure and function of the ecosystem prior to anthropogenic disturbances, which began impacting the coastal wetlands in the early 1900’s (DDOE, 2009).

The coastal wetlands of the Anacostia River have been subject to a century of degradation as a result of dredging and filling activities; urban development; and the construction of a sea wall (DDOE, 2009). According to the EPA (2006), the primary stressors impacting the Anacostia River and associated areas include combined sewer overflows (CSOs), which include stormwater, untreated anthropogenic waste, industrial waste, toxic substances, and debris; sewage system leaks; urban stormwater runoff; sediment and nutrient runoff; and decades of harmful contamination. The environmental impairments associated with the Anacostia River watershed are also exhibited in the Total Maximum Daily Load (TMDL) calculations for bacteria, petroleum, metals, and organic contaminants (EPA, 2006). Specifically, CSOs are a significant problem in the Anacostia River considering that the sewer system experiences an overflow an average of 150 occurrences per year, which is the primary driver of the established bacteria TMDL (EPA, 2006). In terms of nutrients, nonpoint source pollution contributes to an estimated ten percent of Washington D.C.’s nitrogen load and 32 percent of the phosphorus load, which is ultimately directed to the Chesapeake Bay (EPA, 2006). Overall, the coastal wetlands situated along the Anacostia River are subject to significant urban inputs and are vulnerable to anticipated climate change impacts, which prompted the need for restoration.
Case Study #2 Background

Mudford Farm is located on the Eastern Shore of Maryland in Queen Anne’s County and is situated at the headwaters of the Chester River (Summit, 2011). In 2005, the 274-acre farm was purchased from a private landowner by the Biophilia Foundation, which is a non-profit organization whose objective was to restore degraded wetlands, develop riparian buffer zones, and establish upland habitat areas on the property (Summit, 2011). At the time of purchase, the property contained approximately 162 acres of cropland and 113 acres of mature forested areas (Summit, 2011). The row crops at Mudford Farm produced corn, wheat, and soybeans, which were harvested for commercial agricultural production (Summit, 2011). Conservation funds obtained from the USDA Farm Bill and MDE were used to conduct restoration activities (Summit, 2011). In conjunction with the Biophilia Foundation, the Mudford Farm coastal wetland restoration efforts were completed from 2007-2008 as a joint effort between two other non-profit organizations including the Chesapeake Wildlife Heritage and Water Stewardship, Inc. (Summit, 2011).

The Mudford Farm property is significantly influenced by the land use practices in the Chester River watershed, which includes both Kent and Queen Anne’s Counties (MD DNR, 2005). Land use in the watershed is dominated by farming activities with approximately 69 percent of Kent County and 63 percent of Queen Anne’s County classified as agricultural (MD DNR, 2005). In total, the Chester River watershed contains approximately 16,204 acres of tidal wetlands, which accounts for 6.2 percent of the total acreage of tidal wetlands in the State of Maryland (MD DNR, 2005). A majority of the coastal wetlands in the Chester River watershed can be characterized as high brackish marshes, which contain native species such as Eleocharis palustris (spike rush), Baccharis halimifolia (groundsel bush), Spartina patens (meadow
cordgrass), *Iva frutescens* (marsh elder), and *Pontedaria cordata* (pickerelweed) (MD DNR, 2005). Despite the significant acreage of coastal wetlands located in the Chester River watershed, a majority of the ecosystems are subject to inputs from agricultural activities. Specifically, the Mudford Farm wetlands serve as an example of a marsh system that has been negatively impacted by agricultural practices.

During the initial assessment of the environmental conditions on the Mudford Farm property, areas of cropland were found to have poor drainage and anaerobic soils (Summit, 2011). According to the Director and Wildlife Habitat Ecologist at the Chesapeake Wildlife Heritage, John E. Gerber (personal communication, June 1, 2015), excessive runoff from the adjacent agricultural land resulted in severe depressions in the wetland area, which had deviated from the historic hydrological regime. Overall, the long-term agricultural land use practices on the Mudford Farm property caused degraded wetland conditions, which stimulated the need for restoration.

**Case Study #3 Background**

The Blackwater National Wildlife Refuge, located in Cambridge, MD, was established in 1933 for the purpose of preserving a suitable stopover site for migratory birds considering the abundant food supply and wintering resources (USFWS, 2009). Currently, the Refuge is owned and maintained by the U.S. Fish and Wildlife Service (USFWS, 2009). The Refuge consists of over 28,000 acres of natural habitat, which provide a diverse set of environmental and ecological benefits to the Chesapeake Bay region (USFWS, 2009). Due to the large size of the Refuge area, the ecosystem is well suited to influence water quality improvements, support a wide variety of habitats, and facilitate the persistence of wildlife populations (Weber, 2004). Additionally, the coastal wetlands associated with the wildlife refuge provide an assortment of environmental and
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economic benefits such as protection against storms and ecotourism opportunities (USFWS, 2009). The land areas adjacent to the Blackwater National Wildlife Refuge wetlands are utilized for recreational purposes such as fishing, hunting, boating, and ecotourism.

Despite the benefits provided by the wetlands of the Refuge, over 5,000 acres of coastal wetlands have disappeared and/or been degraded since the 1930s as a result of saltwater intrusion; extensive herbivory; invasive species; sea level rise; and land subsidence (USFWS, 2009). One of the most significant threats to the Blackwater National Wildlife Refuge wetlands involves the destruction caused by invasive *M. coypus* populations, which were introduced to the Eastern Shore of Maryland in 1943, and have since devastated thousands of wetland acres throughout the Chesapeake Bay watershed (USFWS, 2009). The behavior of *M. coypus* contributes to increased rates of wetland degradation due to their consumption of whole plants and the development of deep swimming channels throughout a marsh system that ultimately erode sediments (USFWS, 2009). Additionally, as the marshes located within the Refuge continue to diminish, many sensitive and endangered species, such as the *Haliaeetus leucocephalus* (bald eagle) and *Sciurus niger cinereus* (Delmarva fox squirrel), are increasingly at risk due to the reduction of available habitat (USFWS, 2009). Overall, the wetlands of the Blackwater National Wildlife Refuge require restoration measures in an effort to conserve critical habitat areas.

