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The Economic Value of America’s Estuaries: 2021 Report

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The Economic Value of America's Estuaries

2021 REPORT

Prepared for
Restore America's Estuaries

RESTORE AMERICA'S ESTUARIES

PREPARED BY
TBD ECONOMICS, LLC
CENTER FOR THE BLUE ECONOMY
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Finally, we appreciate the support of Zamia Media in helping to assist in the visual design and presentation of this report.

Sincerely,

Hilary Stevens
Coastal Resilience Manager
Restore America's Estuaries

Disclaimer

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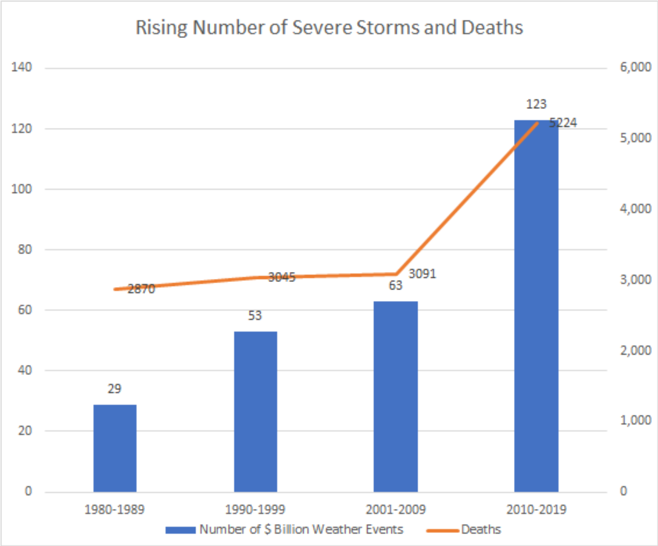
I. Forward

"Economic wellbeing means different things to different people. For some, economic wellbeing means having a good job. For others, economic well-being means happiness that sometimes comes at a financial cost (e.g., the cost of living near the beach). For politicians and public officials, economic wellbeing means economic activity, sustainable taxes, and funding for public projects. The quality of coastal and estuary areas and access to these areas influence all of these measures of economic well being." -

The Economic and Market Value of Coasts and Estuaries: What's At Stake?

Since Restore America's Estuaries published The Economic and Market Value of Coasts and Estuaries: What's At Stake? in 2008 a lot has changed; providing grounds for optimism, concern, and a clear call to action.

For the most part, we have gone beyond a conversation about "if" there is climate change to one about "when" and "how much." In a 2020 survey by the Pew Research Center, over 65% of Americans acknowledge climate change happening now, and affecting their community[1]; the highest percentage since the survey began in 2009.



Unfortunately, this increased public acknowledge ment is due in part to the devastating effects of climate change becoming more evident every day.

2020 set a new US record with $20 billion in costs associated with weather and climate disasters. It was the sixth consecutive year in which ten or more $1 billion+ disasters occurred in the US alone and the 10th year in a row with eight or more.[2]

This report demonstrates there is some good news. We can mitigate these dire climate impacts by protecting our coasts. According to the Nature Conservancy, lands behind existing salt marshes have, on average, 20% fewer property damages when compared to areas where salt marshes have been lost.[3]

From prolonged heat waves to record floods, the impacts have hit us faster than we feared. In 2017, Hurricane Harvey made landfall three times in six days. At its peak on September 1, a third of Houston, America's fourth largest city, was under water. Two feet of rain fell in the first 24 hours and caused $125 billion in damage. Flooding forced 39,000 people out of their homes and into shelters.[4]

Sadly, Hurricane Harvey is not an outlier. Floods are becoming more common and ever more expensive. According to data gathered by the Federal Emergency Management Agency (FEMA) National Flood Insurance Program, Repetitive Loss Properties have grown to well over 60,000 in the US; more than tripling the available mitigation efforts[5] The cost of flooding in 2019 alone was estimated to be between $15 and $29 billion. As staggering as these numbers are, they don't even begin to count the ecological and human toll.

With increased awareness on the impacts of coastal storms and climate change, this report highlights our understanding of the role that estuaries and coasts play as natural infrastructure that protects communities. It also clearly demonstrates the important role that estuaries and coasts play in sequestering carbon through natural processes called "blue carbon." While these features were known in 2008, the economic value and science have become much clearer in the past decade.

As you'll learn in this report, more Americans are living along coasts, increasing both the economic and human risk from coastal floods and storms. Natural infrastructure, like coastal wetlands, oyster reefs, dunes and sea grasses, all help attenuate waves, buffer storm surges and capture (and filter) flood water. They do all this while providing habitat for fish and wildlife and recreational opportunities for millions of Americans. According to the National Institute of Building Sciences, every dollar invested in disaster mitigation leads to $6 in cost savings and a reduction in harm to people and communities. It's hard to come by many investments that pay 6-1.

Many reports on economic health have a contingent "if the technology were available." However, we are in a unique position, to save our estuaries and protect our coastal communities there is no new technology required - we just need to make the decision that estuary regions, that are just 4% of our landscape but house 40% of our people and provide 47% of our economy, are worth protecting and restoring.

While this report is centered on the economic value of estuaries, we must not lose sight of what is at stake if we don't take action. As in the 2008 report, we pointed out that a focus on gross revenues and expenditures centers on activities that produce marketable goods while other activities (such as birdwatching, swimming or surfing) go unquantified from an economic perspective. Coastal areas are shared spaces for our society and therefore are not part of the traditional economic market valuation. As a result, too much attention may be given to the provision of marketed goods on the coast and too little attention given to other non-marketed, but economically and socially valuable, activities.

As we think about what we want to be as a society we should ask: what are fishing villages without fish? What are marshes without marsh grass? What is a beach holiday without sand and birds? Will we want to continue to live along coasts if we are constantly threatened by floods and storms? Now is the time to harness our collective spirit and ensure that change happens and we protect who, what, and where we love.

Daniel Hayden
President and CEO of Restore America's Estuaries

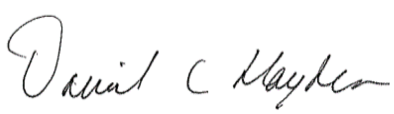



Photo Credit: Tampa Bay Watch

II. Executive Summary

WHY ESTUARIES MATTER

Estuaries have always been an essential feature of the economy. Even before European colonization, Native Americans lived either permanently or seasonally in estuary regions in large part because of food supply. European colonization, and the population and economic growth following it, were centered in the estuary regions where North America could most easily connect with Europe. That history established a pattern of economic importance which continues to today. The counties in the estuary regions of the continental U.S. comprise 4% of the land area of the U.S. but on that 4% sits 47% of the output of the U.S. economy, 39% of the employment, population, and housing (in 2018) (See Figure II-1). According to 2018 data, eight of the ten largest metropolitan areas were located in estuary regions. Estuaries are geographically small and economically huge.

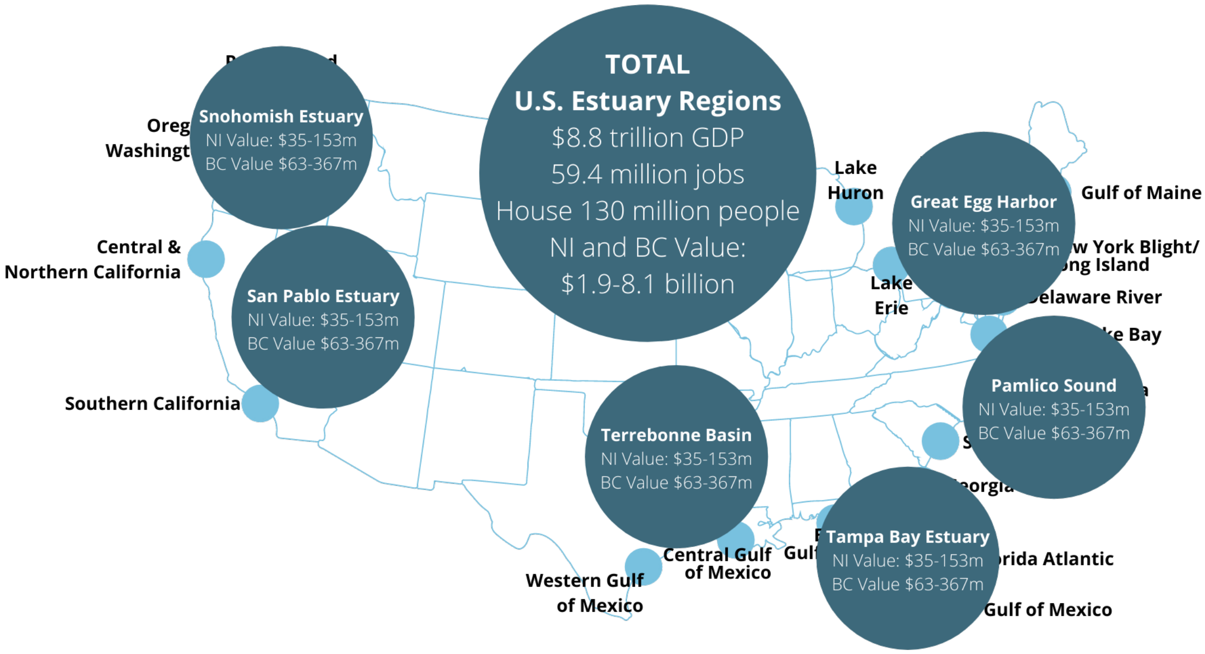
This concentration of people, as year-round or seasonal residents or as employees in the estuary regions, helps drive the national economy. But that same concentration puts enormous pressure on the natural and environmental resources of the estuaries, manifested in loss of wetlands, degraded water quality, and impaired access for economic uses such as recreation and fishing.

According to 2018 data, eight of the ten largest metropolitan areas were located in estuary regions. Estuaries are geographically small and economically huge.

In 2009, Restore America's Estuaries and The Ocean Foundation, with support from NOAA, released The Economic and Market Value of America's Coasts and Estuaries: What's at Stake?, providing a compendium of economic information related to the oceans and coasts. The 2009 report examined economic impacts to gross state and domestic product in twenty-one regions across the continental U.S. It also reviewed the benefits provided by five major sectors of the U.S. economy: fisheries, energy infrastructure, marine transportation, real estate, and recreation.

Since that time, much research has been completed to advance this knowledge; however, there have also been substantial changes in the way economists, coastal resource managers and policy makers think about economics in the last decade. New sectors and ecosystem services have emerged that have garnered a lot

Figure II-1. Economic Importance of Estuaries to the U.S. Economy



of attention from coastal managers and policy makers. However, the economic understanding of those sectors and services has not kept pace. In a changing climate, the economic benefits provided by natural infrastructure along the coast and blue carbon sequestered in estuarine ecosystems are a critical missing piece in policy decisions.

This analysis builds on the work completed in What's at Stake? and provides an update of some of the key national economic indicators previously assessed. The usefulness of studies like this is reinforced by the need for a more accurate picture of America's estuary regions, how they impact the U.S. economy, and how that relationship is changing over time. This project also assesses the values of two services (natural coastal infrastructure and coastal blue carbon storage[6])—which provide coastal resilience benefits and opportunities for mitigating the impacts of climate change—through a series of case studies at six estuaries across the nation that have natural infrastructure or stocks of coastal blue carbon at risk.

The six estuaries chosen were:

- Great Egg Harbor, New Jersey
- Pamlico Sound and the Lower Neuse River, North Carolina
- Tampa Bay, Florida
- Terrebonne Basin, Louisiana
- San Pablo Bay, California
- Snohomish River Estuary, Washington

Research and data on the five economic sectors covered in the 2009 report is much more widely available than it was a decade ago. However, there are still substantial gaps in our understanding of the benefits provided by coastal natural infrastructure and blue carbon. Our intent is to expand our understanding of the economic values of estuarine wetlands by examining the values provided by reduction in flood damages (the natural infrastructure function) and by storing carbon dioxide that would contribute to greenhouse gas emissions if released to the atmosphere (the coastal blue carbon function).

REGIONAL ANALYSIS

The twenty-one regions examined are comprised of 380 counties bordering the Atlantic, Gulf of Mexico, Pacific, and Great Lakes (See Figure II-2). These regions together comprised 4% of the land area of the U.S. but from that 4% come 47% of the output of the U.S. economy ($8.8 trillion in gross domestic product), 39% of the employment (59.4 million jobs) and 40% of the population (130 million people) in 2018. Also, in 2018, eight of the ten largest metropolitan areas were located in estuary regions. This concentration of economic activity and population in a small land area makes estuaries among the most economically valuable areas of the country, but that concentration also implies the potential for significant stresses on the environmental quality and ecosystem health of estuaries.

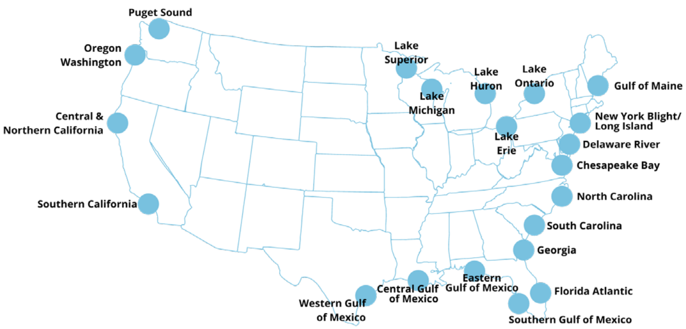


Figure II-2. Estuary Regions for Regional Economic Analysis

This review of the economic and demographic characteristics of America's estuary regions is at a relatively high level in terms of geographic scale. Conclusions from this analysis are more suggestive of key features and require more detailed analysis within each region to support efforts to manage, conserve, and restore key estuarine natural capital. But the following summary, arising from the data, may be useful:

- From 2009-2018, employment and Gross Domestic Product (GDP) grew faster in estuary regions than in the U.S. as a whole, while population and housing rates grew at a similar pace, indicating that the primary driver of change was economic rather than demographic growth. This pattern of faster economic growth compared with demographic change is present in all the estuary regions except for Lake Huron and Lake Erie.
- The pace and location of economic and demographic changes within estuary regions are important long-term drivers of natural resource change. Employment growth rates over 2009-2018 were fastest in the estuary regions on the Pacific and South Atlantic coasts. Population and housing growth were fastest in the Carolinas, the Western Gulf of Mexico, and Puget Sound.
- A key component of the estuary regions' economy are those sectors directly connected to the oceans and Great Lakes, which provided 3.1 million jobs and contributed $301.9 billion to the U.S. economy in 2018. These sectors tend to be largest in the major urban areas such as the New York Bight (598,000 jobs, 5.6% of regional employment) and Southern California (330,000 jobs and 4.0% of regional employment). But water dependent industries are more important in less urban areas such as the coastal areas of South Carolina (81,900 jobs but 15.3% of regional employment) and North Carolina (45,000 jobs but 12.4% of employment).
- The largest Ocean-Great Lakes economic activity as measured by employment in this report is tourism and recreation, which is a labor-intensive sector. Comparisons of employment among regions tend to be dominated by tourism & recreation employment, and this sector is also closely tied to the environmental and ecological health of estuaries.
- Population changes within the estuary regions were relatively small over 2009-2018, but Georgia and South Carolina saw increased populations in their near shore areas. Employment changes shifted towards the shore in the Gulf of Mexico regions but towards inland parts of the estuaries in the major urban areas such as New York, Chicago, and Los Angeles. Where growth occurs within a region matters. Faster growth near the ocean or Great Lakes can impact coastal and marine ecosystem health directly, while faster growth in the upstream parts of estuary regions have cumulative effects from runoff that magnify as they travel down the rivers and streams to the estuaries.

From 2009-2018, employment and Gross Domestic Product (GDP) grew faster in estuary regions than in the U.S. as a whole, while population and housing rates grew at a similar pace, indicating that the primary driver of change was economic rather than demographic growth.

ESTUARY CASE STUDIES

This analysis also examined the role of specific types of wetlands in reducing damages from flooding in estuaries and storing carbon in the soils that could offset carbon releases from other sources. It provides values for two ecosystem services over 30 years, natural infrastructure and coastal blue carbon, in the six estuaries noted above.

There are two important features to values of natural infrastructure and blue carbon. The first is that these are stocks of value derived from the ability of wetlands to avoid future economic damages. The value is based on ecosystem services produced by the wetlands. This value is a form of natural capital, and derived from a future flow of benefits and expressed as a present value estimated for a future period.

Secondly, and most important, the actual value is dependent on keeping existing wetlands intact, and thereby preventing or reducing economic losses. The reduction or elimination of flood losses and the avoided release of carbon stores into the atmosphere are what determine the basic values. It is worth noting that wetlands both store and sequester carbon, i.e., remove it from the atmosphere, however this study only assesses the storage values of wetlands and does not include the value of carbon sequestration in estuaries.