**IV. RESULTS**

Study findings describe the restoration strategies that were applied to each site (Table 1). Each of the restoration sites is highly susceptible to the impacts of climate change, most notably sea level rise, and recommendations to account for climate change are provided (Table 2) in an attempt to promote the long-term success of future restoration efforts.
Restoration Strategies

Case Study #1

The objective of the Anacostia River fringe wetland restoration project involved the reconstruction of six hectares (ha) of tidal freshwater fringe wetlands in a high-energy mainstem area of the Anacostia River, which were separated into two distinct planting areas denoted as Fringe A and Fringe B; Fringe A occupied 1.6 ha along the west bank of the Anacostia River, while Fringe B consisted of 4.4 ha along the east bank of the Anacostia River (DDOE, 2009). The specific coastal wetland areas were identified as the most suitable locations for restoration considering the locations served as existing depositional areas, which is advantageous when attempting to raise marsh elevation and establish wetland plants (EPA, 2012).

During the initial phases of the reconstruction process, sheet piling was used to protect the Fringe A and B areas from erosive forces such as storm events and streamflow (DDOE, 2009). Subsequent to the installation of sheet piling, the wetland areas were graded in an attempt to prepare for planting events (DDOE, 2009). The Anacostia River fringe wetland restoration project also involved the placement of thin layers of dredged material in an effort to develop mudflats and increase the marsh elevation, which was targeted at 1.6-2.0 feet National Geodetic Vertical Data of 1929 (NGVD 29’) (DDOE, 2009). Sediment was hydraulically dredged from a portion of the Anacostia River channel in Bladensburg, MD and pumped in slurry form to the two depositional areas (EPA, 2006).

The second major phase of the Anacostia River coastal wetlands restoration project included the planting of freshwater vegetation. As a result of the planting efforts, approximately 350,000 plants were established in the fringe wetland areas (DDOE, 2009). The planting strategy incorporated the use of indigenous species, which included *Peltandra virginica* (green
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arrow arum), Schoenoplectus tabernaemontani (softstem bulrush), Juncus effuses (common rush), Nuphar lutea (yellow pond-lily), P. cordata, and Sagittaria latifolia (broadleaf arrowhead) (DDOE, 2009). In addition to the aforementioned-planted species, widespread plantings of Zizania aquatica (annual wildrice) were completed a year after the initial species were established (DDOE, 2009). Of the species utilized in the planting efforts at both Fringe A and B, 75 percent of the plantings were comprised of P. virginica and S. tabernaemontani; the selection of P. virginica and S. tabernaemontani as the dominant planted species was based on evidence that the species are less subject to herbivory by local populations of Branta canadensis (Canada geese) (DDOE, 2009). Another related restoration strategy involved the control of invasive species, specifically Phragmites australis (common reed), via herbicide applications (DDOE, 2009). In conjunction with the planting efforts, the installation of fencing, horizontal stringing, and flagging was completed in an attempt to reduce the predation threat from B. canadensis populations (DDOE, 2009).

Subsequent to completion of the coastal wetland restoration project along the Anacostia River (Figure 2), a five-year monitoring program was established in an effort to monitor restoration success and develop adaptive management strategies that can be used to effectively manage the fringe wetland habitats (DDOE, 2009). Overall, the combination of coordinated planning efforts and targeted restoration strategies has aided in the gradual reestablishment of the structure and function of coastal wetlands along the Anacostia River.
Case Study #2

The Mudford Farm restoration project included three primary conservation measures: the development of grass filter strips; the establishment of grass fields bordering the farmed portions of the property; and wetland restoration (Summit, 2011). The wetland restoration activities and the installation of grass buffer zones were used to filter runoff from the surrounding farmlands and provide critical habitat for waterfowl and other wildlife (Summit, 2011). Specifically, the reestablishment of the structure and function of the wetlands adjacent to the Mudford Farm property included the following strategies: construction of a 3-foot berm around the wetland site; planting and wildlife exclusion efforts; invasive plant species control; and the installation of a ditch plug (John E. Gerber, personal communication, June 1, 2015).
The coastal wetland restoration activities occurred in stages, with the first stage involving the construction of a berm around the perimeter of the emergent wetland area. Subsequent to berm construction, John E. Gerber (personal communication, June 1, 2015) communicated that planting was the next phase of the wetland restoration process. Vegetation was modestly planted in the shallow emergent wetland area in the fall months and included species such as: *Cephalanthus occidentalis* (common buttonbush), *E. palustris*, and *P. cordata*. Along the constructed berms, silt fences and straw mulch were initially utilized, followed by the planting of vegetation suitable for stabilizing the soil, which included species such as: *Panicum virgatum* (switchgrass), *Triticum aestivum* (winter wheat), and *Andropogon gerardii* (big bluestem). The restoration measures also involved the application of tree tubes, which served as a tactful wildlife exclusion technique. Invasive plants, such as *P. australis*, were controlled via targeted herbicide applications. Although the extent of planting efforts was somewhat limited to funding availability, the remaining wetland area was quickly populated by volunteer species. Another restoration tool utilized on the coastal wetlands adjacent to the Mudford Farm involved the construction of a ditch plug, which functions as a hydrologic control structure (USDA, 2011). In addition to the aforementioned wetland restoration measures, a portion of the restored wetland exists under a permanent conservation easement and includes a mitigation bank that was constructed to protect 10-acres of wooded wetland areas (USDA, 2011).

Overall, the coastal wetland restoration actions implemented on the Mudford Farm property (Figure 3) restored 38.8 acres of wetlands, 43.6 acres of grass buffers, with the remaining 80 acres available for continued commercial agricultural production activities. The wetland restoration efforts on the Mudford Farm property have resulted in significant reductions of nutrients loads for nitrogen and phosphorus at 75.9 and 75.2 percent, respectively (Summit,
The remaining productive land surrounding the restored wetland areas continues to be used for the commercial agricultural production of corn, wheat, and soybeans; farming practices were modified to include pest control measures, rotational farming, and the use of low impact fertilizers (Summit, 2011).

As a result of the wetland restoration efforts and other environmental enhancements, the Mudford Farm landowner was able to procure financial incentives, which were offered by MDE and the U.S. Department of Agriculture’s Conservation Reserve Enhancement Program (Summit, 2011). Overall, the specific strategies implemented in the restoration of the Mudford Farm wetlands resulted in the reestablishment of the structure and function of the ecosystem to representative historical conditions that existed prior to the impacts from surrounding agricultural land practices.
Case Study #3

The coastal wetland restoration efforts at the Blackwater National Wildlife Refuge (Figure 4) have involved efforts including the eradication of invasive *M. coypus*; reduction of resident *B. canadensis* populations; control of invasive plant species; use of on-site dredged material; and the facilitation of the landward migration of marsh habitats (USFWS, 2013).

Figure 4. Blackwater National Wildlife Refuge wetland restoration (Chesapeake Bay Program, 2011).