Estimates of these values contain uncertainty, and are ultimately best expressed as lying within a range

Table II-1. Summary of Natural Infrastructure and Blue Carbon Benefits by Case Study – Total Value in $Millions

	Wetlands Area (Hectares)		**Natural Infrastructure**		**Coastal Blue Carbon**		**Total Natural Infrastructure and Blue Carbon**	
	Natural Infrastructure	Coastal Blue Carbon	Lowest Estimate	Highest Estimate	Lowest Estimate	Highest Estimate	Lowest Estimate	Highest Estimate
			Total ($Millions)					
Great Egg Harbor	3,600	24,439	$34.1	$153.6	$63.6	$366.9	$97.7	$520.5
Pamlico Sound	62,153	37,000	$48.8	$219.8	$124.8	$720.2	$173.6	$940.0
Tampa Bay	34,377	6,652	$902.0	$2,705.1	$7.7	$44.2	$909.7	$2,749.3
Terrebonne Basin	N/A	133,462	N/A	N/A	$430.0	$2,482.6	$430.0	$2,482.6
San Pablo Bay	29,872	8,451	$15.4	$68.7	$15.9	$91.5	$31.3	$160.2
Snohomish Estuary	906	189	$0.7	$3.4	$0.2	$1.4	$0.9	$4.8
TOTAL	130,908	210,193	$1,001.0	$3,150.6	$642.2	$3,706.8	$1,946.0	$8,118.7

Photo Credit: Save the Bay SF

defined by plausible optimistic and pessimistic assumptions about future impacts of climate change. These ranges are shown in the analysis through the use of “low” and “high” estimates as in the tables below. Table II-1 and Table II-2 summarize the results from the six case studies. The value estimates are presented on both a total basis (Table II-1) and adjusted for area on a per hectare basis (Table II-2). Estuaries are listed geographically from the Northeast, clockwise to the Northwest.

Allowing for the assumptions and simplified methods used in the analysis, it is clear that natural infrastructure and coastal blue carbon values in these six estuaries are quite significant, ranging in total (across all six estuaries studied) from a low estimate of approximately $1.9 billion to a high estimate of approximately $8.0 billion over a 30-year period. Whether the natural infrastructure or blue carbon values are higher varies across the six estuaries studied.

Table II-2. Summary of Natural Infrastructure and Blue Carbon Benefits by Case Study – Value per Hectare in $Thousands

	Wetlands Area (Hectares)		**Natural Infrastructure**		**Coastal Blue Carbon**	
	Natural Infrastructure	Coastal Blue Carbon	Lowest Estimate	Highest Estimate	Lowest Estimate	Highest Estimate
			Dollars Per Hectare ($Thousands)			
Great Egg Harbor	3,600	24,439	$9.6	$42.7	$2.6	$15.0
Pamlico Sound	62,153	37,000	$0.8	$3.5	$3.4	$19.5
Tampa Bay	34,377	6,652	$26.2	$78.7	$1.2	$6.6
Terrebonne Basin	N/A [7]	133,462	N/A	N/A	$3.2	$18.6
San Pablo Bay	29,872	8,451	$0.5	$2.3	$1.9	$10.8
Snohomish Estuary	906	189	$0.8	$3.8	$1.3	$7.5

It is important to look at both per hectare and total values for each estuary. Per hectare values (high and low) for coastal blue carbon generally exceed those for natural infrastructure, except for Great Egg Harbor and Tampa Bay.[8] But when total values are examined, natural infrastructure values for both San Pablo and Snohomish become greater than coastal blue carbon values because there are more wetlands protecting assets than storing carbon. Conversely, the total value for Great Egg Harbor coastal blue carbon is greater than the natural infrastructure value, because while the per hectare value is higher for natural infrastructure, there are more wetlands storing blue carbon than protecting economic assets. These differences are primarily driven by the extent and location of development within the estuaries. Highly developed estuary regions will tend to have larger flood benefits either because the value of protected assets is high, as is the case with Tampa Bay, or more economic assets located behind wetlands, as is the case with San Pablo and Snohomish. Less developed regions, like Pamlico Sound and Terrebonne Basin, tend to have more functional wetlands sequestering and storing carbon, resulting in substantial coastal blue carbon benefits.

In addition to estimating the coastal blue carbon and natural infrastructure benefits, each of the case studies summarized past efforts at restoring wetlands. Data was primarily drawn from the NOAA Restoration Atlas, supplemented by local sources of data. Projects covered the period from 1970 to 2020. Only projects shown as completed were included in the analysis; projects listed in planning or in permitting were not included. There are additional restoration projects discussed in each case study beyond what is presented in the summary tables, however, those projects do not list the area restored, and so are not included in the tables. See each case study for additional detail on restoration data and its sources.

There are a total of 287 projects reported where the area is also reported in the case study estuaries. The largest number of projects are shown in San Pablo Bay, followed by Tampa Bay. Terrebonne Basin has, by far, the largest area restored, according to sources that provide restoration acreage, at 3,403 hectares (8,408 acres).

The largest Ocean-Great Lakes economic activity as measured by employment in this report is tourism and recreation, which is a labor-intensive sector. Comparisons of employment among regions tend to be dominated by tourism & recreation employment, and this sector is also closely tied to the environmental and ecological health of estuaries.

CONCLUSIONS

The analysis of the economies of the estuary regions reconfirms the importance of estuaries to the U.S. economy. The six case studies included in this report add significantly to our understanding of the economic importance of estuaries, showing that the value of America's estuaries is much larger than traditional economic measures reveal.

The case studies used a consistent methodology to assess the values of natural infrastructure flood resilience and coastal blue carbon. Using a consistent methodology has benefits and presents challenges. Benefits include the ability to look across the case studies and begin to discern similar patterns across the different analyses. This information can be used to support national strategies for the future management of U.S. estuaries. More work is needed before this can effectively drive sustainable policy, as the sample size is too small to make any broad characterizations. However, it does provide a basis to start thinking about what criteria in estuaries needs to be present to drive certain types of value and why measuring and monitoring that value is important.

The challenges with using a consistent methodology include limitations on understanding details that are needed for project-siting and management decisions. For instance, the method used to value natural infrastructure benefits could not be used in Terrebonne Basin because the type of wetlands that were examined did not abut any houses or commercial assets. Notably, this study is not intended to drive on the ground, project-level, or siting decisions. Several of the estuaries that were selected for case studies already have assessments of varying degrees of their benefits, developed at a much more local and usable scale. Concerns that the existence of different values for the same service are warranted, however this project explicitly recognizes those concerns, while also recognizing there is room and use for both approaches.

In every case study, in almost all scenarios, the cost of purchasing the right to release the stream of carbon by converting wetlands is much less than the social cost of the released carbon

The coastal blue carbon values derived from this analysis provide needed context and insights into emerging efforts to develop carbon markets and help integrate blue carbon values into the Nationally Determined Contributions (NDCs) required by the Paris Agreement, and state-level emission standards. While the NDCs require a much more stringent approach to assessing the stocks of carbon in coastal soils, this report provides a first look, an indication on whether undertaking the more comprehensive assessment is worthwhile. It also sheds insights on the social cost of carbon. In every case study, in almost all scenarios, the cost of purchasing the right to release the stream of carbon by converting wetlands is much less than the social cost of the released carbon. Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon at least equals the social cost of carbon.

The case studies also shed light on where to look to find certain types of benefits that estuaries provide. The natural infrastructure flood resilience benefits are greatest in the areas that contain the highest levels of economic assets, but placement of the wetlands is key. To maximize the benefits the estuaries must be conserved or restored between those economic assets and the oncoming wind and water. Conversely, natural infrastructure flood resilience benefits are relatively low in the absence of concentrations of economic assets. Terrebonne basin estuary did not have enough potentially impacted parcels that bordered buildings or homes to measure, yet it was by far the richest source of blue carbon benefits in terms of total value, second only to Pamlico Sound in terms of blue carbon benefits per hectare.

To those experienced in assessing and understanding the value of the benefits provided by coastal habitats like estuaries these concepts may seem obvious. However, they are often overlooked in broader planning and budgeting processes. Restoration investment decisions should not be driven solely by the potential for economic return, but it should be considered as part of the equation. Continued investment in the assessment and monitoring of the ecosystem services provided by our nation's estuaries can improve decisions and allow for future potential benefits to be included in current efforts to restore America's estuaries.

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Photo Credit: EarthCorps

II. Background & Context

INTRODUCTION

In 2009, NOAA, Restore America's Estuaries and The Ocean Foundation released *The Economic and Market Value of America's Coasts and Estuaries: What's at Stake?*[10] providing a compendium of economic information related to the oceans and coasts. The 2009 report examined economic impacts to gross state and domestic product, and benefits provided by five major sectors of the U.S. economy: fisheries, energy infrastructure, marine transportation, real estate, and recreation. Since that time, much research has been completed to advance this knowledge, however, there have also been substantial changes in the way economists, coastal resource managers and policy makers think about economics in the last decade. New sectors and ecosystem services have emerged that have garnered a lot of attention from coastal managers and policy makers, however the economic understanding of those sectors and services has not kept pace. In a changing climate, the economic benefits provided by natural infrastructure along the coast and blue carbon sequestered by and stored in estuarine ecosystems are a critical missing piece in policy decisions.

This project builds on the work completed in What's at Stake? and provides an update of some of the key national economic indicators previously assessed. The need for studies like this one is supported by the need for a more accurate picture of America's estuary regions, how they impact the U.S. economy, and how that relationship is changing over time. Millions of people live, work, and play in our Nations' estuaries, where rivers meet the sea. Almost half of U.S. Gross Domestic Product (GDP) is created in estuary regions which cover only about 4% of the U.S. landmass. Estuary regions provide almost 40% of American jobs, and house almost 40% of our people. As our coastal communities continue to get more and more crowded— coastal populations increased by 40 million people between 1960 and 2008[11]— increasing concentrations of people put increasing pressure on the coastal ecosystems that support these communities. This analysis will help to shed light on the pace and location of economic and demographic changes within estuaries, an important long-term driver of natural resource change.

This project also assesses the values of two services (natural coastal infrastructure and coastal blue carbon[12])—which provide coastal resilience benefits and opportunities for mitigating the impacts of climate change—through a series of case studies at six estuaries across the nation that have natural infrastructure or stocks of coastal blue carbon at risk. Research and data on the five economic sectors covered in the 2009 report is much more widely available than it was a decade ago. However, there are still substantial gaps in our understanding of the benefits provided by coastal natural infrastructure and blue carbon.

The case studies are based on locally specific data, and are intended to give a general picture of conditions in regions across the Continental U.S. The values for natural infrastructure flood resilience and carbon sequestration presented in the case studies exemplify the current economic benefits provided by these two services in regions across the country. These two new perspectives on the values of estuaries are intended to be helpful in shaping overall strategies for future management of wetlands resources, and are not intended to guide local, project-specific decisions. However, in a changing climate, the economic benefits provided by natural infrastructure along the coast and coastal blue carbon stored in estuarine ecosystems can be a valuable tool for adaptation and mitigation.

VALUING NATURAL INFRASTRUCTURE AND COASTAL BLUE CARBON

NOAA defines **natural infrastructure** as "healthy ecosystems, including forests, wetlands, floodplains, dune systems, and reefs, which provide multiple benefits to communities, including storm protection through wave attenuation or flood storage capacity and enhanced water services and security."[13] An estuary's capacity to protect shoreline property from climate hazards and flood risk is the ecosystem service that is usually measured when assessing the benefits of coastal natural infrastructure, even though there are many co-benefits that should also be considered to determine the total value. Considered broadly, natural infrastructure can offer co-benefits that contribute to the economic prosperity and well-being of coastal communities and enhance community resilience, such as plant and animal habitat, improved water quality, and recreational opportunities. However, measuring all the co-benefits that natural infrastructure can provide is beyond the scope of this analysis both in terms of cost and timeframe. The only economic role that this analysis will value is the wetlands' ability to reduce possible damages from floods—measured in terms of avoided losses to property, including flooding in the river, bay, and ocean areas within an estuary.

Over the past decades, as the relationship between greenhouse gases and climate change became clear, the scope of analyses for estuary conservation opportunities expanded to consider the role of coastal wetlands in the global carbon cycle. Coastal estuary habitats, such as salt marshes, mangrove forests, and seagrass beds sequester vast amounts of the greenhouse gas carbon dioxide, and store that carbon in their soils. The carbon sequestered and stored in coastal estuaries is called **coastal blue carbon.** Conserving and restoring estuaries rich in coastal blue carbon mitigates the impacts of climate change[14][15] and provides additional benefits that support local communities and can bolster local economies. These benefits include providing nursery habitat for fish[16], reducing the impact of storm surge,[17,18,19] and improving water quality.[20,21,22] Researchers estimating global coastal blue carbon emissions have observed the rapid disappearance of coastal wetlands due to human activity, despite federal and regional wetland protection and planning.[23] As the U.S. rejoins the Paris Agreement, an ambitious global agreement to fight climate change, showing climate leadership will be an increasingly important part of domestic policy efforts.

Photo Credit: Tampa Bay Watch

III. Methods

METHODS FOR REGIONAL ANALYSIS

One of the purposes of the original report, The Economic and Market Value of Coasts and Estuaries: What's at Stake, was to raise awareness of estuaries as locations of significant economic contributions to the states and nation. This was accomplished by assembling data on employment, population, and contributions to gross domestic product in each of twenty-one regions on the Atlantic, Pacific, Gulf of Mexico, and Great Lakes coasts. The relative size and economic contribution on each measure were identified, and trends in the economic and demographic measures noted. The economies of estuary regions were re-examined in Section V using the same measures of population, employment, and GDP. The same data sources (Census, Bureau of Labor Statistics, Bureau of Economic Analysis and NOAA) were used for this updated analysis. Additional data have been added to the current analysis, including housing units, commercial fisheries landings and values, and data on employment and GDP in industries related directly and indirectly to oceans and the Great Lakes.

The regional analysis covers:

- The population of each region in 2018 or the most recent year available.
- Changes in population for each region from 2009 to 2018.
- The proportion of state and national economies located in each estuary region
- Changes in the major economic drivers shaping each region.

GEOGRAPHIC SCOPE

The original "What's at Stake" analysis used counties as the primary unit of analysis and that continues in the current, updated analysis. Estuary counties are defined by the intersection between county's boundaries and the NOAA Medium Resolution Shoreline dataset.[24] In addition, the regional analysis will examine trends in population, and employment in the near shoreline areas of each county defined by shore-adjacent zip code areas. Figure IV-1 displays the breakdown of regions across the Continental United States (CONUS).

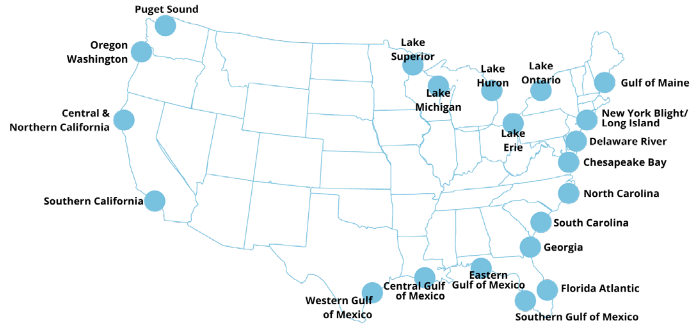


Figure IV-1. Estuary Regions for Regional Economic Analysis

The natural infrastructure analyses in each case study are also based on county boundaries because the economic value data used to support the assessment of flood damage reduction is available at the county level. The natural infrastructure analysis was based on hydrologic units with economic data drawn from multiple counties within the hydrologic boundaries of the estuary.

The blue carbon boundaries are based on hydrologic features of the estuary, rather than the political boundaries that form the basis for the natural infrastructure analysis. The geographic boundaries for the blue carbon analysis in each case study are based on locally specific carbon stock data, with estuary boundaries reflecting an 8-digit Hydrologic-Unit-Code (HUC[25]) surrounding available carbon core samples. The 8-digit HUC was used because it represents a single watershed, however, these HUCs can also be part of larger estuaries and watersheds. For example, Pamlico Sound is part of the larger Neuse-Pamlico subregion, and Terrebonne Basin joins with the Barataria Basin to make up the Central Louisiana Coastal Basin, more commonly known as the Barataria-Terrebonne Basin. For the blue carbon assessments, estuary sizes range from 756 km^2 (Snohomish Estuary) to about 8,000 km^2 (Terrebonne Basin), with most of the estuaries in the 2,000-3,000 km^2 range, which includes all the land and water within the boundaries of the 8-digit HUC.

SELECTION OF CASE STUDY ESTUARIES

The first step in the Case Study analysis was to select the six estuaries that would be analyzed. The project team first developed a set of seven criteria that allowed for an objective choice of estuaries within the scope of the project (see Table IV-1). Thirty-five estuaries were identified as an initial candidate list based on best professional judgement and including considerations of size; availability of blue carbon data; and relevance to NOAA restoration efforts, relevance to RAE (i.e., restoration or research projects were ongoing or had been completed there), or were part of the Environmental Protection Agency's National Estuary Program. Estuary size was a key initial consideration, as was data quality and availability. Large estuaries were broken down into smaller sub-estuaries (less than 10,000 km^2). For instance, Barataria-Terrebonne estuary was divided into two sub-estuaries, West Central Louisiana, and East Central Louisiana, representing the Terrebonne and Barataria watersheds, respectively. Fifteen estuaries were excluded because they did not have carbon stock core data available in the Coastal Carbon Research Coordination Network (CCRCN) database, which was the main source of carbon stock data for this analysis. The CCRCN was chosen because it provides high quality, consistent carbon stock data.