As a result of the significant threats that *M. coypus* populations pose to the coastal wetland resources within the Blackwater National Wildlife Refuge, one of the primary restoration initiatives involved the eradication of the *M. coypus* populations, which was accomplished via the U.S. Department of Agriculture’s Maryland Nutria Project (USFWS, 2009). The Maryland Nutria Project eliminated *M. coypus* from approximately 150,000 acres of land on the Delmarva Peninsula, which included the Blackwater National Wildlife Refuge
In addition to *M. coypus*, *B. canadensis* also threaten the coastal wetlands of the Blackwater National Wildlife Refuge. Due to the significant vegetation loss as a result of extensive herbivory by *B. canadensis* populations, restoration actions also involved the installation of fencing around newly vegetated coastal wetland areas in an effort to deter and/or reduce the geese population at the Blackwater National Wildlife Refuge (USFWS, 2009). In addition to the control of invasive and nuisance animal species, coastal wetland restoration measures at the Blackwater National Wildlife Refuge also included the control of invasive plant species, most notably *P. australis* (Lerner, Curson, Whitbeck, & Meyers, 2013). The control of *P. australis* is an ongoing effort that is achieved via targeted herbicide applications in an effort to prevent the invasive species from outcompeting native plants, especially those that are critical to the survival of wildfowl (Lerner et al., 2013).

Another primary restoration strategy involved the use of on-site dredged material to increase the coastal marsh elevation and stabilize the shoreline at the Blackwater National Wildlife Refuge, which was achieved in coordination with the USACE, Maryland Department of Natural Resources, National Fish and Wildlife Foundation, NOAA, National Aquarium in Baltimore, Ducks Unlimited and Friends of Blackwater (USFWS, 2009). Coastal wetland restoration measures at the Blackwater National Wildlife Refuge also included actions used to facilitate the landward migration of marshes in response to sea level rise. Techniques used to assist the wetlands in transitioning to upland areas included the acquisition of priority marsh areas and adjacent upland areas; the removal of dead trees; and planting of transitional species such as *P. virgatum* (Lerner et al., 2013). Overall, coastal wetland restoration efforts at the Blackwater National Wildlife Refuge have aided in the reestablishment of the coastal wetlands, which are maintained as critical habitat areas.
Table 1. Summary of the surrounding land use patterns and the strategies used in the coastal wetland restoration case studies.

**Recommendations to Account for Climate Change**

Based on the strategies utilized in the coastal wetland restoration case studies, the following recommendations (Table 2) are provided in an effort to 1) enhance the selection of restoration strategies to promote the reestablishment of the structure and function of coastal wetland systems prior to anthropogenic and/or environmental disturbances, and 2) identify efforts that can be implemented to account for climate change impacts to support the long-term effectiveness of restoration objectives.

**Localized Approaches**

In an effort to account for climate change in the design and implementation of coastal wetland restoration strategies, resources managers should focus on restoration techniques that
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will allow a wetland system to naturally adjust with sea level rise. Boesch (2006) recommends that wetland restoration goals should consider anticipated disturbances to the system, such as sea level rise, and how to facilitate wetland resiliency. As sea level continues to rise, resource managers should focus on facilitating the landward migration of wetland systems in an effort to preserve the ecological and economic integrity of the Chesapeake Bay region. For instance, NWF (2008) recommends the following actions regarding coastal wetland restoration objectives: expand coastal wetland restoration footprints to accommodate for landward migration; distinguish wetland areas that require targeted restoration strategies, such as sediment replenishment activities; include diverse habitat types in restoration and protection plans in an effort to support cumulative ecosystem functions; prioritize coastal wetland restoration sites based on both ecological significance and susceptibility to climate change impacts; and include adaptive management practices in restoration monitoring plans. Facilitating the natural adjustment of a wetland system in response to sea level rise is an important consideration in the development of coastal wetland restoration strategies and should be incorporated in future restoration initiatives.

Relative to planting efforts utilized as a targeted restoration strategy, the selection of coastal wetland vegetation could be used to account for climate change impacts. For instance, Coops, Geilen, Verheij, Boeters, and van der Velde (1996) conducted an experiment using a wave tank to determine the net erosion rate of beds planted with *Scirpus lacustris* (bulrush), *P. australis*, and unplanted sediment. Results of the study indicated that planted beds exhibited reduced erosion rates compared to exposed beds considering that *S. lacustris* and *P. australis* were capable of reducing net erosion rates by 33% and 82%, respectively (Coops et al., 1996). Additionally, Tiner (2003) explains that coastal wetland systems containing a greater number of
woody vegetation contribute more significantly to flooding delay considering that trees and shrubs have a higher frictional resistance factor; therefore, selecting woody vegetation as a component of the planting efforts could help to reduce flooding frequency and intensity. Overall, the careful selection of planted species in a restoration project could aid in the ability for a coastal wetland system to accommodate for climate change impacts.

In relation to protected wetland systems, such as those located within the U.S. National Wildlife Refuge System, climate change is a complex challenge that requires careful consideration in the selection of restoration strategies. One recommendation that could be applied to the Blackwater National Wildlife Refuge in an effort to account for climate change involves the implementation of a unified regional conservation approach. For instance, Griffith et al. (2009) recommends the establishment of a national interagency organization that can be used to facilitate the distribution of climate change information, which will allow for the coordination and collaboration between government agencies and improve the effectiveness of restoration efforts to account for climate change impacts. In summary, an appropriate level of regional interagency coordination could help to tailor restoration objectives for specific coastal wetland sites and incorporate a broader restoration perspective.

Another recommendation, as described by Rannow et al. (2014), that can be used to account for climate change impacts in protected coastal wetland restoration sites involves the application of sensitivity, vulnerability, and risk assessments. The implementation of these assessments serves many purposes that could benefit coastal wetland restoration efforts including, but not limited to: documenting existing information relative to potential climate change impacts; identifying vulnerable coastal wetland systems and/or wetland-dependent species; determining ecosystem features that influence climate change vulnerability; incorporate
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uncertainties associated with climate change impacts; and provide a structure that can be used to identify suitable response actions (Rannow et al., 2014). Overall, protected coastal wetland systems serve as a foundation for conservation activities and are becoming an increasingly important resource as climate change impacts become more apparent.