The remaining 20 estuaries were then ranked according to blue carbon potential, natural infrastructure potential, and fisheries economy (combined and equally weighted), and sorted into five regions with a goal of selecting at least one estuary from each region. Tampa Bay estuary and West Central Louisiana estuary (Terrebonne Basin) ranked first and second, respectively, in the Gulf of Mexico region. Both estuaries were chosen for analysis because of their importance to the commercial and recreational fisheries, ports, and shipping sectors in the Gulf. The final set of estuaries chosen for analysis, listed from northeast to northwest is Great Egg, NJ, Pamlico Sound, NC, Tampa Bay, FL, West Central Louisiana, LA, San Pablo Bay, CA and Snohomish estuary, WA.

VALUING NATURAL INFRASTRUCTURE IN COASTAL ESTUARIES

The focus in this study is on the value of estuarine wetlands on reducing the possible economic losses resulting from flooding. This value is difficult to precisely estimate because it depends ultimately on the number of times that flood events of varying severity occur, and on future patterns of coastal development which are inherently unpredictable. The estimation procedure used here yields results that are illustrative, intended to show how healthy estuarine wetlands can make a significant difference in reducing the costs of the most damaging natural hazard in the United States.

Table IV-1. Estuary Selection Criteria

Criterion	Description
Approximate size	Estuaries should be "medium-sized", defined as approximately the size of an 8-digit HUC. Smaller HUCs were chosen from within larger estuaries (e.g., the Terrebonne Basin was chosen from within the Barataria-Terrebonne Estuary)
Geographic diversity	Five regions were identified within the CONUS: northeast, southeast, Gulf coast, California, and the Pacific northwest. Hawaii and Alaska were excluded from the choice of regions.
Ecosystem type	Four primary ecosystem types were considered: tidal marshes, mangroves, seagrass, and peatlands.
Data Quality	This criterion considered the quality of available socioeconomic data and carbon stock data, both critical to evaluate economic and ecosystem service metrics. Scores were on a high-medium-low scale.
Blue Carbon potential	Scored on a high-medium-low scale. Initial carbon stock measurements were compiled for 20 estuaries, high and low values were determined and then values were grouped into three categories using identified groupings and breaks in the data (<9900 g/m^2 = low, 9901-20,000 g/m^2= Medium, >20,000 g/m^2= High)
Natural Infrastructure potential	Scored on a high-medium-low scale. This criterion considered nearby communities and population size, and the value of commercial assets, high and low values were determined and then values were grouped into three categories (high, medium, low) using identified groupings and breaks in the data.
Fisheries Economy	Scored on a high-medium-low scale. Initial values for commercial and recreational fisheries contribution to GDP were compiled for 20 estuaries, high and low values were determined and then values were grouped into three categories (high, medium, low) using identified groupings and breaks in the data.

The ways in which coastal habitats, including saltmarsh, beaches and dunes, mangroves, seagrasses, and coral reefs can reduce flood damage are well understood and consist of three principal effects.[26]

- Flood Attenuation- wetlands can serve as barriers to flooding in two ways: as physical barriers to water flows or as sponges absorbing flood waters so that less water reaches economically valuable assets. Sand dunes provide a barrier, beaches and marshes absorb water.
- An important part of how floods cause damage is the amplification of rising waters by wind or tide. Coastal storms exacerbate flooding through a combination of tide, wind, and an increase in water levels driven by changes in atmospheric pressure called storm surge. Wetlands serve as both barrier to higher water levels and absorption of increased water volumes.
- Shoreline Stabilization- Water flows erode shorelines, and in estuaries flows and erosion can be accelerated by reforming channels, adding hardened structures to the shore, and other means. Wetlands slow the erosion process so that shorelines remain intact and serve as additional barriers to flooding.

At any given time, possible flood damages can be estimated by answering these questions:

1. What is the probability that a flood will occur?
2. What area will be flooded?
3. How severe will the flood be?
4. What are the economic values at risk from the flood?

The answers to these questions set a baseline of possible losses. The value of the natural infrastructure is the reduction in possible losses from floods that occur because of the presence of wetlands. Thus, the benefits of natural infrastructure are equal to the avoided costs from flooding. The difference between flood damages with and without wetlands present is termed the "wetland effect".

Estimating the benefits requires either a set of measurements after a flood, or an estimate of the size and severity of possible floods if estimates are to be made in advance of actual events. The illustrative approach to estimation, such as is used in this study, requires a methodology that is based on realistic assumptions of what could happen without exploring all possible future risks. For this study, publicly available data is used, and fit to a set of assumptions about flooding that reflect a range of possible flood risks. The wetlands effect in reducing flood damages is derived from studies that examine flooding with and without wetlands present.

The data sources for this analysis can be divided into five categories:

1. Flood Extent and Severity
2. Wetlands Location
3. Economic Values at Risk
4. Flood Damages
5. Wetlands Effect on Damages

1. Flood Extent and Severity

The probability of flooding and the extent of flooding are indicated together by the Flood Hazard Zones used by the Federal Emergency Management Agency (FEMA) to define flood insurance rates.[27] Flood areas are defined based on historic flooding experience and frequency is measured as the probability of a flood extending over a specific area. The standard measure for the area where flood insurance may be required is called the 100-year flood zone, although this can be misleading. The actual definition is the area which has, based on historical records, a 1% chance of flooding every year. The 100-year flood zone is thus a measure of space (the area to be flooded) and probability (1% each year).

It should be noted that factoring climate change into the estimation of potential natural infrastructure benefits would be more realistic, but would complicate the analysis since it requires assumptions about how much climate change will occur, and when—as well as how much—sea level will rise. The number of probabilities representing fundamentally unknown factors increases significantly. But adjusting the annual probability of a storm of such severity that it affects the area of the 1% flood zone to 2% has the effect of representing the increased frequency of flooding that is a likely consequence of climate change.

For this study, the cumulative probability of a 1% or 2% annual chance over the years is used because estimates of benefits are taken as the present value of benefits over a 30-year period. In the case of the 100-year flood zone for a 30-year period (the length of the typical residential mortgage) the probability of a flood occurring is 0.26. For the 50-year (2% annual) flood, the probability over 30 years is .34.

2. Wetlands Location

The wetlands chosen for the analysis were those designated as "estuarine and marine" wetlands in the National Wetlands Inventory prepared by the U.S. Fish and Wildlife Service.[28] These wetlands are generally different types of saltmarshes and submerged aquatic vegetation (SAV) beds located in shallow water. For the Tampa Bay case study, mangroves were separately analyzed, as mangroves are known to have very high flood protection values.[29]

3. Economic Values at Risk

A wide range of economic values can be disrupted by floods. Damages can be done to buildings, to land, to the contents of buildings, or to public infrastructure. Damages can be measured in terms of the value of physical damages (i.e., the cost of repairing or replacing assets) or in terms of the economic disruptions such as lost business activity or lost incomes. For simplicity, this study looks at the value of buildings and lands as measured for property taxes in each relevant jurisdiction. This data has the advantage of being publicly available and can be attached to geographically located parcels of land with high precision. Variances in assessment methods and time frames of assessment in different jurisdictions limit full comparability between all the eighteen county jurisdictions whose data is used. All data was obtained from the relevant county tax assessor's offices either online or by special request.

4. Flood Damages

Precise estimates of the possible extent of damage requires substantial amounts of data. The FEMA Hazards U.S. Multi-Hazard (HAZUS) model provides extensive information about a range of possible damages from floods and other natural hazards such as wind. But this model works best with detailed local information, and the large amount of information needed for that model precludes its use at the more general level of analysis for this project. Average values for damages (not adjusted for depth of flooding) were assumed based on data from the HAZUS model. These assumed damages were 30% of the building value ("improvements" in property tax terms) and 15% of the land value. These costs of flooding will overestimate some floods and underestimate others.

5. Wetlands Effect on Damages

As with the other components of the estimation process, there is a great deal of possible variability in how much wetlands could reduce the possible damages from flooding. Unlike other elements of the analysis, such as the extent of flooding or damages, there are no extensive data to draw from to estimate what the wetlands effect will be. This is because it is not feasible to measure this effect without detailed analysis of specific flood events, which has generally not been done. An alternative is to simulate the absence of wetlands in a computer model and to compare the level of damages from an actual storm with and without the wetlands.

This was done in two studies by Narayan et. al. One of the studies examined the wetlands effect along the Mid-Atlantic shoreline in New Jersey and New York from flooding associated with Hurricane Sandy in 2012.[30] This study estimated the wetlands effect at between 10% and a 20% reduction in damages from flooding. The other study took a similar approach to studying the effects of mangroves affecting flood damages in Collier County, Florida. Mangroves are known to have higher flood damage reduction effects than salt marshes,[31] and the effect was estimated at 25%.[32] Mangroves are found extensively in Tampa Bay and this second study is used only in that case study.

The use of these studies in the diverse settings of the case studies does present some challenges. The geography of each estuary is different. Some, such as Egg Harbor and Pamlico, are similar to the geography studied in the Hurricane Sandy analysis, but others such as San Pablo and Snohomish sit inside bays, and the kind of storm surge involved in Sandy is extremely unlikely. In these cases, the wetlands effect will most likely be at the low end of the range used.

Calculating the Value of Natural Infrastructure

Taken together then, the estimated possible damages from flooding for any estuary region can be calculated as:

$$V = \sum_{1}^{30}\left[\frac{\left((db)(\sum_1^k BV)\right) + \left(dl\sum_1^k LV)\right) * (w)}{1 + i^n}\right](p)$$

Where:

V = the value of natural infrastructure for a given estuary region
dB= damage function for buildings. (0.3)
BV= Sum of building values from k parcels
dL= damage function for land (.15)
LV= Sum of land values from k parcels
P = the probability of a flood occurring over the planning period of 30 years
W= Wetland effect (.10 or .20 for marsh/other and .25 for mangroves)
i= Discount Rate. (2.5%)

The time period of the analysis is 30 years.

The parcels in each region (k) are identified by location in the FEMA 100-year flood hazard zone and its location relative to wetlands. This is done by using GIS techniques to merge data from the parcel file obtained from local taxing jurisdictions, the location of wetlands drawn from the U.S. Fish & Wildlife Service's National Wetlands Inventory, and the flood hazard information drawn from the FEMA flood hazard maps.

To illustrate the calculation, assume an area within the 100-year flood zone that has $10 million in building value and $1 million in land value. The cumulative probability over 30 years for the 1% annual (100 year) is 26% and we assume a wetland effect of 10% reduction in damages. A discount rate of 2.5% is assumed. Substituting these values into the equation 1, yields the following calculations. For illustrative purposes, Year 5 of the 30-year period of analysis. The infrastructure value for that year would be:

$$V_5 = \frac{\left((0.30)(10{,}000{,}000\right) + (0.15)(1{,}000{,}000) * (.10)}{1.025^5}$$

$$V_5 = \frac{3{,}000{,}000 + (150{,}000) * (.10)}{1.025^5}$$

$$V_5 = V_5 = \frac{81{,}900}{1.131}$$

$$V_5 = 72{,}413$$

The same calculation is performed for each year from 1 to 30 (with the export in the denominator changing from 1 to 30 as appropriate). The sum of all the present values is then multiplied by the cumulative probability of a 1% flood occurring over 30 years, or 0.26.v

The result of this analysis yields four estimates of the values of natural infrastructure for each estuary region:

		Wetlands Effect	
		Low (10%)	High (20%)
Storm Frequency	1% Annual		
	2% Annual		

Where mangroves are present (in Tampa Bay) the same calculations as above are used for those parcels adjacent to mangroves except that the wetlands effect is calculated only at 25%:

		Mangroves (25%)
Storm Frequency	1% Annual	
	2% Annual	

VALUING BLUE CARBON IN COASTAL ESTUARIES

Carbon Flows

Wetland vegetation sequesters carbon and stores it in the plant biomass and soil. Site-specific estimates of carbon sequestration rates and the amount of carbon stored in plant biomass are not available for the areas that are the subject of the six case studies. For this reason, the estimates in this report reflect only that portion of value associated with the storage of carbon in the soil beneath wetlands.

For each of the six study areas, core samples obtained from the CCRCN database that measure carbon in grams per square meter were used to compute the average metric tons of carbon stored in soil per hectare. These cores are of various depths, averaging about a half-meter in depth. The authors used previously developed methods[33] to estimate the metric tons of carbon stored in the top meter of soil per hectare which suggested two adjustments to the carbon measurements from the cores, the first to account for variations in core depths and the second to convert the measurement units from grams per square meter to metric tons per hectare.

No adjustment was made to account for variations in core depths. The amount of carbon stored in soil beneath the sample is unknown and the amount of carbon stored in soil generally declines with depth.[34] For this reason, the computations in this report reflect the conservative assumption that no carbon is stored at depths below the core samples.

To determine the area in each estuary to distribute the carbon stock across, we used ArcGIS with NOAA's Coastal Change Analysis Program (C-CAP) National Land Cover Database to measure, in hectares, the spatial extent of the "estuarine emergent wetland" (i.e., saltmarsh) vegetation type for all estuaries except for Tampa Bay, where we measured "estuarine forested wetland" (i.e., mangrove), as the dominant vegetation in Tampa Bay's wetlands. While "blue carbon" is stored in vegetation types other than estuarine emergent wetland, core samples in the RCN were not consistently available for other vegetation types, so, to maintain a consistent methodology, this analysis only measures carbon stored in the estuarine emergent wetland vegetation type, except for Tampa Bay as noted above. As there is likely to be additional measurable blue carbon stored in the soils of other vegetation types in these estuaries, this report understates the total amount of carbon stored in the estuaries chosen for each case study.

Intact wetlands serve as carbon sinks, but much of that carbon is released if a wetland is lost and the underlying soil is disturbed, making the wetland a source of greenhouse gas emission. This carbon release from developed or degraded wetlands occurs gradually, with high initial release rates declining over time because it takes longer for carbon stored more deeply in the soil to be emitted.[35] Avoiding the release of carbon from these sinks is a measurable benefit of habitat conservation. As suggested by previous research,[36] this analysis takes the baseline value of existing wetlands, and uses exponential decay functions to estimate the rate of carbon release for a period of 30 years, with half the carbon in the top meter of soil being released from the soil in 7.5 years, and only 6% of the total remaining by year 30.

Because the valuation approach in this study measures the value of avoided costs—that is the difference between keeping the carbon intact and releasing it over time—the time frame is in this analysis different than other potential policy applications of carbon storage values. For example, blue carbon offsets under The Paris Agreement, under the United Nations Framework Convention on Climate Change (UNFCCC), require carbon storage for a time frame of 100 years.

The benefits of conservation in this study reflect the value of the carbon today, assuming these wetlands remain intact in the future.

Carbon Costs and Prices

The value of carbon sequestration and storage is the product of carbon flows and the expected price of carbon. This analysis considers a range of estimates of the social cost of carbon and the market price of carbon, as revealed in the two primary carbon markets in North America.

This report considers two different ways of thinking about the price of carbon, market prices and the social cost of carbon. Market prices generally reflect the need to sequester carbon by some technological method and are driven by caps on carbon emissions established by policy or regulation. Using technology to capture or reduce carbon emissions is often more costly than keeping the carbon in the ground and using these values as an offset. Moreover, market prices are limited by the caps that are set in a cap-and-trade policy. However, the nature of the market is that it doesn't capture all impacts, particularly those that impact society at large. The social costs of carbon represent the added costs to society if stored carbon is released, in essence defining the total cost to society of the impacts of climate change. At the margin, in a well-developed and long-standing carbon market, the market price of carbon and social costs of carbon would tend to converge. However, in the absence of those conditions it is useful to consider both the market price and the social costs. It is important to note that neither measure is "right" or "wrong", and both types of carbon prices have their uses in the policy and regulatory arena.

The Social Cost of Carbon. The social cost of carbon (SCC) is a measure of the global losses that result from emitting one additional unit of carbon or an equivalent amount of another greenhouse gas. When carbon is released, it remains in the atmosphere for years to come. Furthermore, the losses associated with the release of a unit of carbon is a function of the concentration of atmospheric carbon, which is expected to vary over time. For these reasons, the SCC represents the sum of decades of varying effects with SCC results being sensitive to global emission and carbon concentration forecasts.[37] Losses reflected in SCC estimates include, but are not limited to, "changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change".[38]

Federal agencies use estimates of SCC to incorporate the societal benefits of reducing carbon emissions into cost-benefit analyses of regulatory actions.[39] The Interagency Working Group on the Social Cost of Greenhouse Gases[40] publishes technical guidance on the application of SCC to regulatory decision-making. The most recent guidance was issued in 2016 and states:

> *"...the Interagency Working Group (IWG) selected SC-CO2 values for use in regulatory analyses. For each emissions year, four values are recommended. Three of these values are based on the average SC-CO2 from three integrated assessment models (IAMs), at discount rates of 2.5, 3, and 5 percent. ... The fourth value is ... included to represent the marginal damages associated with ... lower-probability, higher-impact outcomes. Accordingly, this fourth value is selected from further out in the tail of the distribution of SC-CO2 estimates; specifically, the fourth value corresponds to the 95th percentile of the frequency distribution of SC-CO2 estimates based on a 3 percent discount rate."*[41]

SCC values published by the IWG on Social Cost of Greenhouse Gases in 2016 were presented at 2007 price levels as shown in Table IV-2.

Table IV-2. 2016 Social Cost of Carbon Values (in USD 2007)

	Discount Rate			
Year	5%	3%	2.50%	High Impact (95th Pct @ 3%)
2020	$12.00	$32.00	$62.00	$123.00
2025	$14.00	$46.00	$68.00	$138.00
2030	$16.00	$50.00	$73.00	$152.00
2035	$18.00	$55.00	$78.00	$168.00
2040	$21.00	$60.00	$84.00	$183.00

For use in this study, these values were updated to January 2020 price levels using the GDP Implicit Price Deflator as shown in Table IV-3.

Table IV-3. 2016 Social Cost of Carbon Values (in USD 2020)

Year	5%	3%	2.50%	High Impact (95th Pct @ 3%)
2020	$14.84	$39.57	$76.68	$152.11
2025	$17.31	$56.89	$84.10	$170.66
2030	$19.79	$61.83	$90.28	$187.98
2035	$22.26	$68.02	$96.46	$207.77
2040	$25.97	$74.20	$103.88	$226.32

The figures shown above represent averages from the most recent (as of 2016) results of four IAMs (DICE, PAGE, and FUND[42]). Although not incorporated into this analysis, it is important to note that in a 2017 version of the DICE model, the estimated SCC was substantially higher than the 2013 version whose results are reflected in the guidance document and shown in the tables above.

The Market Price of Carbon. In contrast to SCC, which is a measure of the expected societal loss associated with carbon emission, the market price of carbon represents the buyer's willingness to pay for carbon emission allowances which is a reflection of the buyer's and seller's costs of reducing emissions ("Marginal Abatement Costs"). Applying SCC to carbon storage provides an indicator of the prevented losses to all of society; applying the market price of carbon to carbon storage provides an indicator of prevented losses to purchasers of emission allowances.

The market price of carbon is determined within markets where, for example, emission trading systems (ETS) cap the total level of greenhouse gas emissions and allow the purchase and sale of emission allowances. Also known as "cap and trade" systems, ETS create supply and demand for emission allowances, allowing traders to set the market price. The ETS can influence market prices by adjusting the emission limits ("caps").

Two large carbon markets operate in North America: (1) the Regional Greenhouse Gas Initiative (RGGI, pronounced "Reggie") and (2) the Western Climate Initiative (WCI). Among global carbon markets, only the European Union ETS is larger in volume and value than the two North American markets.[43] Operational since 2009,[44] RGGI is the oldest ETS in the United States. RGGI is a cooperative effort among the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.[45] WCI became operational in 2016 and currently serves California, Quebec, and Nova Scotia. Both RGGI and WCI host quarterly auctions where emission allowances are traded. Table IV-4 summarizes auction results from 2018 to 2020.

Table IV-4. U.S. Carbon Market Prices 2018-2020

	WCI	RGGI
2020 Average	$ 17.08	$ 6.07
2019 Average	$ 16.82	$ 5.43
2018 Average	$ 14.90	$ 4.42

Although prices are trending upward in both markets, forecasts of future carbon prices are beyond the scope of this effort. Instead, the most recent (and highest) values were used in computations for the case studies.

IV. The Contributions of America's Estuary Regions to the National Economy

Estuaries have always been an essential feature of the economy. Even before European settlement, Native Americans lived either permanently or seasonally in estuary regions because of food supply. European settlement and the following growth were centered in the estuary regions where North America could most easily connect with Europe. That established a pattern of economic importance which continues to the present. The counties in the estuary regions of the continental U.S.[46] comprise 4% of the land area of the U.S. but on that 4% sits 47% of the output of the U.S. economy, 39% of the employment, population, and housing (in 2018). Also, according to 2018 data, eight of the ten largest metropolitan areas were located in estuary regions. Estuaries, in other words, are geographically small and economically huge.

The concentration of people, as year-round or seasonal residents or as employees in the estuary regions, helps drive the national economy. But that same concentration puts enormous pressure on the natural and environmental resources of the estuaries, manifested in loss of wetlands, degraded water quality, and impaired access for economic uses such as recreation and fishing. Economic and demographic data can be used to show both aspects of the economic life of estuaries. The total contribution of these regions to the economy can be measured in both output (gross domestic product)[47] and employment.

The effects on natural systems can also be seen in the intensity of development measured on a density basis, the distribution of development in the upstream and downstream parts of the estuaries, and the performance of key water dependent economic activity such as recreation and fishing. The data presented in this chapter discusses each of these aspects of the complex interrelationships between the economy and estuary regions.

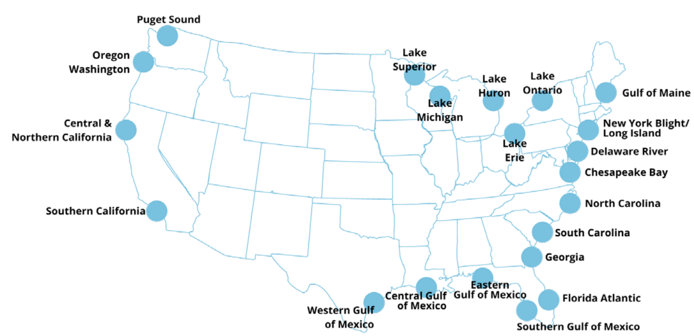


Figure V-1. Estuary Regions of the Continental U.S.

One of the challenges of dealing with these issues in the U.S. is that there is a great deal of variety among the estuary regions. So, it is important to understand not only the aggregate economic role of estuaries but to understand the economic characteristics of the various regions. This chapter provides a brief overview of the size and changes in twenty-one estuary regions as defined in the 2009 paper.[48] These are shown in Figure V-1. The regions are delineated by counties that intersect with the NOAA medium resolution shoreline dataset (See Figure V-2). This dataset is a digitized version of the shoreline based on NOAA nautical charts.[49] It touches the boundaries of 382 counties and (in Virginia) independent cities (See Appendix B for full list of counties). Figure V-3 shows an enlarged view of the NOAA medium resolution shoreline dataset overlaid on county boundaries for the states of Florida and Alabama as an example. The county is the primary geographic unit of analysis for most of the discussion in this chapter because the largest amount of economic data is available for this area. However, a closer look at the geography within the counties using zip codes is also provided.

To understand the contribution of estuaries to the nation it is necessary to examine them using a variety of measures. The following tables provide comparisons using employment, output (Gross Domestic Product), population and housing.[50] In each table, the value of the variable is shown. Those appearing in bold font have values above the average for all the estuary regions, those in black are below the average. The bars in each cell provide a simple visual representation of the relative sizes of each region in each measure. Tables are arranged by major section of the U.S. coast and in clockwise order starting from the northeastern-most region, the Gulf of Maine. Each table is thus a compact way of seeing both the absolute and relative size of each of the twenty-one regions. For more detailed information on the trends notified, including break downs by state and county, can be found in Appendix B.

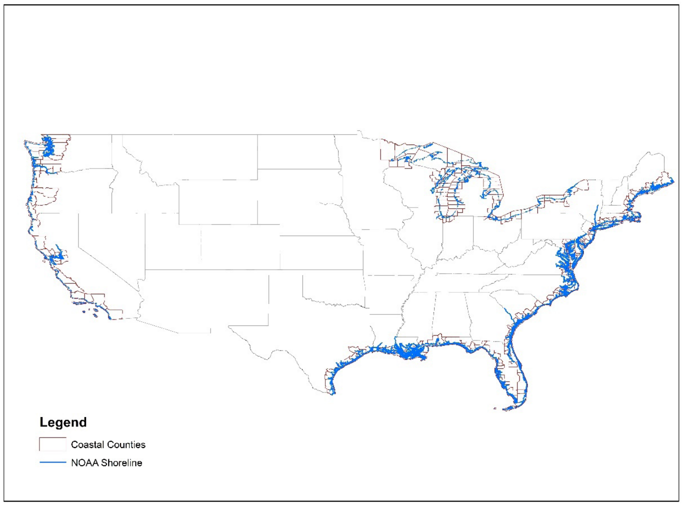


Figure V-2. NOAA Medium Resolution Shoreline and Intersecting Counties

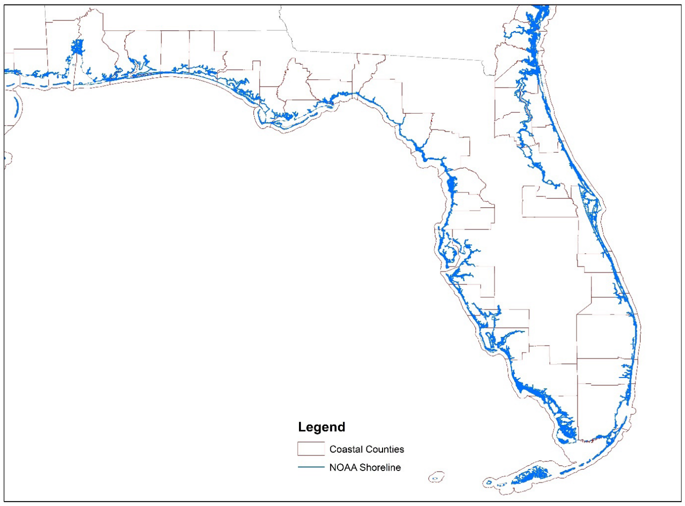


Figure V-3. Enlarged View of Florida and Alabama Shoreline and County Boundaries

Taken together the counties in the 21 regions accounted for over 59 million jobs[51] in 2018 and $8.8 trillion in Gross Domestic Product. The estuary regions were home to over 131 million people and the location of 54 million housing units. Not surprisingly, the economically largest estuary regions are those in the largest metropolitan areas, with the New York Bight being the largest, followed by the two regions in California (with Los Angeles-San Diego in the South and the San Francisco Bay area in the North) and then Lake Michigan (with Chicago and Milwaukee). The smallest regions are in the Carolinas and Georgia (with 1.2 million jobs between them and $116.3 million in GDP), and in the other Great Lakes which have smaller cities. Lake Superior and Lake Huron are the smallest economies in terms of jobs and GDP.

The proportion of each estuary region's economy in the United States is shown in Table V-2. In 2018, the twenty-one regions together comprised 47% of GDP and 39% of employment, population, and housing. The five largest estuary regions noted above (New York Bight, Chesapeake, Lake Michigan, Southern California, and Central-Northern California) together comprise 21% of U.S. employment and 29% of U.S. GDP. In general, the shares of employment and GDP in the larger, more urban areas are larger than the shares of population and housing, while the shares of population and housing tend to be slightly greater for the less urban regions.

Table V-1. Size of Estuary Regions by Employment, GDP, Population, and Housing Units 2018

		Employment (000s)	GDP (Millions)	Population	Housing Units
Atlantic	Gulf of Maine	1,428.6	$194,912.8	3,132,510	1,395,735
	New York Blight	**8,770.3**	**$1,455,283.0**	**18,473,409**	**7,538,417**
	Delaware River	2,054.8	$276,956.4	4,823,574	**2,087,301**
	Chesapeake Bay	1,892.3	$241,610.2	4,150,795	1,710,996
	North Carolina	257.9	$24,812.5	717,005	371,535
	South Carolina	505.6	$51,947.9	1,107,346	566,467
	Georgia	194.1	$21,242.6	371,023	166,982
	Florida Atlantic	**3,043.4**	**$352,628.8**	**7,507,897**	**3,246,989**
Gulf of Mexico	Southern Gulf	1,913.1	$212,366.4	4,458,635	**2,259,658**
	Eastern Gulf	803.1	$75,687.0	2,390,183	1,160,906
	Central Gulf	1,039.1	$139,708.0	2,513,227	1,097,313
	Western Gulf	**2,889.9**	**$474,827.9**	**6,224,863**	**2,380,832**
Pacific	Southern California	**8,063.7**	**$1,202,792.4**	**17,856,917**	**6,264,289**
	Central Northern CA	**5,467.8**	**$1,149,005.4**	**11,344,632**	**4,239,682**
	Oregon Washington	754.0	$112,742.7	1,422,306	627,123
	Puget Sound	**2,356.3**	**$523,462.8**	4,750,222	1,976,690
Great Lakes	Lake Superior	26.6	$2,661.1	66,939	34,803
	Lake Michigan	**4,510.8**	**$691,830.2**	**9,447,551**	**3,977,122**
	Lake Huron	161.6	$17,041.4	457,130	207,653
	Lake Erie	681.3	$71,193.3	1,475,193	679,790
	Lake Ontario	625.6	$64,951.2	1,467,786	673,117
Estuary Regions	**TOTAL**	**47,440**	**$7,367,663.8**	**104,159,143**	**42,663,400**

Above Average Values in Bold

Table V-2. Estuary Regions Share of The U.S. Economy 2018

		Percent of US (%)			
		Employment	GDP	Population	Housing Units
Atlantic	Gulf of Maine	1.0	1.0	1.0	1.0
	New York Blight	**6.0**	**7.8**	**5.7**	**5.4**
	Delaware River	1.4	1.5	1.5	**1.5**
	Chesapeake Bay	1.3	1.3	1.3	1.2
	North Carolina	0.2	0.1	0.2	0.3
	South Carolina	0.3	0.3	0.3	0.4
	Georgia	0.1	0.1	0.1	0.1
	Florida Atlantic	**2.1**	**1.9**	**2.3**	**2.3**
Gulf of Mexico	Southern Gulf	1.3	1.1	1.4	**1.6**
	Eastern Gulf	0.5	0.4	0.7	0.8
	Central Gulf	0.7	0.7	0.8	0.8
	Western Gulf	**2.0**	**2.5**	**1.9**	**1.7**
Pacific	Southern California	**5.5**	**6.5**	**5.5**	**4.5**
	Central Northern CA	**3.7**	**6.2**	**3.5**	**3.1**
	Oregon Washington	0.5	0.7	0.4	0.5
	Puget Sound	**1.6**	**2.8**	1.5	1.4
Great Lakes	Lake Superior	0.0	0.0	0.0	0.0
	Lake Michigan	**3.1**	**3.7**	**2.9**	**2.9**
	Lake Huron	0.1	0.1	0.1	0.1
	Lake Erie	0.5	0.4	0.5	0.5
	Lake Ontario	0.4	0.3	0.4	0.5
Estuary Regions	**TOTAL**	**36.9**	**39.5**	**31.9**	**30.8**

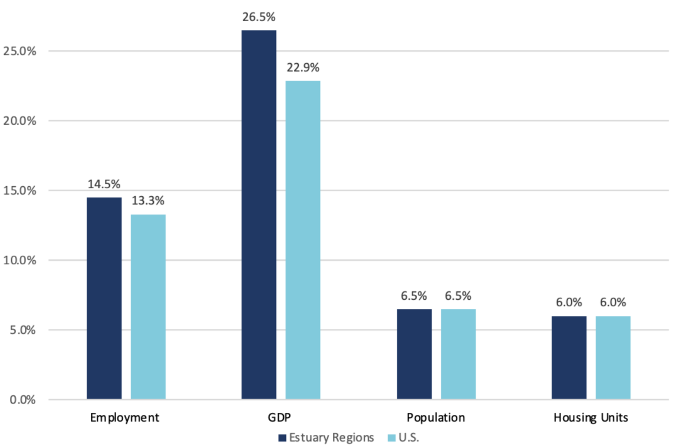
Above Average Values in Bold

Figure V-4 compares the growth in employment, GDP, population, and housing units for the sum of the estuary regions and for the U.S.[52] Estuary regions grew faster in both employment and GDP and at the same rates in population and housing from 2009-2018, indicating that the primary driver of change was economic rather than demographic growth. This pattern of faster economic growth compared with demographic change is present in all the estuary regions except for Lake Huron and Lake Erie (See Table V-3).

However, there are some discrepancies between growth rates on the different measures. Output (GDP) growth is faster than employment growth in all but two of the regions: North Carolina and Lake Ontario. In the former case, the North Carolina coast is generally nonurban and GDP growth occurred in what were nationally slower growing industries. In the latter case, the Lake Ontario shoreline is primarily found in upstate New York, a region that has endured a high level of deindustrialization.

Also noteworthy is that housing grew faster than population growth in six of the regions (Gulf of Maine, New York Bight, Delaware River, the Central Gulf of Mexico, Lake Superior and Lake Michigan). Since overall housing and population growth were balanced in the estuary regions, the implication is that housing units in excess of the needs of the local population were being built. In coastal regions, the most likely reason for this is growth in seasonal housing. Those trends are discussed below.

Figure V-4. Comparison of Growth in Estuary Regions and the U.S. 2009-2018



Discussing economic growth rates in this period must take account of the fact that the Great Recession occurred during part of this decade. The National Bureau of Economic Research, generally accepted as the official arbiter of the duration of recessions, found that the Great Recession began in December 2007 and ended in June 2009.[53] The 2009-2018 period examined here includes the last six months of the recession, but primarily covers the expansion that began in July 2009.

The fastest growth rates in employment were recorded in the South Atlantic regions of South Carolina, Georgia, and the Atlantic coast of Florida, along with all four of the Pacific regions and the Southern and Western Gulf of Mexico. GDP growth was fastest in Central & Northern California and Puget Sound, not surprising since both these regions are homes to the rapidly growing industries in information and communications technology. Lake Michigan and South Carolina were also rapidly growing in GDP, while the North Carolina and Lake Ontario regions were the slowest growing as noted above.