_Landscape-level Approaches_

Another primary recommendation that could be applied to coastal wetland restoration initiative involves the application of landscape-level approaches, such as a watershed analysis. Conducting a watershed analysis aids in the selection of wetland restoration strategies by prioritizing restoration objectives and identifying potential disturbances and causes of wetland degradation (Kershner, 1997). Impacts from climate change could be incorporated into a watershed analysis and provide information regarding more effective planting strategies. For example, perennial plant species, compared to annual plant species, are more capable of persisting albeit gradual environmental changes, such as sea level rise; therefore, a watershed analysis could influence the planting of more perennial plant species in an attempt to increase the probability of restoration success considering climate change (Neubauer & Craft, 2009).

Understanding how a watershed impacts a specific wetland site is beneficial because it increases the success of restoration initiatives via incorporating information about the surrounding land use. Additionally, wetland restoration strategies should be selected using a scientific basis that will foster the continuance of ecosystem services in a watershed that is dominated by anthropogenic activities (Boesch, 2006).

In terms of the geographic configuration of wetland restoration activities, De Laney (1995) recommends that wetlands should be designed for function, rather than form, which denotes that restoration designs should avoid highly structural shapes, such as rectangles, and
other types of rigid structures. Wetland restoration strategies should focus on wetland functions and be designed in a method that facilitate key wetland functions; requires minimal maintenance; and allows the wetland system to utilize natural hydrologic regimes (De Laney, 1995). Future coastal wetland restoration efforts should emphasize more natural configurations in an effort to promote wetland function, rather than form. Overall, utilizing a landscape-level approach in the establishment of restoration criteria could aid in increasing the success of coastal wetland restoration objectives.

Targeted Adaptation Measures

Adaptation measures involve methods that can be applied to accommodate for environmental problems that exist in specific wetland systems. One recommendation that could be used to enhance current coastal wetland restoration strategies in early successional wetlands involve the establishment of a controlled reduced tide system, as described by Beauchard (2011). A controlled reduced tide system aids in the creation of a suitable tidal regime in embanked areas of a tidal wetland in an effort to restore critical hydrological functions (e.g. establish flood resistance) and restore favorable habitat areas (Beauchard, 2011). The development of a controlled reduced tide system could be easily applied to restored coastal wetland systems, such as the wetlands adjacent to the Mudford Farm property, in an attempt to facilitate success as factors, such as sea level rise, increased flooding, and increased storm intensity become more apparent. Another consideration, in terms of adaptation measures, involves the environmental setting associated with coastal wetland restoration sites. The success of a coastal wetland restoration project is highly dependent on environmental setting and sites selected for wetland restoration should be carefully examined in an effort to ensure success. For instance, coastal wetland restoration efforts in locations with a high fetch (i.e. greater than nine kilometers) are
often unsuccessful; therefore, structures such as reef balls could be used to reduce the fetch and increase the probability of restoration success (Knutson, Ford, Inskeep, & Oyler, 1981).

Relative to the restoration of wetlands adjacent to agricultural land practices, such as in the case of the Mudford Farm property, Lles and Marsh (2012) recommend the application of diversified farming systems in which farmers adopt agricultural practices that purposely include the maintenance of ecosystem services, such as those acquired from wetlands. In an effort to promote diversified farming systems, Lles and March (2012) recommend public policy improvements, such as increased investments in agricultural conservation programs and support for farm-related ecosystem services, in an effort to support ecological diversification associated with agricultural lands. Generally, stress on wetlands (e.g. nonpoint source pollutants) due to surrounding agricultural land use practices occurs on a seasonal basis, considering the fluctuations in agricultural activities (De Laney, 1995). In an attempt to adapt to significant agricultural inputs, De Laney (1995) recommends that grass buffer strips contain a minimum width of 100 feet; sufficient grass buffer strips remove approximately 80 percent of the sediment entering a water system. Overall, adaptation measures such as diversified farming systems and sufficient grass buffer strips could be used to increase restoration success in wetlands situated adjacent to agricultural lands.

Another adaptation measure, in response to armored shorelines, could be used to provide coastal wetlands with the capability to naturally adapt to sea level rise. Armoring sensitive shorelines is a common practice in the Chesapeake Bay region, which is implemented in an effort to protect a coastline against erosive forces (EPA, n.d). For instance, 28 percent of Maryland coastlines have been armored and approximately 220 miles of coastline have been hardened in Virginia in the last two decades (EPA, n.d.). Despite the seemingly effective
restoration tool involving the hardening, or armoring, of a coastline, hardened areas of the coastline are especially susceptible to impacts from sea level rise (EPA, n.d.). Alternatives to shoreline hardening, such as the creation of a “living shoreline” could be implemented in an effort to allow wetlands the ability to naturally adapt to sea level rise (EPA, n.d.). The development of a living shoreline is a techniques used to protect coastlines from erosion via planting of native vegetation in conjunction with the installation of bioengineering materials such as coir logs (CBF, 2007). Living shorelines provide a variety of benefits to coastal wetland systems including, but not limited to: water quality improvements; increasing wildlife access; and the absorption of wave energy (CBF, 2007). In the case of the Anacostia River fringe wetlands, which are unable to undergo landward migration due to surrounding urban land use, the wetland system could benefit from replacing the sheet piling, which armors the wetlands, with a living shoreline. Coastal urban areas could also accommodate for climate change impacts by requiring the inclusion of adaptation measures, such as green roofing projects and the implementation of no-construction zones, in infrastructure and development planning (McGranahan et al., 2007). Overall, the establishment of living shorelines and environmentally conscious development decisions are recommended to enhance the success of coastal wetland restoration initiatives.

Lastly, an adaptation measure that can be applied to any coastal wetland restoration project involves the use of long-term adaptive monitoring. For instance, Griffith et al. (2009) explains that adaptive management can aid in highlighting how climate change will impact habitat alterations in addition to species abundance, diversity, and distribution. Adaptive management can be used to tailor restoration objectives, based on anticipated climate change impacts, and detect climate related changes to a wetland system (Griffith et al., 2009).
Generally, the selection of coastal wetland restoration strategies should incorporate climate change impacts in an effort to promote long-term success of the wetland system. The aforementioned recommendations to account for climate change, particularly sea level rise, could be used to enhance restoration actions by improving the long-term integrity of the coastal wetland systems. Understanding the impacts of climate change will aid resource managers and urban planners in the establishment of coastal wetland restoration objectives that can accommodate for future alterations to wetland structure as climate change impacts become more apparent.