Two regions, Lake Huron and Lake Erie lost population during this period and Lake Huron even showed a small drop in housing stock. The most rapidly growing areas in terms of population and housing were in the South Atlantic and the Western Gulf of Mexico, while the regions of the northeast Atlantic all grew at slower than average rates in population and housing as was true of all the Great Lakes regions. Analysis of the proportions of the U.S. economy found in the estuary regions and of growth rates gives a general picture of key trends, but size depends in part of the geographic size of the estuary region.

The twenty-one regions and 382 counties average 35,295 square kilometers (13,628 square miles) in area, but there is substantial range in sizes from the smallest (Georgia at 10,129 square kilometers (3,911 square miles)) to the largest (Oregon-Washington at 75,229 square kilometers (29,046 square miles)). The discrepancy in size arises primarily because of differences in the way the boundaries of counties are determined in each state. Counties in the east, particularly in the south, tend to be rather small having been fixed in colonial times, where counties in the west tend to be larger to conform to the terrain. Thus, adjusting the trends for size by looking at the density (the amount per square mile) provides a somewhat more accurate comparison.

Density is also important because the amount of physical area occupied by commercial, industrial, and residential space, with associated development of roads and other infrastructure like parking lots, is a major reason for the impacts on estuarine resources. This includes loss of wetlands and reductions in water quality from runoff and intensified storm-related flows.

Table V-4 shows the employment, GDP, and population per square mile for the estuary regions in 2018. The distribution roughly conforms to the pattern of Table V-1, with the largest regions also the most dense. But there are some changes. The Delaware River region is below average in the total measures, but above average once adjusted for area. This is also the case with the Southern Gulf of Mexico region on the west coast of Florida. This indicates these areas have relatively high densities. Conversely, the Western Gulf of Mexico and Central and Northern California are below average in density but above average in total size, indicating these regions are among the less dense.

The discussion so far considers all economic activity in each estuary region, but some activity is more closely tied to their location in estuary and coastal regions. One measure of this is the size of the "marine economy"[54] in each region, a term that includes the U.S. Great Lakes. The marine economy comprises twenty-one industries grouped into six sectors. At the county level only the sector level data is available for confidentiality reasons.[55] These sectors are:

- Marine Construction
- Living Resources (fisheries and aquaculture)
- Ship & Boat Building
- Marine Transportation and related industries
- Tourism & Recreation
- Minerals

		Percent of US (%)			
		Employment	GDP	Population	Housing Units
Atlantic	Gulf of Maine	12.5	18.3	4.3	5.8
	New York Blight	14.1	16.4	1.5	4.1
	Delaware River	8.8	12.4	2.8	4.1
	Chesapeake Bay	8.4	16.1	4.0	4.5
	North Carolina	11.4	8.5	**16.9**	**14.4**
	South Carolina	**24.8**	**34.3**	**22.3**	**18.3**
	Georgia	**17.3**	23.1	**15.0**	**9.8**
	Florida Atlantic	**19.8**	21.3	**11.9**	**6.9**
Gulf of Mexico	Southern Gulf	**20.5**	23.0	**14.9**	**8.1**
	Eastern Gulf	14.1	15.6	**9.5**	**8.1**
	Central Gulf	5.1	20.1	**8.2**	**10.1**
	Western Gulf	**15.2**	26.1	**16.5**	**12.5**
Pacific	Southern California	**14.7**	22.4	5.4	5.2
	Central Northern CA	**21.8**	**53.6**	**10.0**	**6.0**
	Oregon Washington	**18.0**	**26.8**	**10.5**	**9.3**
	Puget Sound	**20.6**	**42.5**	**14.5**	**11.6**
Great Lakes	Lake Superior	-1.6	20.0	2.5	0.9
	Lake Michigan	8.8	**36.3**	0.2	1.9
	Lake Huron	2.8	**26.9**	-4.7	-1.1
	Lake Erie	3.6	9.2	-0.4	1.4
	Lake Ontario	3.6	2.4	0.1	3.5
Estuary Regions	**TOTAL**	**14.5**	**26.5**	**6.5**	**6.0**

Above Average Values in Bold

Table V-3. Growth Rates in Economic Measures for Estuary Regions 2009-2018

Employment and ocean-related GDP for the estuary regions are shown in Table V-5. This table illustrates a general trend that the marine economy tends to comprise a larger share of smaller, less urban economies, even if the absolute size of these sectors is greater in larger economies. In addition to the smaller Great Lakes regions, this is also the case in estuary regions of the Carolinas and Georgia. This data is for 2018, the most recent year available. The New York Bight is the largest sector for employment, mostly because of tourism and recreation related employment in New York City. The data series for the marine economy defines tourism and recreation industries as industries such as hotels, restaurants, sporting goods, and water tours located in zip codes adjacent to the shoreline of the ocean, bays, or lakes. It overcounts the actual ocean or Great Lakes related purpose of trips in major metropolitan areas like New York City. The Western Gulf of Mexico has the highest ocean GDP because of the offshore oil and gas industry located there. In neither of these regions, however, is the proportion of the region's total marine dependent employment and GDP above average. The regions where marine economic activity does account for higher proportions of overall economic activity within the region are in the central and eastern parts of the Gulf of Mexico and in the South Atlantic. Lake Superior, which is among the smallest estuary regional economies, has the highest proportion in the marine economy sectors. This points to a general trend that the marine economy tends to comprise a larger share of smaller, less urban economies, even if the absolute size of these sectors is greater in larger economies. In addition to the smaller Great Lakes regions, this is also the case in estuary regions of the Carolinas and Georgia.

The largest marine economic activity as measured by employment in this data series is tourism and recreation, which is a labor-intensive sector. Comparisons of employment among regions tend to be dominated by tourism and recreation employment, and this sector is also closely tied to the environmental and ecological health of estuaries.

		Density Per Square Mile			
		Employment	GDP (Millions)	Population	Housing Units
Atlantic	Gulf of Maine	**295.70**	$34,384.6	**648.38**	**288.89**
	New York Blight	**1,148.08**	**$190,506.3**	**2,418.29**	**986.83**
	Delaware River	**458.54**	**$61,806.3**	**1,076.44**	**465.81**
	Chesapeake Bay	**445.35**	**$56,860.6**	**976.85**	**402.67**
	North Carolina	85.46	$8,222.3	237.60	123.12
	South Carolina	135.52	$13,924.2	296.82	151.84
	Georgia	227.68	$24,913.1	435.13	195.83
	Florida Atlantic	226.31	$30,856.3	**656.97**	**284.12**
Gulf of Mexico	Southern Gulf	271.84	$30,174.9	**633.52**	**321.07**
	Eastern Gulf	89.07	$8,394.2	265.09	128.75
	Central Gulf	113.04	$15,197.5	273.39	119.37
	Western Gulf	**427.90**	**$70,305.3**	**921.68**	**352.52**
Pacific	Southern California	**591.21**	**$88,185.8**	**1,309.22**	**459.28**
	Central Northern CA	224.26	**$47,126.4**	465.30	173.89
	Oregon Washington	55.18	$6,522.0	104.10	45.90
	Puget Sound	199.94	$34,347.4	403.07	167.73
Great Lakes	Lake Superior	14.68	$1,471.0	37.00	19.24
	Lake Michigan	**493.18**	**$75,639.2**	**1,032.92**	**434.83**
	Lake Huron	82.24	$8,675.6	232.72	105.71
	Lake Erie	197.40	$20,627.4	427.42	196.96
	Lake Ontario	84.83	$8,807.6	199.04	91.28

Above Average Values in Bold

Table V-4. Employment, GDP, and Population Per Square Mile by Estuary Region 2018

Table V 5. Marine Economy by Estuary Region 2018

		Marine Economy 2017			
		Employment	GDP	Population	Housing Units
Atlantic	Gulf of Maine	100,518	$5,797.8	**7.0%**	3.0%
	New York Blight	**514,623**	**$37,124.4**	5.9%	2.6%
	Delaware River	100,085	$5,547.2	4.9%	2.0%
	Chesapeake Bay	**143,370**	$9,837.4	**7.6%**	**4.1%**
	North Carolina	33,568	$1,456.9	**13.0%**	**5.9%**
	South Carolina	74,219	$4,362.4	**14.7%**	**8.4%**
	Georgia	21,671	$986.6	**11.2%**	**4.6%**
	Florida Atlantic	**213,982**	**$15,479.3**	**7.0%**	**4.4%**
Gulf of Mexico	Southern Gulf	**166,541**	$9,425.5	**8.7%**	**4.4%**
	Eastern Gulf	88,114	$4,531.6	**11.0%**	**6.0%**
	Central Gulf	115,488	**$11,736.6**	**11.1%**	**8.4%**
	Western Gulf	**152,418**	**$66,466.9**	5.3%	**14.0%**
Pacific	Southern California	**322,969**	**$28,819.8**	4.0%	2.4%
	Central Northern CA	**244,039**	**$16,927.3**	4.5%	1.5%
	Oregon Washington	24,444	$1,540.7	3.2%	1.3%
	Puget Sound	120,716	**$12,974.4**	5.1%	2.5%
Great Lakes	Lake Superior	2,091	$57.4	**7.9%**	2.2%
	Lake Michigan	**153,924**	$9,762.5	3.4%	1.4%
	Lake Huron	5,368	$139.5	3.3%	0.8%
	Lake Erie	19,269	$759.8	2.8%	1.1%
	Lake Ontario	13,464	$547.0	2.2%	0.8%

Above Average Values in Bold

Table V-6. Tourism & Recreation Economy by Region 2018

		Maritime Tourism & Recreation 2018		Share of Regional Economy		Percent Change 2009-18	
		Employment	GDP	Employment	GDP	Employment	GDP
Atlantic	Gulf of Maine	**114,479**	**$6,740.8**	4.5%	2.0%	32.9%	**52.9%**
	New York Blight	**496,352**	**$35,852.6**	4.6%	2.1%	**53.1%**	**36.6%**
	Delaware River	78,075	$3,891.7	2.8%	1.0%	**48.7%**	**30.4%**
	Chesapeake Bay	**132,125**	$5,871.2	2.8%	0.9%	25.3%	10.7%
	North Carolina	41,808	$1,609.5	**11.3%**	**4.7%**	31.4%	**43.7%**
	South Carolina	75,256	$4,421.2	**13.7%**	**7.9%**	31.8%	**42.8%**
	Georgia	14,977	$642.1	**6.1%**	**2.5%**	**39.7%**	**54.3%**
	Florida Atlantic	**211,206**	**$11,793.0**	**5.5%**	**2.6%**	**38.8%**	12.9%
Gulf of Mexico	Southern Gulf	**157,686**	**$8,096.7**	**8.2%**	**3.8%**	**54.0%**	19.0%
	Eastern Gulf	77,671	$3,235.0	**9.3%**	**4.1%**	**51.7%**	25.2%
	Central Gulf	68,675	$3,060.1	4.8%	1.6%	**68.6%**	8.1%
	Western Gulf	46,647	$1,818.8	1.6%	0.4%	**50.9%**	15.5%
Pacific	Southern California	**232,839**	**$13,134.0**	2.9%	1.1%	**43.5%**	17.5%
	Central Northern CA	**208,470**	**$13,333.2**	3.8%	1.2%	26.9%	22.4%
	Oregon Washington	31,234	$1,592.1	2.8%	1.3%	**40.1%**	**50.8%**
	Puget Sound	77,306	$5,200.6	3.2%	1.3%	**45.5%**	**48.3%**
Great Lakes	Lake Superior	18,463	$645.7	**9.3%**	**3.4%**	37.2%	**53.9%**
	Lake Michigan	**147,614**	**$8,020.5**	3.2%	1.1%	16.8%	7.4%
	Lake Huron	9,413	$421.2	4.1%	1.8%	4.3%	4.1%
	Lake Erie	52,180	$2,133.4	1.4%	0.4%	27.0%	25.4%
	Lake Ontario	11,576	$417.8	1.8%	0.6%	22.4%	15.6%
Estuary Regions Total		2,304,052	$131,931.0	3.9%	0.0%	39.9%	25.9%

Above Average Values in Bold

Table V-6 shows employment and GDP in the tourism and recreation sector by estuary region including the size of the sector in 2018, the share of the estuary region employment, and the growth rate from 2009-2018.

The tourism and recreation economy is very similar in distribution to the overall economy, with the major metropolitan areas having the largest economic activity. There are some notable differences, however, even among large cities. For example, the total employment of the Florida Atlantic region is about one third the size of the Southern California region, but in tourism and recreation jobs it is 88% of Southern California, indicating a much heavier concentration of tourism employment in the Florida Atlantic region. A similar pattern occurs with GDP: the Florida Atlantic region is 29% of Southern California's total GDP compared with 56% of Southern California's tourism and recreation GDP.

At the other end of the size range, tourism and recreation comprises a much larger share of the Lake Superior regional economy than in any other region. Overall tourism and recreation has shown substantial growth in both employment and GDP over 2009-18, growing nearly 40% across all estuary regions, but fastest in the Mid-Atlantic (New York Bight and Delaware River) and in the Gulf of Mexico regions. Lake Superior was also among the faster growing regions.

These comparisons also tend to understate the role of tourism and recreation, which is a highly seasonal activity; summer (or in Florida's case spring) employment can be two to three times the annual average employment used in these measures. An indicator of how seasonal changes in the economy can be an important part of an estuary region's economy is the number and proportion of seasonal housing, a major feature of the landscape in almost all coastal areas. The number, share and change in seasonal housing are shown in Table V-7.

Table V-7. Seasonal Housing by Estuary Region 2018

		Seasonal Housing		
		Seasonal Housing	Percent of Housing	Percent Change 2009-18
Atlantic	Gulf of Maine	**123,172**	**8.8%**	21.3%
	New York Blight	**241,578**	3.2%	**27.5%**
	Delaware River	**95,890**	4.6%	8.3%
	Chesapeake Bay	15,359	0.9%	13.7%
	North Carolina	56,004	**15.1%**	**31.0%**
	South Carolina	80,048	**14.1%**	**29.1%**
	Georgia	7,518	4.5%	12.7%
	Florida Atlantic	**270,609**	**8.3%**	24.7%
Gulf of Mexico	Southern Gulf	**309,248**	**13.7%**	22.5%
	Eastern Gulf	**100,024**	**8.6%**	11.4%
	Central Gulf	23,035	2.1%	**52.4%**
	Western Gulf	41,207	1.7%	16.6%
Pacific	Southern California	**87,681**	1.4%	**58.4%**
	Central Northern CA	71,981	1.7%	**27.9%**
	Oregon Washington	13,709	2.2%	**46.6%**
	Puget Sound	36,919	1.9%	14.1%
Great Lakes	Lake Superior	5,799	**16.7%**	8.5%
	Lake Michigan	**59,905**	1.5%	**26.5%**
	Lake Huron	3,709	1.8%	16.4%
	Lake Erie	13,627	2.0%	**26.8%**
	Lake Ontario	30,164	4.5%	**26.1%**
Estuary Regions Total		1,687,186	4.0%	24.2%

Above Average Values in Bold

The largest stocks of seasonal housing are in the northeastern Atlantic estuary regions, and in Florida. Seasonal housing as a proportion of total housing stock is highest in the Carolinas, the eastern half of the Gulf of Mexico and, in the Lake Superior and Lake Huron regions. Seasonal housing grew at above average rates in the New York Bight, South Carolina, Florida Atlantic, the Western Gulf, and on the Pacific Coast (except for Puget Sound). The eastern Great Lakes led the Great Lakes region in seasonal housing growth.

Another key economic sector tied to the ecological health of the region is fisheries.[56] Table V-8 shows commercial fisheries landings[57] and values for 2018 for each of the estuary regions.[58] Recreational fishing, a significant activity in many regions, is not reflected in this catch data, but spending on recreational fishing goods and services such as tackle and guide services is reflected in the tourism and recreation data.

In this analysis of the CONUS, the eastern and southern Gulf of Mexico are combined into a single region as "Florida Gulf of Mexico" as this is the aggregation level reported by NOAA. There is very wide variance among the regions in terms of fishing activity. The Central Gulf including Louisiana and eastern Texas, is by far the largest in terms of total volume of landings, but the Gulf of Maine has both the largest landed value and the highest average price, largely because of the lobster fishery in Maine and scallops in Massachusetts. The fisheries of the Great Lakes regions have shrunk to barely measurable levels over decades of overfishing and development on both sides of the border.[59]

The analysis so far has been based on county-level data. But as noted above, the size of these regions varies as much as nine-fold from the smallest to the largest. Adjusting the economic data for the size of the region partly accommodates for this variety, however, there is still a great deal of territory included in county-based regional definitions that is upstream of estuaries. For this reason, a finer geographic scale is needed to examine both population and employment. The smallest geography that contains this data is the zip code.

For this finer scale geographic analysis, data from the Census Bureau's Zip Code Business Patterns[60] is combined with Census of Population data at the zip code level.[61] Zip codes were selected for each of the estuary counties and then the NOAA medium resolution shoreline was used to further select those zip codes immediately adjacent to the shore. This created two subareas for examination: shoreline zip codes and inland zip codes which are the balance of zip codes within the county. Because the employment estimates differ between the Bureau of Labor Statistics data in the county analysis and the Census data used in Zip Code Business Patterns[62] the distribution

		Commercial Fish Landings		
		Landings (lbs)	Landed Value	Average Value
Atlantic	Gulf of Maine	**524,334,207**	**$1,333,604,573**	**$2.54**
	New York Blight	**357,444,963**	**$340,054,747**	$0.95
	Delaware River	6,486,736	$10,807,226	**$1.67**
	Chesapeake Bay	**434,051,344**	**$250,651,277**	$0.58
	North Carolina	72,599,623	$78,856,485	$1.09
	South Carolina	17,492,766	$21,526,109	**$1.23**
	Georgia	15,892,922	$17,657,895	$1.11
	Florida Atlantic	102,780,977	$58,620,664	$0.57
Gulf of Mexico	Southern Gulf	144,540,017	$190,576,509	**$1.32**
	Eastern Gulf	58,356,751	$67,669,768	$1.16
	Central Gulf	**1,363,816,319**	**$420,330,149**	$0.31
	Western Gulf	84,384,688	**$211,847,821**	**$2.51**
Pacific	California	187,334,688	$182,920,364	$0.98
	Oregon Washington	**315,461,236**	$172,461,062	$0.55
	Puget Sound	199,657,009	**$240,371,609**	**$1.20**
Great Lakes	Lake Superior	2,685,292	$3,097,041	$1.15
	Lake Michigan	5,232,224	$8,011,571	**$1.53**
	Lake Erie	3,755,700	$3,772,409	$1.00
Estuary Regions Total		3,896,306,971	$3,612,837,279	$0.93

Above Average Values in Bold

Table V-8. Fisheries Landings and Values by Estuary Region 2018 of employment is calculated using the Zip Code Business Pattern data and then applied to the BLS data.[63] Figure V-5 illustrates how the county, zip code, and shoreline interact using the Gulf of Maine estuary region as an example.

Table V-9 shows the employment and population levels of the shore adjacent zip codes, together with their share of the estuary region counties and the change in the shore zip codes proportion of the estuary county. The share of the estuary region counties' employment is highest in the South Atlantic and Gulf of Mexico states; this reflects the smaller counties in the southern U.S. It is also high in the Puget Sound area as the counties extend into the mountains but most of the development is to be found in the lower parts of the rivers flowing from the mountains into the Sound. In some of the larger urban estuary regions such as New York or Southern California, however the proportion of developed areas (measured by employment and population) is at the lower end of the ranges, implying a more diffuse pattern of development.

The most interesting part of Table V-9 is found in the "change" columns showing rates of change for employment and population over 2009-2018. A negative growth rate in the proportion of county employment and population for shore zip codes implies in that estuary region, growth was concentrated away from the shore zip codes. In other words, development shifted "inland". This effect was most noticeable in terms of employment in the southern Atlantic coast and Gulf of Mexico estuary regions. It was also true to some extent with population, especially in Georgia.

Of the ten regions where employment and population are shifting in opposite directions, the trend is for employment to be shifting upstream and population to be shifting downstream very slightly. The population changes are so small that the shifts may not be meaningful. It is also possible that the population shift is happening in the upstream areas of the counties which are, particularly in more rural areas, relatively large geographies. Additional finer scale analysis of specific regions is needed to test this.

This upstream/downstream distinction is important for understanding the relationship between regional economic and demographic trends and the health of estuaries. Shifts downstream are more likely to put pressure on shorelines and wetlands for development purposes and increase the need for careful planning and management of shore and near shore habitats and ecosystems. Upstream shifts put less pressure on the shoreline but more pressure on watersheds. The upstream ends of the estuary waters are more likely to be affected by nonpoint runoff pollution from different activities, but particularly from impervious surfaces associated with transportation.

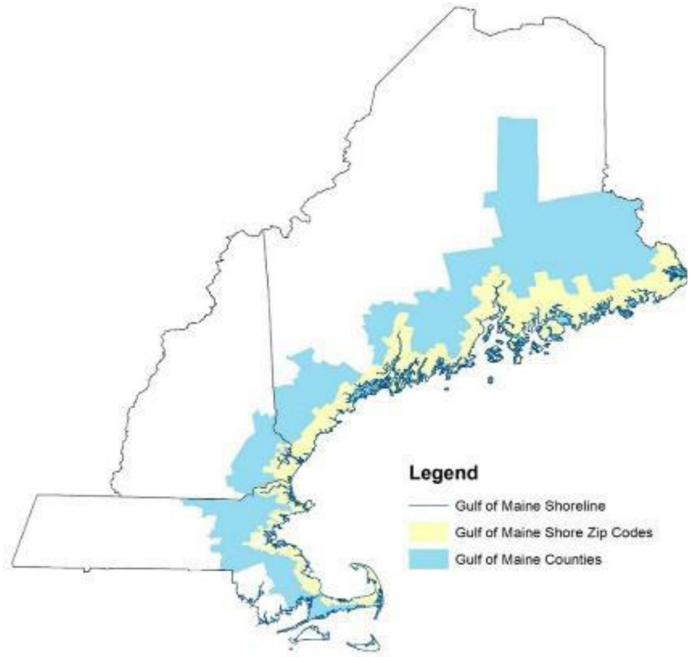


Figure V-5. Zip Codes in the Gulf of Maine Region

Table V 9. Shore Adjacent Zip Code Level Employment and Population by Estuary Region 2018

		Employment			Population		
		2018 Value	Percent of Estuary Region (%)	Percent Change 2009-18 (%)	2018 Value	Percent of Estuary Region (%)	Percent Change 2009-18 (%)
Atlantic	Gulf of Maine	**1,583,666**	46.8	-0.5	3,270,117	42.1	-0.2
	New York Blight	**5,523,508**	49.1	0.3	**12,818,082**	44.0	0.0
	Delaware River	1,141,673	32.7	1.0	2,886,847	34.0	0.4
	Chesapeake Bay	**2,528,339**	40.4	0.6	**6,867,057**	42.8	0.3
	North Carolina	445,663	**65.2**	0.2	1,614,775	**67.0**	0.0
	South Carolina	632,593	**78.2**	-0.4	1,714,042	**70.4**	-1.3
	Georgia	199,580	**72.9**	-0.4	522,990	**52.9**	-2.5
	Florida Atlantic	**2,306,250**	**63.7**	-1.4	**5,987,399**	**56.5**	-0.1
Gulf of Mexico	Southern Gulf	115,834	**56.3**	-0.6	298,515	**46.7**	0.1
	Eastern Gulf	**2,579,631**	41.7	1.4	**5,474,922**	36.8	-0.3
	Central Gulf	236,313	**61.2**	-1.0	709,870	**47.8**	-0.6
	Western Gulf	1,040,270	24.7	-0.7	2,555,589	23.6	0.0
Pacific	Southern California	236,803	26.1	-0.5	794,405	28.8	0.2
	Central Northern CA	1,314,580	**74.1**	-1.7	**3,362,298**	**67.8**	-1.0
	Oregon Washington	480,936	**53.2**	-1.7	1,677,518	44.1	-0.3
	Puget Sound	1,182,055	**66.0**	-1.8	**3,758,766**	**64.0**	0.1
Great Lakes	Lake Superior	747,891	23.2	-1.3	2,141,155	21.9	0.1
	Lake Michigan	1,227,939	16.5	1.0	2,790,318	14.1	0.2
	Lake Huron	**2,242,575**	40.9	-0.6	**5,090,175**	36.4	0.2
	Lake Erie	441,848	33.4	-0.2	1,202,947	33.7	0.3
	Lake Ontario	**1,458,272**	**67.6**	0.6	**3,487,766**	**62.6**	-0.5
Estuary Regions Total		27,666,219	49.2		69,025,533	39.8	-0.2

Above Average Values in Bold

SUMMARY

This review of the economic and demographic characteristics of America's estuary regions is at a relatively high level in terms of geographic scale. Conclusions from this analysis are more suggestive of key features and require more detailed analysis within each region to support efforts to manage, conserve, and restore key estuarine natural capital. But the following suggestions, arising from the data, may be useful:

- There are many reasons for focusing attention on America's estuaries, but one of the most important is that estuaries are the location of a major portion of the U.S. economy. The counties comprising the 21 estuary regions of the continental U.S.[64] comprise 4% of the land area of the U.S. but from that 4% come 47% of the output of the U.S. economy ($8.8 trillion), 39% of the employment (59.4 million jobs) and 40% of the population (130 million people).
- In 2018, eight of the ten largest cities and metropolitan areas were located on estuaries.
- The relative size of the twenty-one estuary regions depends in part on the geographic area of the regions, which are built on counties of varying size. Adjusting for area alters the relative ranking of some of the regions. The Delaware River and Southern Gulf of Mexico regions are below average in the total employment and GDP, but above average once adjusted for area. Conversely, the Western Gulf of Mexico and Central and Northern California are below average in density but above average in total size.
- The pace and location of economic and demographic changes within estuary regions are important long-term drivers of natural resource change. Employment growth rates over 2009-2018 were fastest in the estuary regions on the Pacific and South Atlantic coasts. Population

and housing growth were fastest in the Carolinas, the Western Gulf of Mexico, and Puget Sound.

- A key component of the estuary regions' economy are those sectors directly connected to the marine economy, which provided 3.1 million jobs in 2018, and contributed $301.9 billion to the U.S. economy. These sectors tend to be largest in the major urban areas such as the New York Bight (598,000 jobs, 5.6% of regional employment) and Southern California (330,000 jobs and 4.0% of regional employment). But water dependent industries are more important in less urban areas such as the coastal areas of South Carolina (81,900 jobs but 15.3% of regional employment) and North Carolina (45,000 jobs but 12.4% of employment).
- Population changes within the regions were relatively small over 2009-2018, but Georgia and South Carolina saw increased populations in their near shore areas. Employment changes shifted towards the shore in the Gulf of Mexico regions but towards inland parts of the estuaries in the major urban areas such as New York, Chicago, and Los Angeles. Where growth occurs within a region matters. Faster growth near the ocean or Great Lake can affect coastal and marine ecosystems, while faster growth in the upstream parts of estuary regions have cumulative effects from runoff that magnify as they travel down the rivers and streams of estuaries.

The characteristics and trends noted in the analysis of the estuary regions defined in this study are important, but the regions are very large in area, averaging 33,700 square kilometers (13,000 square miles). The patterns of economic and population distribution and growth depicted in the comparison between regions can also be seen to one extent or another within each of the regions. Similar studies at a finer geographic scale would be needed to examine those patterns within a region.

The need for such studies is created not only by the need for a more accurate picture of America's estuary regions but also because the relationship between development and estuaries is undergoing significant changes. In the 2009 Value of Estuaries report, the value of estuaries for various, market-based, sectors such as ports, energy, fisheries, and real estate were explored. However, this study recognizes an evolution in our understanding of the economic value of estuaries, a shifting interest to those benefits provided by estuaries that aren't easily measured by market data.

In the accompanying case studies, natural infrastructure flood resilience and carbon storage benefits are examined in six estuaries to illustrate these economic values. The two new perspectives on the values of estuaries are important contributions to making decisions to expand conservation and restoration of wetlands in estuarine environments. These values are, in turn, closely tied to the patterns of economic and population growth outlined here.

As discussed in the case studies, the value of estuarine wetlands for flood resilience is dependent to a large extent on the values of property and associated economic activity at risk from flooding. These values may remain intact if wetlands are conserved or expanded through restoration. The type and quantity of development that occurs along the shoreline will determine the value of flood resilience. For example, development could be intended to accommodate employment in commercial activities or for housing (both year-round and seasonal) or for the transportation system that connects the two. The current and potential natural infrastructure of the estuary should be fit into patterns of development, and treated similarly to other forms of infrastructure. The flood resilience benefits of wetlands may also provide a potential pool of capital to fund conservation and restoration, particularly in an era of climate change when the threat of flooding from both river and coastal sources is growing.[65]

On the other hand, preventing the loss of the carbon storage and sequestration values of coastal wetlands is likely to be a key part of state and national climate action plans.[66] Coastal blue carbon values will depend on minimizing the effects of development on existing wetland systems and restoring degraded wetlands. These values will often be maximized where there is the least disturbance to wetlands, either through the maintenance of estuarine wetlands through various conservation measures or restoration of wetlands. Understanding how development occurs within an estuary is necessary to find the right balance between the socio-economic systems and the values of the natural systems in the estuaries. The accompanying case studies show how this balance is being struck currently in six very different locations.

Figure VI-1. Protected Wetlands. Cape May, New Jersey.

VI. Case Study 1: Great Egg Harbor, New Jersey

GREAT EGG HARBOR ESTUARY

The Great Egg Harbor Estuary is located in southern New Jersey's Atlantic Coastal Plain across Atlantic and Cape May Counties, approximately 10 miles southwest of Atlantic City and 105 miles south of New York City.[1] The U.S. Census Bureau estimated in 2019 that the population of Atlantic County is 263,670. Within Atlantic County 71% of the population is white, 19% is Hispanic or Latino, 17% is Black or African American, and 8% is Asian. The population estimate for Cape May County is 92,039 with 91% of the population being white, 8% of the population Hispanic or Latino, and 5% is Black or African American. The combined population for the estuary region is 355,709.[2]

Great Egg Harbor Estuary encompasses the entire Great Egg Harbor River, which drains a 338 square mile area within the New Jersey Pinelands, from its headwater streams to its interface with open waters of the New York Bight via Great Egg Harbor Inlet.[3] It is also fed by the Tuckahoe River, Patcong Creek, and Cedar Swamp Creek. The estuary includes all wetlands and open water of the Great Egg Harbor River and its tributaries as well as the open water and islands within Great Egg Harbor and Peck Bays and the adjacent saltmarsh and sandy shoreline habitat.[4] It is part of the New Jersey back-barrier lagoon system and is often referenced as part of the New Jersey Pinelands or Cape May Peninsula habitat complex.[5] The bays include open water, salt marsh, sandy shoreline, and extensive sandflats and mudflats from the sediment load from the river and influx of sand through Great Egg Harbor Inlet.[6] There are 18, 932 acres of tidal marsh in the estuary that are extensively ditched.[7]

The Great Egg Harbor estuary was initially inhabited by native Leni-Lenape who utilized the bay for fishing and clamming.[8] Seventeenth century English colonists called this tribe "the Delawares," after the name they gave to the river, bay, and inhabitants to honor Sir Thomas West, the third Lord de la Warr. In the 18th century shipyards were built along Great Egg Harbor to support a growing shipbuilding industry.[9]

The Great Egg Harbor Estuary is a very productive ecosystem hosting a diversity of aquatic and terrestrial habitats and species. The estuary provides critical habitat for a variety of anadromous, estuarine, marine, and freshwater fish and shellfish, waterfowl, waterbirds, and raptors, and rare plants and invertebrates. The estuary is one of the top 20 migratory bird locations in the United States and Cowpens Island within the bay has been designated as a bird sanctuary and heron rookery. Sixty-seven species of fish were identified by the National Fish and Wildlife Service in a one-year inventory of the estuary the most abundant of which were Atlantic silversides, Atlantic menhaden, the bay anchovy, white perch, and winter flounder.[10] Benthic invertebrates include oysters, mussels, barnacles and crabs and the Bay provides breeding grounds for oysters and clams.[11] The National Fish and Wildlife Service also reported average of 12,000 waterfowl on midwinter aerial surveys and found that American black duck, greater and lesser scaup, brand, mallard, and Canada geese were most prevalent.[12]

The greatest environmental threats to Great Egg Harbor Estuary are nutrient and sediment influx from wastewater and sewage treatment plants, stormwater runoff, septic system leaching, and agricultural runoff.[13] Stormwater drains in Ocean City feed into Great Egg Harbor, and water quality issues are exacerbated by residential development in the watershed which results in significant habitat loss.[14] There is also concern that sand and gravel mining operations are contaminating the groundwater.[15] Sea level rise threatens the marshy islands within the Bay which are eroding at a rate of 7 mm per year.[16]

Environmental Policies

There are 145 species of special emphasis in the Great Egg Harbor Estuary including 41 species of fish and 87 species of birds including six federally listed species and 10 state-listed species. Among these are the federally endangered peregrine falcon, and the federally threatened bald eagle and piping plover.[17] Species of concern include the northern diamond terrapin, eastern oyster, blue crab, horseshoe crab, and Atlantic menhaden.[18]

New Jersey wetlands are regulated under several state laws including the Wetlands Act of 1970, the Freshwater Protection Act, and the New Jersey State Coastal Area Facilities Review Act in coordination with the federal Rivers and Harbors Act of 1899 and the Clean Water Act of 1977.[19] The underwater lands of Great Egg Harbor Estuary are owned and managed by the State of New Jersey. The New Jersey Division of Fish, Game, and Wildlife oversees a large Wildlife Management Area encompassing 13,300 acres of salt marsh.[20] The majority of the watershed falls within the Pinelands Management Area (66%). Priority biodiversity sites with particular emphasis on rare plant species and ecological communities within the estuary have been identified by the New Jersey Natural Heritage Program.[21] Additionally, a significant portion of the Great Egg Harbor River and tributaries have been designated as National Wild and Scenic Rivers, a system created by Congress in 1968 to preserve rivers that have outstanding natural, cultural, and recreational characters and manage their use and development.[22] As part of this designation a river management plan was developed in 1994 for the Great Egg Harbor River to enable local governments within the estuary to manage the river resources using local controls.[23] The New Jersey Department of Environmental Protection also designated waters within the Pinelands as Outstanding Natural Resource Waters, a classification under the Clean Water Act which sets aside these waters for posterity because of their unique ecological significance. Under this designation they are protected from manmade wastewater discharges and any activity that may degrade surface water quality.[24] While this designation provides protections to the upstream reaches of the Great Egg Harbor River, the estuary is still at risk. The Great Egg Harbor Watershed Effort launched in 2000 to preserve and protect the estuary. After the program lost funding from the Department of Environmental Protection in 2003, Atlantic County and the DEP authorized the reallocation of funds to start a water conservation campaign called "Water- Use it Wisely" to engage citizens in water conservation and increase public awareness of water consumption.[25]

Commercial fishing has historic significance to Atlantic and Cape May Counties dating back to the late 1600s.[26] Commercial fishing is the second largest industry in Cape May County which is also the center of fish processing and freezing in New Jersey.[27] In 2013 commercial landings were 20 million pounds valuing $35 million.[28] Top target species within the counties include scallops, butterfish, summer flounder, scup (also known as porgy), black sea bass, surf clams, ocean quahog, lobster, herring, and monkfish, although many of these species are found outside of estuarine waters.[29] Charter boats and private recreational fishing activities also operate within the two counties. Summer flounder, scup (porgy), black sea bass, and bluefish are key recreational species targeted, with mackerel forming a small but important niche fishery for anglers.[30]

VALUE OF NATURAL INFRASTRUCTURE IN THE GREAT EGG HARBOR ESTUARY

NOAA defines natural infrastructure as "healthy ecosystems, including forests, wetlands, floodplains, dune systems, and reefs, which provide multiple benefits to communities, including storm protection through wave attenuation or flood storage capacity and enhanced water services and security."[31] An estuary's capacity to protect shoreline property from climate hazards and flood risk is an important ecosystem service.