**Universal Restoration Strategy Recommendations**

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<td>1.</td>
<td>Select wetland restoration strategies using a scientific basis</td>
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<td>2.</td>
<td>Utilize woody vegetation as a component of the planting efforts</td>
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<td>3.</td>
<td>Conduct a watershed analysis</td>
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<td>4.</td>
<td>Focus restoration strategies on function; rather than form</td>
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<td>5.</td>
<td>Select restoration sites based on environmental settings</td>
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<td>6.</td>
<td>Conduct long-term adaptive monitoring</td>
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<td>7.</td>
<td>Conduct sensitivity, vulnerability, and risk assessments</td>
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**Table 2. Recommended restoration strategy adjustments to account for climate change impacts.**

<table>
<thead>
<tr>
<th><strong>Case Study #1: Targeted Recommendations</strong></th>
<th><strong>Case Study #2: Targeted Recommendations</strong></th>
<th><strong>Case Study #3: Targeted Recommendations</strong></th>
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<td>1. Replace the sheet piling with a living shoreline 2. Expand the coastal wetland restoration footprint to accommodate for landward migration</td>
<td>1. Apply a diversified farming system 2. Expand the coastal wetland restoration footprint to accommodate for landward migration 3. Establish sufficient (i.e. minimum width of 100 feet) grass buffer strips 4. Establish a controlled reduced tide system</td>
<td>1. Implement a unified regional conservation approach</td>
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V. DISCUSSION

Based on the restoration actions applied in the case studies, the following discussion highlights: 1) the appropriateness of the strategies used in each restoration scenario, based on surrounding land use; 2) the common restoration strategies implemented in the case studies; and 3) an evaluation of the long-term effectiveness of the restoration strategies used in each case study, based on anticipated climate change impacts.

Selection of Restoration Strategies

*Case Study #1*

The coastal wetland restoration strategies utilized in the Anacostia River fringe wetland restoration project were significantly influenced by the surrounding urban land use patterns. One of the restoration strategies implemented in the project involved the installation of sheet piling, which was used to protect against erosive forces, such as significant wave energy generated by boat traffic on the Anacostia River, which is likely a result of the nearby urban centers. For instance, a survey of boat traffic included in the Anacostia River Navigation Evaluation Final Report indicated that from July 2013 to October 2013, approximately 5,328 vessels were observed using the River channel (District Department of Transportation, 2014). Considering the significant degree of boat traffic in the Anacostia River, the installation of sheet piling proved to be a critical restoration strategy in an effort to protect the restored fringe wetlands from excessive wave energy.

Another principal restoration objective associated with the project was related to the establishment of coastal wetland systems capable of managing the significant quantity of urban runoff considering the high degree of impervious surfaces located in the Washington D.C. area. To date, the Anacostia River fringe wetland restoration project has been considered a successful
urban wetland restoration project based on the significant vegetative advancements subsequent to restoration efforts (EPA, 2006). For instance, since the completion of the restoration project, the coverage of plants has increased by about 80 percent and over 70 species have been identified and recorded in the restored wetland areas, most of which are volunteer species (EPA, 2012). The colonization of dense layers of vegetation in the coastal wetlands has provided the marsh systems with the ability to effectively absorb nutrients, filter industrial and urban runoff, and trap sediments (EPA, 2012).

Contributing factors to the vegetative success of the Anacostia River fringe wetlands involves the use of material dredging from the Chesapeake Bay navigation channels; the control of invasive plant species; and the implementation of wildlife exclusion methods. Managing the elevation of the wetlands and associated mudflats is critical to the success of tidal freshwater wetland vegetation, which is needed to trap and filter the significant degree of urban runoff, generated from the Washington D.C. metropolitan area (EPA, 2006). Increasing the marsh elevation via placement of dredged material afforded the wetland areas the capacity to successfully support emergent vegetation and reduce the threat of invasion by *P. australis*, which is a nonnative species capable of dominating a wetland system (DDOE, 2009). Findings from the monitoring program support the increase in wetland elevation considering that the higher elevation allows for the growth of annual plants and other upland vegetation (EPA, 2006). Additionally, U.S. Geological Survey (USGS) investigations have revealed that the Anacostia River contains a functional and diverse seed bank of freshwater wetland species that are capable of colonizing dredged material; therefore, the rapid progression of vegetative growth at the fringe marsh sites was facilitated by voluntary colonization coupled with targeted planting efforts and managed herbivory (Neff & Baldwin, 2005). Results from the USGS studies also indicated that
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tidal wetland diversity is maintained and/or enhanced when invasive species, such as *P. australis*, are controlled (Cahoon, 2007). Therefore, the invasive plant control measures that were included as a restoration tool serve a beneficial function in regards to vegetative diversity associated with the Anacostia River fringe wetlands.

The implementation of wildlife exclusion methods served as another restoration strategy used to facilitate restoration success of the Anacostia River fringe wetlands. The wildlife exclusion techniques were aimed at preventing excessive herbivory by *B. canadensis* populations and included the use of fencing, horizontal stringing, and flagging (DDOE, 2009). The aforementioned wildlife exclusion techniques are recognized as beneficial methods used to prohibit *B. canadensis* populations from feeding on wetland vegetation (Smith, Craven, & Curtis, 1999). For instance, Smith et al. (1999) explain that fencing, horizontal stringing, and flagging above and/or around vegetated areas will repel larger birds by preventing them from landing and/or walking into the wetland areas, consequently protecting vegetation and facilitating continued growth.

Overall, restoration of the Anacostia River fringe wetlands is beneficial in reestablishing a natural buffer zone that will aid in flood attenuation, which will protect urban areas, such as Washington D.C., that are situated in a coastal zone. Additionally, the restored wetland areas will serve to filter industrial/urban runoff and retain sediments that enter the system from the adjacent urban land use practices.

*Case Study #2*

The coastal wetland restoration strategies selected for the Mudford Farm wetland restoration project were chosen based on the impacts from surrounding agricultural land use practices. The main objective of the restoration efforts was to establish a means of sediment
retention and filtering nutrient runoff from the adjacent agricultural lands. One of the initial restoration measures implemented at the Mudford Farm wetland involved the construction of a berm. John E. Gerber (personal communication, June 1, 2015) explained that a 3-foot horseshoe-shaped berm was constructed around the shallow emergent freshwater wetland area in an effort to control drainage and restore the depressed portions of the wetland. Since construction, the berm has demonstrated the successful retention of runoff before sediment and nutrients enter the headwaters of the Chester River, which is consistent with restoration goals.

Vegetation planting was another primary restoration strategy used to reestablish the structure and function of the coastal wetlands adjacent to the Mudford Farm. The planted species were selected and distributed across the restoration site based on the environmental conditions. For instance, *C. occidentalis* was one of the most highly utilized species in the low marsh area considering that *C. occidentalis* is best suited for saturated soils and can consistently tolerate water depths up to three feet (USDA, 2002). Additionally, the use of *C. occidentalis* in restored wetlands is especially beneficial considering that the seeds and twigs provide a food source for many waterfowl species and other wildlife (USDA, 2002). The vegetation that was planted on the constructed berm was used to stabilize soils. For instance, *A. gerardii* was one of the primary species selected for the berm planting considering it is used to control erosion via soil stabilization; *A. gerardii* produces rhizomes that spread one to two inches below the soil surface and contain roots that extend up to ten feet below the soil surface (USDA, 2004). In terms of ecological benefits, *A. gerardii* also provides suitable nesting and foraging resources for birds and other wildlife (USDA, 2004). In conjunction with the planting efforts, the control of invasive plant species, most notably *P. australis*, was another strategy utilized during the
restoration process, which contributed to the ability of the coastal wetland site to undergo rapid colonization of native freshwater plants.

Another restoration action that contributed to the vegetative success of the coastal wetland adjacent to the Mudford Farm property involved the implementation of a wildlife exclusion technique, which included the application of tree tubes or shelters. Tree tubes are designed to exclude juvenile trees from competition from weeds and excessive herbivory from wildlife (Sweeney, Czapka, & Yerkes, 2002). The tubes are normally ventilated and light in color, which allows for trees the capacity to continue growing at a normal rate (Sweeney et al., 2002). Additionally, tubes utilized on seedlings exhibit a survival rate four times greater than seedlings without tubes, as well as, more significant vertical growth (Sweeney et al., 2002). Overall, the use of targeted planting efforts, invasive species control, and wildlife exclusion techniques proved to be beneficial restoration strategies capable of producing vegetative success in the Mudford Farm coastal wetland restoration project.

The installation of a ditch plug was completed as part of the actions used to restore the Mudford Farm coastal wetland, which functions as a hydrologic control structure to aid in the regulation of water levels in the wetland area and manage the mudflats (USDA, 2011). The incorporation of a ditch plug allowed the wetland to reestablish the historic hydrological regime, which supported the functional success of the restoration project. In addition to the direct actions used to restore the coastal wetland system neighboring the Mudford Farm property, indirect measures, such as the establishment of grass buffer strips were also implemented in an effort to promote restoration success.

Sensitive ecosystems, such as wetlands, that are situated adjacent to agricultural land use practices are subject to significant threats due to sediment runoff and the widespread use of
agricultural pesticides, which are primarily transported to bordering systems via erosion and surface runoff (Reichenberger, Bach, Skitschak, & Frede, 2007). Of the actions performed at the Mudford Farm property, one of the indirect coastal wetland restoration measures involved the establishment of grass buffer strips, which were situated between the agricultural field and the restored wetland. As sediments enter a wetland, the system is subject to significant accumulations of sediment, which can create drier conditions and alter the vegetative patterns causing shifts to more upland plants (De Laney, 1995). The planting of grass buffer strips is a beneficial technique that aids in relieving sedimentation stress on the wetland system and allowing the system to function effectively (De Laney, 1995). Additionally, grass buffer strips situated along the edges of agricultural fields have demonstrated the ability to reduce pesticide runoff into surface waters (Reichenberger et al., 2007). Overall, the implementation of grass buffer strips on the bordering agricultural fields is highly effective tool that can be used to reduce negative impacts to restored wetland systems.

The establishment of a conservation easement to protect a portion of the wetland system was also conducted in conjunction with the restoration measures. The current landowners, the Biophilia Foundation, have an invested interest in maintaining the conservation values of the land and enhancing the ecological conditions of the wetland area; however, the succeeding landowners may not maintain the same level of motivation to manage the conservation area. For instance, Stroman and Kreuter (2014) explain that as landownership changes occur, the long-term support and success of conservation easements may be inhibited. Although the Biophilia Foundation has disclosed their intention of selling the farmland to a responsible owner, the long-term maintenance of the conservation easement may be impacted by factors such as: lack of landowner motivation and/or knowledge, subsequent changes in landownership, and/or the level
of support from the easement holder (Stroman & Kreuter, 2014). Therefore, the establishment of a conservation easement can serve as an effective conservation tool, although there are many limitations to long-term support for appropriately maintaining the easement.

As a result of the restoration measures implemented in the coastal wetland area adjacent to the Mudford Farm, many ecological benefits were reinstated, including the provision of habitat for local wildlife such as waterfowl, wild turkey, and quail (Summit, 2011). For instance, the Chesapeake Wildlife Heritage collected bird sightings data from 2005 to 2010 on the Mudford Farm property and results of the data collection indicated that the presence of ducks and shorebirds were a direct result of the restoration activities (Summit, 2011). Additionally, the restoration actions performed on the Mudford Farm are consistent with the recommendations from the Chesapeake Bay Program, which supports that agricultural best management practices, such as the restoration of wetlands and the establishment of grass buffer zones are the most cost-effective methods that can be used to reduce direct sources of nutrient pollution (e.g. nitrogen and phosphorus) that enter the Bay system (Chesapeake Bay Foundation [CBF], 2005). According to the Chesapeake Bay Foundation (2005), it is estimated that approximately 66 percent of nitrogen and phosphorus reductions to the Chesapeake Bay could be achieved via agricultural best management practices (CBF, 2005). The Mudford Farm wetland restoration efforts serve as an example of how innovative funding methods can be used on farmlands to maintain commercial agricultural production activities while providing environmental services via restoration that uphold environmental compliance measures (Summit, 2011). In the case of the Mudford Farm, environmental markets allowed the property owner to modify farming practices via compensation for reducing nutrient loads, which could be applied to other coastal farm properties (Summit, 2011).
Overall, the coastal restoration efforts associated with surrounding land use patterns consisting of commercial agricultural production proved to restore the structure and function of the wetland system prior to disturbance. The wetland system is subject to significant agricultural inputs; however, the selected restoration strategies were designed to provide the wetland with the ability to retain sediments and filter nutrients, as well as, other contaminants resulting from agricultural land use practices.

Case Study #3

The coastal wetland restoration strategies utilized at the Blackwater National Wildlife Refuge were selected based on the surrounding recreational land use practices. Although the Refuge wetlands are not subject to urban and agricultural inputs, the primary objective of the restoration strategies aim to enhance wildlife habitat.