The measurement of this service is, however, complex. The value depends on how often and how severe floods will be. It depends on the value of the economic assets vulnerable to floods of different sizes and types. And it depends on the extent of lost economic activity, as well as the issue of disproportionate effects on populations which may not have the capacity to recover from flood events.

The analysis in this section uses a method that focuses on damages to real property from flooding that might be reduced by the presence of estuarine wetlands adjacent to the property. It is a very simplified perspective that is designed to raise awareness of natural infrastructure benefits as a prelude to incorporating these values into planning for the future of estuaries using more complete information. More detail on the methodology is available in Section IV of the main report.

Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $68.3 million and $153.6 million (Table VI-1). These values are for damages to property exposed to flooding and do not include The analysis for the Great Egg Harbor estuary shows that these benefits can range from $34.4 million to $76.8 million over a 30-year period for a flood that historically would occur once in 100 years. the damages to business sales or employment, nor the value of possible losses from effects on human health. These damage estimates should thus be considered conservative, that is, likely to be lower than actual total values.

For Great Egg Harbor the benefits area can be found throughout the developed portions of the Harbor and River, particularly on the barrier island where Ocean City is located and in the areas of Beesley Point (in the southern part of the bay) and Somers Point (in the northern part of the bay). Figure VI-2 shows these areas in the left panel. In the right panel, the parcels located in the 100-year flood zone and adjacent to wetlands are added to the map. This spatial analysis results in the identification of 3,600 hectares (8,896 acres) of wetlands offering protection to 20,240 parcels which intersect with the selected wetlands. The parcel data was drawn from Cape May and Atlantic County Tax Assessors' databases.

Table VI-1. Summary of Findings: Great Egg Harbor Estuary Natural Infrastructure Benefits

Area (Ha) of Estuarine and Marine Wetlands Offering Protective Benefits	Number of wetlands-adjacent parcels in 100 Year Flood Zone	Values at Risk (Millions)	1% Annual Probability Storm Benefits (Millions)		2% Annual Probability Storm Benefits (Millions)	
			Wetland Effect Low (10%)	Wetland Effect High (20%)	Wetland Effect Low (10%)	Wetland Effect High (20%)
3,600	20,240	$13,848.00	$34.41	$76.81	$68.27	$153.61

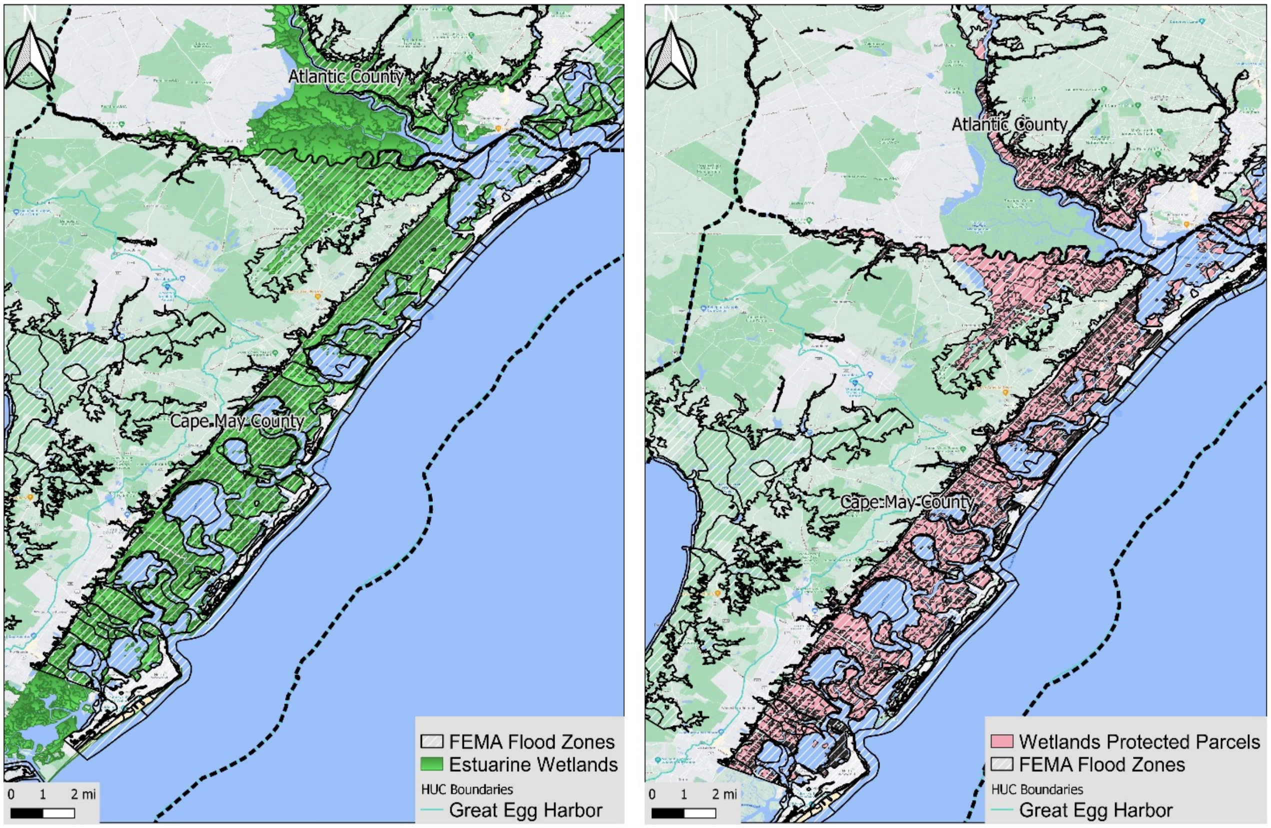


Figure VI-2. Great Egg Harbor estuarine wetlands and floodzone

Wetlands can reduce the damage from coastal or river flooding by absorbing and slowing runoff, stabilizing riverbanks and coastlines, dissipating wave energy, and serving as a physical barrier. The benefits can be measured as the reduction in flood damages resulting from the presence of the wetlands and is a function of the location of vulnerable economic assets (e.g., buildings and land), the frequency and severity of floods, the likely extent of damages, and the possible reductions in those damages resulting from the presence of the wetlands. The exact extent of the damage that determines benefits cannot, of course, be known with precision in advance so estimates and assumptions must be used. These assumptions and the calculations used to estimate benefits are explained in Section IV of the accompanying technical report.

Flood damage reductions depend on the frequency and severity of flooding. A measure that combines frequency and severity is the 100-year flood zone designated by FEMA for purposes of administering the National Flood Insurance Program. This zone identifies areas likely to be inundated by a flood of such severity that it only has a 1% chance of occurring each year. For this analysis, an alternate scenario is used to examine the potential effects of climate change, one of which is an increase in the frequency of severe storm events. To reflect estimation of benefits related to a changing climate, we assumed the 100-year storm becomes the 50-year storm, which means the annual probability of a storm at least this severe doubles from 1% to 2%.

To calculate the benefits of wetlands the total likely damages to property from a 100-year flood first. These damages were estimated by applying flood damage factors for land and buildings to the assessed values of the property; buildings were assumed to be subject to twice the damages of land. These estimated damages were multiplied by the probability of a flood occurring over a 30-year period. For the 1% annual probability, the *cumulative* probability of a flood over 30 years is 26%. For the 2% annual probability the cumulative probability is 45%. The result is the total expected flood damage over 30 years. Since any flood damages will occur in the future, the value of the expected damages is discounted over the 30-year time period and the results are presented in $2020, or the present value. These expected damages are the basis for calculating the reductions in flood damages that may be attributable to wetlands as described above.

The extent to which wetlands can reduce flood damages is highly variable depending greatly on the type and extent of wetlands at any given location. For purposes of this analysis the "wetlands effect" is the reduction in the dollar value of likely damages from a 100-year storm that may be attributable to the presence of wetlands expressed as a percentage of damages. A range of 10% to 20% reduction is used based on a study of wetlands damage reductions from an actual storm on the Atlantic coast.[32]

Table VI-2 provides the results of the analysis for the counties affected. The table shows the market values of land and buildings plus the total market value by parcel as estimated by the county assessors. The majority (80%) of the parcels examined and the value at risk (84%) is in Cape May County, in the southern part of the Bay. The vulnerable property values are primarily land in Atlantic County and primarily buildings in Cape May County.

The estimated natural infrastructure benefits for the 100-year storm range in total from $5.5 million to $11.9 million in Atlantic County and between $28.9 million and $129.8 million in Cape May County. This is the present value of potential flood damages over a 30-year period.[33] These would increase to $10.6 to $23.8 for Atlantic County and to between $57.7 and $129.8 in Cape May County if the frequency of flooding doubles.

VALUE OF COASTAL BLUE CARBON IN GREAT EGG HARBOR ESTUARY

Over the past decades, as the relationship between greenhouse gases and climate change became clear, the scope of analyses for estuary conservation opportunities expanded to consider the role of coastal wetlands in the global carbon cycle. Coastal wetlands sequester vast amounts of the greenhouse gas carbon dioxide, and store that carbon in their soils. The carbon sequestered and stored in coastal estuaries is called coastal blue carbon.[34] Conserving and restoring estuaries rich in coastal blue carbon mitigates the impacts of climate change,[35,36] and provides additional benefits that support local communities and can bolster local economies. These benefits include

Table VI-2. Great Egg Harbor Natural Infrastructure Benefits by County

County	Parcels	Buildings Value (Millions)	Land Value (Millions)	Total Value (Millions)	1% Annual Probability Storm Benefits (Millions)		2% Annual Probability Storm Benefits (Millions)	
					Wetland Effect Low (10%)	Wetland Effect High (20%)	Wetland Effect Low (10%)	Wetland Effect High (20%)
Atlantic	3,520	$705.1	$1,503.0	$2,208.1	$5.5	$11.9	$10.6	$23.8
Cape May	16,720	$8,245.3	$3,394.4	$11,639.7	$28.9	$64.9	$57.7	$129.8
TOTAL	**20,240**	**$8,950.4**	**$4,897.40**	**$13,847.8**	**$34.4**	**$ 76.8**	**$ 68.3**	**$ 153.6**

providing nursery habitat for fish,[37] reducing the impact of storm surge,[38,39,40] and improving water quality.[41,42,43] Researchers estimating global coastal blue carbon emissions have observed the rapid disappearance of coastal wetlands due to human activity, despite federal and regional wetland protection and planning.[44]

In this case study, coastal blue carbon values are estimated by multiplying the stock of carbon in the "emergent estuarine" land cover class of each estuary by estimates of the social cost of carbon (SCC) published by the Interagency Working Group on Social Cost of Greenhouse Gases in February 2021.[45]

SCC is "a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO_2) emissions in a given year."[46] SCC can also represent the value of damages avoided for emission reductions (i.e., the benefit of a CO_2 reduction). Whether used to measure costs or benefits, SCC values include such wide-ranging effects as global changes in economic output, human health, property damages from increased flood risk, and the value of ecosystem services.

The economic effects of releasing carbon into the atmosphere continue long into the future and increase as the total concentration of atmospheric carbon increases. Annual SCC values for this study's twenty-year period of analysis were discounted to show their value in today's dollars (present value). Values were calculated for each of four SCC scenarios using different discount rates. The "high" and "low" coastal blue carbon values presented in this summary correspond to the use of a 2.5 percent and 5.0 percent discount rate, respectively.

Land cover in the Great Egg Harbor estuary is diverse, with large areas of deciduous forest, cultivated land, and urban land use (See Figure VI-3). Large expanses of estuarine emergent wetland lie between the Garden State Parkway and the coast and in the Tuckahoe Wildlife Management Area.

Carbon Profile

In 2016, the Great Egg Harbor study area contained 24,439 hectares (more than 60,000 acres) of estuarine emergent vegetation (saltmarsh, see Figure VI-4). The Coastal Carbon Research Coordination Network (RCN) database contained data from 8 cores sampling the soil beneath estuarine emergent vegetation, with values ranging from 78 to 301 metric tons of carbon per hectare in the soil, with an average value of 226 metric tons per hectare. The depth of core samples ranges from 25 to 90 centimeters, averaging 68 centimeters.

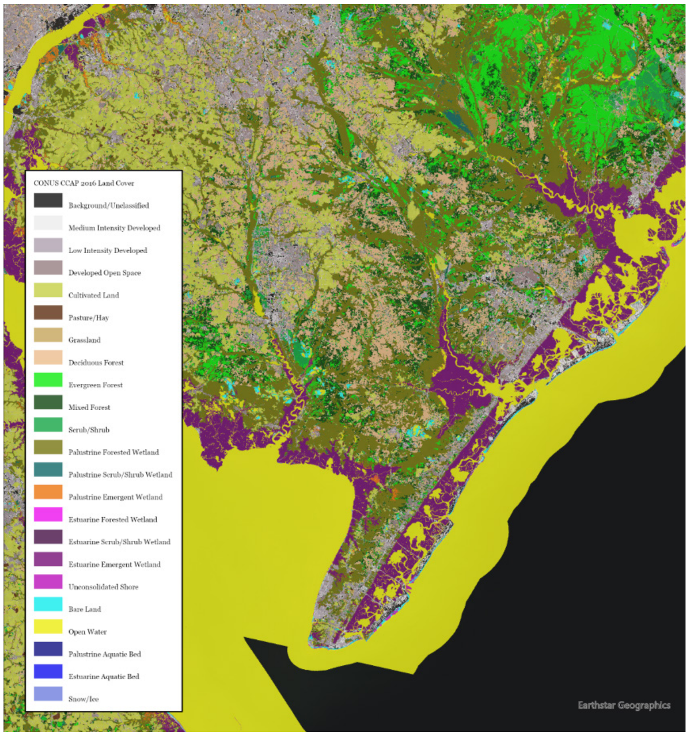


Figure VI-3. Map of vegetation types in the Great Egg Harbor Estuary

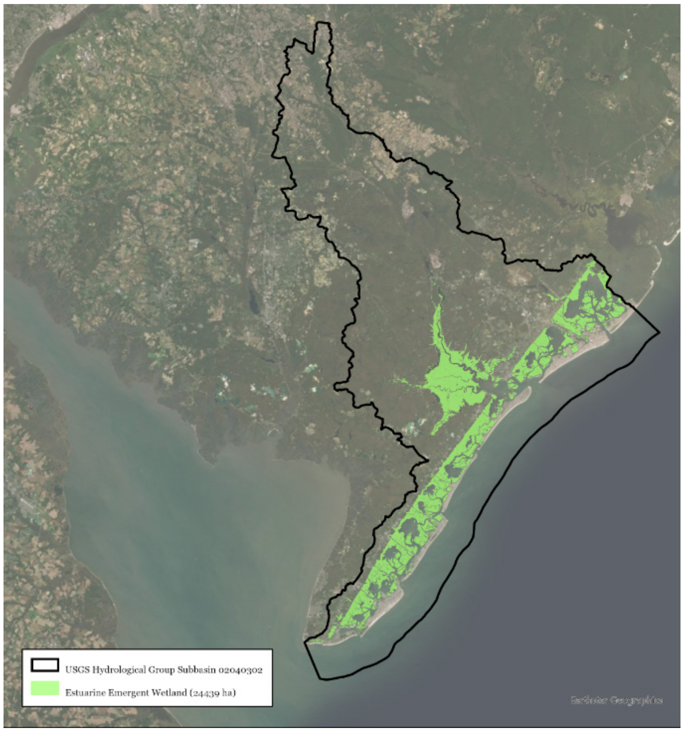


Figure VI-4. Estuarine Emergent Wetlands in the Great Egg Harbor Estuary

These figures suggest that more than 5.5 million tons of CO_2e[47] are stored in the soil beneath the study area's 24,439 hectares of estuarine emergent vegetation. This is approximately equivalent to the annual emissions of approximately 1.2 million cars.[48]

The Value of Coastal Blue Carbon Stock Stored in Soil

Although carbon is also stored in the biomass of the plants and continues to be sequestered over time, data limitations allow only an analysis of the value of carbon that is stored in soil. The value of the coastal blue carbon stock in the soil of the Great Egg Harbor's estuarine emergent wetland is estimated as the cost to society that would be incurred if the wetlands upper layers were disturbed or developed, and the carbon was released. These computations are described below. A more comprehensive assessment of the effects of wetland loss (and, thus, the value of conservation) would include the cessation of carbon sequestration and the emission of carbon stored in the biomass. However, sequestration rates and the amount of carbon stored in biomass vary significantly among sites, even within the same class of vegetation.[49] Reliable, site-specific estimates of carbon sequestration rates and the amount of carbon stored in biomass are not available for the Great Egg Harbor Estuary or the areas that are the subject of the other five case studies. For this reason, no attempt was made to estimate these values.