In the marshes of the Blackwater National Wildlife Refuge, the primary cause of erosion is a result of prolonged soil saturation, which reduces plant productivity and slows sediment accretion rates (Lerner et al., 2013). Considering that the marshes receive minimal sediment deposits, organic matter serves as the primary foundation for increasing the marsh elevation (Lerner et al., 2013). As a result of the conditions at the Blackwater National Wildlife Refuge, one of the primary restoration initiatives involved the addition of thin sediment layers via hydraulic dredging in an effort to enable the marsh to increase in elevation and fill the severely eroded areas of the marsh (Lerner et al., 2013). In addition to sustaining the marsh elevation for the provision of wildlife habitat, the control of invasive plant species has aided in the ability of the marsh to retain native vegetation species preferred by waterfowl and other wildlife (Lerner et al., 2013). Another effort to preserve and/or restore wildlife habitat areas within the marsh system included wildlife exclusion techniques in the form of fencing, which was used to reduce
and/or deter resident *B. canadensis* populations in an attempt to prevent excessive herbivory, and the eradication of invasive *M. coypus* populations. The control of targeted animal species helps to maintain the native wetland vegetation for desired species.

In an effort to restore the Blackwater National Wildlife Refuge marsh areas, the facilitation of landward migration, in response to sea level rise, serves as one of the most significant restoration measures that aim to salvage the disappearing marshes. Resource managers at the Refuge have implemented three primary actions to facilitate landward migration, which include: the acquisition of land for wetland migration purposes, the removal of dead/dying trees, and the introduction of a salt-tolerant transitional species. In terms of land acquisition, the partnering agencies including The Conservation Fund, the USFWS, and the Chesapeake Conservancy have procured 508 acres of land that will be managed for wetland migration and adaptation purposes (The Conservation Fund, 2015). The total land area was acquired from the Holt property and the Besley and Rodgers property, which total 355 and 153 acres, respectively, will aid in the facilitation of natural landward migration as the marshes become inundated due to sea level rise (The Conservation Fund, 2015).

In addition to the acquisition of land to accommodate for the landward migration of wetlands, resource managers are also removing dead and dying trees on the borders of the transitioning habitat, which is primarily a result of soil saturation and increases in salinity (Lerner et al., 2013). The removal of dead and/or dying trees will facilitate the transition of vegetative species as the marsh areas migrate inland and increase the habitat availability for waterfowl species (Lerner et al., 2013). Many birds that utilize wetlands require a significant distance between nesting areas and the edge of a forest considering the taller, more mature trees
signify areas containing potential predators; therefore, removing large trees will aid in maintaining habitat suitable for many bird species (Lerner et al., 2013).

Lastly, the introduction of a transitional species was used in combination with the aforementioned techniques aimed at facilitating the landward migration and adaptation of the coastal wetlands. As sea level continues to rise, salinity will also increase in a coastal wetland system; therefore, the Blackwater National Wildlife Refuge partners have been planting *P. virgatum* due to the species tolerance for salinity increases (Lerner et al., 2013). Planting more salt-tolerant species in the marsh areas will likely give rise to other salt-tolerant species and allow for the continued persistence of vegetation as the wetlands transition landward due to sea level rise.

Overall, the use of dredged material, control of invasive and/or nuisance species, and facilitation of landward migration has aided in the ability of the Blackwater National Wildlife Refuge coastal wetlands to enhance wildlife habitat via the reestablishment of the structure and function of the marshes prior to environmental disturbances related to sea level rise.

**Common Restoration Approaches**

Despite the significant differences in surrounding land use patterns, there were a few common restoration strategies that existed between the case studies. For instance, a restoration strategy that was utilized in all three case studies involved the control of invasive plant species, specifically *P. australis*, via herbicide applications. The mid-Atlantic region of the United States has experienced a rapid expansion of *P. australis* into coastal wetlands (Chambers, Meyerson, & Saltonstall, 1999). The extensive colonization of *P. australis* could be a result of the significant hydrological and biogeochemical changes to coastal wetlands (e.g. nutrient enrichment) since the settlement of Europeans (Chambers et al., 1999). A major impact of the invasion of *P. australis*
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involves the reduction of biodiversity considering that *P. australis* is effective at outcompeting the local flora (Chambers et al., 1999). Despite the rapid colonization of *P. australis*, it has been documented that ecosystem services, such as the improvement of water quality and sediment stabilization, are not weakened by the settlement of *P. australis* stands provided that the hydrologic regime is maintained (Chambers et al., 1999). Restoration efforts to control for *P. australis* will help to maintain biodiversity within a coastal wetland system; however, it is particularly difficult to eradicate stands of *P. australis* due to its ability to rapidly colonize and dominate local species. Despite these difficulties, maintenance of the hydrologic regime is of upmost importance considering that it is capable of sustaining critical ecosystem services despite the presence of a dominant invasive species.

The placement of dredged material served as another common restoration measure, which was used in the Anacostia River and Blackwater National Wildlife Refuge case studies in an effort to increase marsh elevation. In addition to increasing marsh elevation, the deposition of thin layers of dredged material in coastal wetlands also enhances the vegetative cover, soil density, and the amount of organic matter that exists within the marsh areas (Ford et al., 1999). According to Neubauer and Craft (2009), coastal wetlands that contain a higher availability of sediments are better equipped to grow vertically via sediment accretion, making them more resilient to sea level rise.

Lastly, wildlife exclusion techniques were utilized in all three case studies as a primary restoration strategy. The Anacostia River and Blackwater National Wildlife Refuge case studies experienced problems specific to overgrazing of *B. canadensis*, while the Mudford Farm case study used wildlife exclusion tactics to promote the growth of seedlings. The use of wetlands by certain wildlife species often results in the loss of vegetation due to excessive grazing, which can
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impact the survival of native plant species and threaten the habitat requirements for more desired wildlife species.

Overall, common restoration strategies were demonstrated between the case studies, which may be, in part, due to the relatively close proximity of the restoration sites in the Chesapeake Bay region. Another possible reason for the commonalities between restoration sites with significantly different surrounding land use patterns may be due to the fact that each of the case studies involved coastal freshwater wetlands; therefore, the similar wetland classification may explain why comparable restoration measures were utilized.

Long-term Effectiveness of Restoration Efforts

Based on the land use practices adjacent to the coastal wetland restoration efforts described above, it appears that the wetlands associated with the Mudford Farm property and the Blackwater National Wildlife Refuge have the geographic ability to migrate landward in response to sea level rise, while the Anacostia River wetlands are limited by urban development.

Case Study #1

The Anacostia River fringe wetlands are especially vulnerable to sea level rise considering the surrounding urban land use patterns. Historically, populations and/or economic activities have been concentrated in coastal regions, which increase the safety, environmental, and economic risks associated with climate change impacts (McGranahan, Balk, & Anderson, 2007). Land use patterns associated with urban areas often contribute to the increased risk of flooding as a result of activities such as the construction of impervious surfaces and land subsidence via extraction of groundwater (McGranahan, et al., 2007). Additionally, the incidental taking of coastal wetland areas, which is often caused by urban development projects, diminishes the natural buffer zone used to protect upland areas from coastal flooding.
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(McGranahan, et al., 2007). Therefore, as a result of the implications of urban land use, adjacent wetland systems are often unable to combat and/or adapt to climate change impacts.

In response to rising sea levels, the urban land use practices in Washington D.C. leave little opportunity for the Anacostia River fringe wetland to undergo landward migration due to the existing infrastructure. Additionally, sea level rise will result in increased flooding events, which will impact the integrity of structures designed for flood protection and inundate the coastal wetlands, thus rendering them incapable of performing their intended ecological and environmental functions (Titus et al., 1991).

Due to the lack of landward migration opportunities for the Anacostia River fringe wetlands, the vegetation patterns will likely experience significant impacts as a result of sea level rise. In coastal freshwater wetlands, biotic variation is often dependent on vertical elevation, which results in a gradual progression of habitats such as mudflats, low marsh areas, and high marsh areas (Barendregt & Swarth, 2013). In terms of vegetative distribution and diversity, perennial species often dominate low marsh areas, whereas annual species dominate high marsh areas, and all the species located in a coastal wetland system are accustomed to fluctuating environmental conditions that produce high levels of biological productivity (Barendregt & Swarth, 2013). As sea level rise becomes more apparent, the pulsed system of a conventional coastal wetland system begins to disappear, which impacts the habitat gradation and natural vegetation patterns (Barendregt & Swarth, 2013). Additionally, vegetation plays a significant role in the ability of a marsh to trap sediments and achieve vertical accretion rates capable of adjusting to sea level rise (Darke & Megonigal, 2003). Overall, the Anacostia River fringe wetlands are not well equipped to account for climate change impacts due to their physical proximity to a major metropolitan area.
Case Study #2

The coastal wetlands adjacent to the Mudford Farm are characterized as shallow emergent freshwater wetlands, and although the ecosystem will not be directly impacted by sea level rise and associated impacts, the potential to account for climate change still exists. For instance, the coastal wetlands of the Chesapeake Bay provide many essential functions for waterfowl including: serve as a significant stopover and wintering site for migratory birds, and provide critical breeding, nesting, and feeding habitat (NWF, 2008). Due to the rapid disappearance of tidal marshes in the Chesapeake Bay region via sea level rise, waterfowl will likely become more dependent on emergent freshwater wetlands for the aforementioned functions (Neubauer & Craft, 2009). The existence of emergent coastal wetlands in the Chesapeake Bay region will benefit waterfowl species as nearby tidal wetlands experience dry periods or become excessively inundated (Conner, & Gabor, 2006). For instance, Bolduc and Afton (2008) explain that water depth is one of the primary criteria used to describe waterfowl density, based on habitat availability considering that species diversity is normally greater at lower water depths; therefore, ample sea level rise in tidal wetlands will reduce the habitat availability for some species of waterfowl, making them more dependent on emergent wetland systems that exhibit a more controlled hydrologic regime. The restoration and management of coastal wetlands, such as the wetland system adjacent to the Mudford Farm property, will become increasingly important to waterfowl species in an effort to account for climate change impacts as tidal wetlands disappear in response to sea level rise.

Case Study #3

The coastal wetland system at the Blackwater National Wildlife Refuge has experienced a significant degree of erosion in the last few decades and supporting data suggests that the
marshes are incapable of keeping pace with sea level rise, making them especially vulnerable to climate change impacts (Stevenson, Kearney, & Pendleton, 1985). A major factor contributing to the degradation of the marsh is related to the dominance of ebb-tides, which results in an annual output of 720,000 metric tons of sediment, thus limiting the amount of inorganic sediment that reaches the marsh system (Stevenson et al., 1985). Another primary factor contributing to marsh degradation involves the slow, stagnant, and or decreasing rate of vertical sediment accretion (Cahoon, 2007). As a result of the lack of inorganic sediment entering the wetland system, the majority of vertical accretion is achieved via the deposition of peat (Stevenson et al., 1985). Data from lead isotopes has indicated that the sediment accretion rate in the Blackwater National Wildlife Refuge marsh system ranges from 1.7 to 3.6 millimeters (mm) per year, which does not keep pace, and in some cases is decreasing, compared to sea level rise which occurs at an approximate rate of 3.9 mm per year (Stevenson et al., 1985). In terms of marsh modifications, a digital elevation model (DEM) of the land surfaces at the Blackwater National Wildlife Refuge was generated using 2002 Light Detection And Ranging (LIDAR) data; DEM simulations indicated that high marsh areas will be converted to low marsh, and the low marsh areas will be converted to open water, based on the current rate of sea level rise (Cahoon, 2007). The synergistic effects of considerable erosion and sea level rise makes it difficult for the coastal wetlands to adapt to climate change; however, the restoration strategies implemented at the Blackwater National Wildlife Refuge have established specific measures to account for climate change impacts via the facilitation of landward migration.

The government agencies responsible for managing the Blackwater National Wildlife Refuge have taken additional steps in an attempt to account for climate change in concert with coastal wetland restoration efforts by identifying and procuring areas suitable for landward
marsh migration (Lerner et al., 2013). In the case of the Blackwater National Wildlife Refuge, the potential to secure and maintain marsh migration corridors is feasible considering that the coastal wetlands are surrounded by recreational land use and is not subject to encroaching urban development. Overall, the coastal wetlands of the Refuge are well equipped to account for climate change due to the flexible surrounding land use patterns and the long-term forecasting associated with the selected restoration strategies.

V. CONCLUSIONS

Climate change and surrounding land use patterns can have a significant impact on the selection of strategies used to restore a degraded coastal wetland system. Subsequent to the investigation of three case studies in the Chesapeake Bay region, which exhibited different surrounding land use practices (i.e. urban, commercial agricultural production, and recreational), results of the study highlight the importance of selecting appropriate restoration strategies and how restoration measures translate into the ability of a restored ecosystem to account for climate change impacts. The study also provides recommendations in terms of accommodating for climate change impacts, landscape-level approaches, and adaptation measures that can be used to increase the success of coastal wetland restoration initiatives. Further investigations could be used to evaluate the long-term effectiveness of innovative restoration techniques compared to conventional restoration methods.
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