The value of restoring estuarine emergent wetland arises from the restoration of carbon sequestration, which increases over time as the marsh matures. The data limitations described prevent the estimation of these values.

An exponential decay function with a half-life of 7.5 years yields was used to estimate the annual metric tons of carbon that would be released from soil when one hectare of estuarine emergent wetland is converted to another use.[50] The results of this analysis are shown in Table VI-3. In year 30, only 6 percent, or 14.3 metric tons of the initial store of 226 tons of CO_2e remain in the hectare of disturbed wetland soil.

SCC values are projected increase over time corresponding to increases in the concentration of atmospheric greenhouse gases. For purposes of this computation, it was assumed that the wetland was converted in 2020. The initial carbon stock (Year 2020) is 226 metric tons per hectare. Table VI-3 shows that, in the first year after conversion, 19.9 metric tons of carbon would be released, 18.1 metric tons would be released in the second year, etc. The SCCs for 2020 (see Table VI-4) were applied to carbon releases during Year 1 (assuming the wetland was converted in 2020), SCC values for 2021 would be applied to carbon released during Year 2, etc. This yields the annual social cost of the carbon that would be released if the marsh were converted.

Table VI-3. Annual Carbon Released from the Soil of Converted Estuarine Emergent Wetlands (metric tons per hectare)

Year	Carbon in Soil	Cumulative Carbon Release	Annual Carbon Release
2020	226.0	0.0	0.0
2021	206.1	19.9	19.9
2022	188.0	38.0	18.1
2023	171.4	54.6	16.5
2024	156.3	69.7	15.1
2025	142.6	83.4	13.8
2026	130.0	96.0	12.5
2027	118.6	107.4	11.4
2028	108.2	117.8	10.4
2029	98.6	127.4	9.5
2030	90.0	136.0	8.7
2031	82.0	144.0	7.9
2032	74.8	151.2	7.2
2033	68.2	157.8	6.6
2034	62.2	163.8	6.0
2035	56.8	169.2	5.5
2036	51.8	174.2	5.0
2037	47.2	178.8	4.6
2038	43.1	182.9	4.2
2039	39.3	186.7	3.8
2040	35.8	190.2	3.5
2041	32.7	193.3	3.2
2042	29.8	196.2	2.9
2043	27.2	198.8	2.6
2044	24.8	201.2	2.4
2045	22.6	203.4	2.2
2046	20.6	205.4	2.0
2047	18.8	207.2	1.8
2048	17.1	208.9	1.7
2049	15.6	210.4	1.5
2050	14.3	211.7	1.4

Table VI-4. Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates

Year	2020 Dollars Per Ton of CO_2e					
	RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	$17	$6	$14	$51	$76	$152
2025	$17	$6	$17	$56	$83	$169
2030	$17	$6	$19	$62	$89	$187
2035	$17	$6	$22	$67	$96	$206
2040	$17	$6	$25	$73	$103	$225
2045	$17	$6	$28	$79	$110	$242
2050	$17	$6	$32	$85	$116	$260

This computation was performed for each of the four sets of published SCC values and each stream of annual costs was discounted to calculate its present value. Three of the four sets of published SCC values differ only with respect to the discount rates that are applied to future economic values; in Table VI-4, these values are shown in columns labeled "SCC, 5%," "SCC, 3%," and "SCC, 2.5%".[51] Present value computations for these estimates of the SCC use the discount rate upon which each estimate was based. These present values range from $2,602/hectare to $15,014/hectare of estuarine emergent marsh, with the total value for the 24,439 hectares in the estuary ranging from $63.6 million to $366.9 million.

The fourth set of published SCC values differs significantly from the other three. These values capture the potential for low-probability, high-impact outcomes from climate change and correspond to the 95th percentile of the frequency distribution of SCC estimates using a 3 percent discount rate. The present value associated with this set of SCC values is $29,834/hectare with a total value for the estuaries 24,439 hectares of $729.1 million.

The broad range in these present value estimates is in part due to uncertainty about future economic conditions (reflected in differing discount rates) and the appropriate level of risk-taking with regard to climate policy (reflected in the set of SCC values associated with low-probability, high-impact outcomes).

Prices from the Regional Greenhouse Gas Initiative (RGGI) and Western Climate Initiative (WCI) carbon markets were also applied (with a 3% discount rate) to the future stream of carbon releases associated with the loss of one hectare of saltmarsh in Great Egg Harbor. In almost all scenarios, the cost of purchasing the right to release this stream of carbon is much less than the social cost of the released carbon.

Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon equals the SCC. Prices from these two carbon markets result in values that range from $1,026 per hectare to $2,888 per hectare with totals for the 24,439 hectares of salt marsh in the study area ranging from $25.0 million to $70.6 million. The results of these computations are shown in Table VI-5.

Table VI-5. Coastal Blue Carbon Values for Great Egg Harbor Estuary 2020-2049 (Nominal/Net Present Value)

Annual Value	Carbon Released (t CO_2e/ ha)	Value of Released Carbon					
		RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	19.9	$120.72	$339.69	$278.43	$1,014.29	$1,511.49	$3,022.98
2021	18.1	$110.10	$309.79	$272.07	$943.17	$1,414.75	$2,811.37
2022	16.5	$100.41	$282.53	$248.13	$876.71	$1,306.80	$2,630.13
2023	15.1	$91.57	$257.67	$241.38	$814.65	$1,206.88	$2,443.94
2024	13.8	$83.51	$234.99	$220.14	$756.72	$1,128.20	$2,283.91
2025	12.5	$76.16	$214.32	$213.31	$702.67	$1,041.46	$2,120.57
2026	11.4	$69.46	$195.46	$194.54	$652.28	$961.26	$1,979.73
2027	10.4	$63.35	$178.26	$187.86	$615.75	$897.54	$1,836.82
2028	9.5	$57.77	$162.57	$171.33	$571.09	$828.07	$1,713.26
2029	8.7	$52.69	$148.26	$164.93	$529.51	$763.88	$1,588.53
2030	7.9	$48.05	$135.22	$150.42	$490.83	$704.58	$1,480.41
2031	7.2	$43.83	$123.32	$144.40	$454.86	$657.02	$1,379.01
2032	6.6	$39.97	$112.46	$138.28	$421.41	$605.78	$1,277.41
2033	6.0	$36.45	$102.57	$126.11	$390.33	$564.48	$1,189.02
2034	5.5	$33.24	$93.54	$120.49	$361.46	$520.29	$1,106.29
2035	5.0	$30.32	$85.31	$109.88	$334.65	$479.50	$1,028.92
2036	4.6	$27.65	$77.80	$104.77	$314.31	$446.41	$956.59
2037	4.2	$25.22	$70.96	$95.55	$290.80	$411.28	$884.88
2038	3.8	$23.00	$64.71	$90.93	$269.00	$378.88	$822.16
2039	3.5	$20.97	$59.02	$86.38	$248.79	$352.45	$763.63
2040	3.2	$19.13	$53.82	$78.78	$230.04	$324.58	$709.04
2041	2.9	$17.45	$49.09	$74.72	$212.67	$298.89	$655.27
2042	2.6	$15.91	$44.77	$68.15	$196.58	$277.83	$608.09
2043	2.4	$14.51	$40.83	$64.54	$184.06	$255.77	$561.75
2044	2.2	$13.23	$37.24	$61.04	$170.04	$235.45	$521.03
2045	2.0	$12.07	$33.96	$55.67	$157.07	$218.70	$481.15
2046	1.8	$11.01	$30.97	$52.58	$145.06	$201.27	$446.06
2047	1.7	$10.04	$28.24	$49.61	$133.95	$185.21	$411.77
2048	1.5	$9.15	$25.76	$45.24	$123.67	$171.93	$381.56
2049	1.4	$8.35	$23.49	$42.64	$115.54	$158.18	$352.11

Table VI-5. Coastal Blue Carbon Values for Great Egg Harbor Estuary 2020-2049 (Nominal/Net Present Value) (cont'd)

Discounted Value	**0.03**	**0.03**	**0.05**	**0.03**	**0.025**	**0.03**
2020	$120.72	$339.69	$278.43	$1,014.29	$1,511.49	$3,022.98
2021	$106.89	$300.77	$259.11	$915.70	$1,380.25	$2,729.48
2022	$94.64	$266.31	$225.06	$826.38	$1,243.83	$2,479.15
2023	$83.80	$235.80	$208.51	$745.52	$1,120.71	$2,236.55
2024	$74.20	$208.79	$181.11	$672.33	$1,022.09	$2,029.22
2025	$65.70	$184.87	$167.14	$606.13	$920.50	$1,829.22
2026	$58.17	$163.69	$145.17	$546.28	$828.89	$1,657.99
2027	$51.51	$144.94	$133.51	$500.66	$755.07	$1,493.51
2028	$45.61	$128.33	$115.96	$450.82	$679.64	$1,352.46
2029	$40.38	$113.63	$106.32	$405.83	$611.66	$1,217.48
2030	$35.76	$100.61	$92.34	$365.22	$550.42	$1,101.56
2031	$31.66	$89.09	$84.43	$328.60	$500.74	$996.23
2032	$28.03	$78.88	$77.00	$295.57	$450.43	$895.95
2033	$24.82	$69.84	$66.88	$265.80	$409.49	$809.66
2034	$21.98	$61.84	$60.85	$238.97	$368.22	$731.39
2035	$19.46	$54.76	$52.86	$214.80	$331.08	$660.42
2036	$17.23	$48.48	$48.00	$195.87	$300.71	$596.12
2037	$15.26	$42.93	$41.69	$175.94	$270.29	$535.37
2038	$13.51	$38.01	$37.78	$158.01	$242.92	$482.93
2039	$11.96	$33.66	$34.19	$141.88	$220.47	$435.49
2040	$10.59	$29.80	$29.69	$127.37	$198.08	$392.58
2041	$9.38	$26.39	$26.82	$114.32	$177.96	$352.24
2042	$8.30	$23.36	$23.30	$102.59	$161.38	$317.36
2043	$7.35	$20.69	$21.01	$93.26	$144.95	$284.63
2044	$6.51	$18.32	$18.93	$83.65	$130.17	$256.31
2045	$5.76	$16.22	$16.44	$75.02	$117.97	$229.80
2046	$5.10	$14.36	$14.79	$67.26	$105.92	$206.84
2047	$4.52	$12.72	$13.29	$60.30	$95.09	$185.37
2048	$4.00	$11.26	$11.54	$54.05	$86.12	$166.77
2049	$3.54	$9.97	$10.36	$49.03	$77.29	$149.42
Present Value, 30 years	**$1,026.36**	**$2,888.02**	**$2,602.48**	**$9,891.46**	**$15,013.81**	**$29,834.48**

ESTUARY SUMMARY

Restoration Efforts

Fourteen projects are reported in the Great Egg Harbor between the NOAA Restoration Atlas and a report from the Army Corps of Engineers[52] (See Figure VI-5). Data from the NOAA Restoration Atlas and the Army Corps of Engineers New Jersey Back Bays-Engineering with Nature program shows fourteen restoration projects covering 216 hectares (533 acres), although one fish passage project accounted for 142 hectares (350 acres) of this total.

Table VI-6 Restoration Projects in Great Egg Harbor

	Number of Projects
Debris Removal	2
Dune Restoration	3
Habitat	2
Island Creation	3
Levee	2
Oyster Restoration	1
Wetland Creation	1
Grand Total	14

Restoration projects in the Great Egg Harbor region tend to be located in the back bays behind the barrier beach regions, but there are three dune restoration projects. The location of the restoration projects will tend to increase both the coastal blue carbon and natural infrastructure benefits for the area.

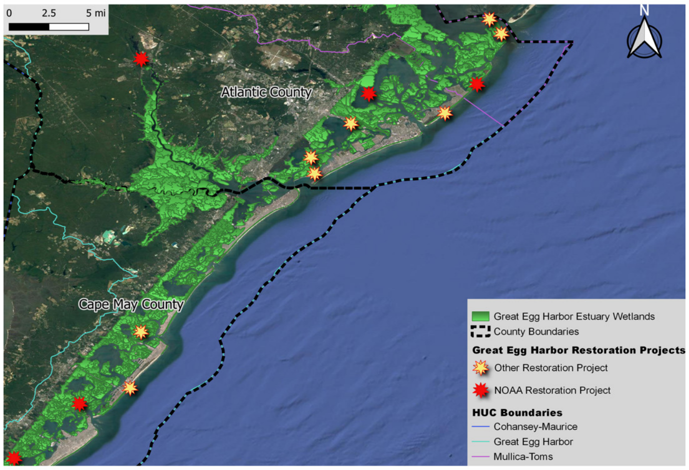


Figure VI-5 Restoration Projects in Great Egg Harbor Area

Natural Infrastructure and Coastal Blue Carbon Benefits

The estimated wetlands benefits for the 100-year storm range in total from $5.5 million to $11.9 million in Atlantic County and between $28.9 million and $64.9 million in Cape May County. Including both counties together, the values range from $34.4 million to $76.8 million. This is the present value of potential flood damages over a 30-year period.[53] These increase to $10.6 million to $23.8 million for Atlantic County and to between $57.7 million and $129.8 million in Cape May County if the frequency of flooding doubles.

The value of retaining coastal blue carbon in wetland soils ranges from $2,602/hectare to $15,014/hectare using various discount rates. The total value for the 24,439 hectares in the estuary under the three more likely SCC scenarios ranges from $63.6 million to $366.9 million. The low-probability, high-impact climate outcome scenario resulted in a coastal blue carbon value of $729.1 million.

The broad range in these benefit estimates is due to several factors:

- variation in the "wetlands affect" arising from differences in the precise location, and quantity of wetlands between the valued assets and the water,
- uncertainty about future economic conditions (reflected in differing discount rates in the coastal blue carbon analysis), and
- assumptions about the increasing severity of storms due to climate change.

Bounded north and south by the cities of Somers Point and Ocean City, and east and west by the Pork Island, Malibu Beach, and Tuckahoe-Corbin City Fish and Wildlife Management areas the Great Egg Harbor region is a well-developed area from an economic and population perspective, and also is rich in natural resources.

Table VI-7. Natural Infrastructure and Coastal Blue Carbon Benefits Summary

Great Egg Harbor	Total hectares in analysis	Estimated benefits per hectare of wetlands ($Thousands)		Total Estimated Benefits ($Millions)	
		Low estimate	High estimate	Low estimate	High Estimate
Natural Infrastructure	3,600	$9.6	$42.7	$34.1	$153.6
Coastal Blue Carbon[54]	24,439	$2.6	$15.0	$63.6	$366.9
Total				$97.7	$520.5

Table VI-7 summarizes the range of benefits from natural infrastructure and coastal blue carbon determined by this analysis. The table also includes the combination of the two ecosystem service values that were analyzed in this report. The analysis includes all areas of wetlands within the study area that provide one service or the other, as well as areas that provide both services. Because the two benefits provide complementary services, presenting a total value is appropriate. Combined, the natural infrastructure and coastal blue carbon benefits range from $97.7 to $520.5 million. In terms of total value, coastal blue carbon values in Great Egg Harbor are greater than those provided by natural infrastructure. Those values exist now, and should be recognized and maintained. However, in terms of increasing value in the estuary over time, the benefits per hectare is higher for natural infrastructure, and conserving or restoring wetlands to continue to increase natural infrastructure benefits will provide the greatest addition to the existing value.

These estimates must be considered very preliminary and are intended to be helpful in shaping overall strategies for the future management of the wetlands resources of the Great Egg Harbor Estuary, strategies that account for both local goals of a healthy estuary and global goals of mitigation of climate change. They are part of a broader attempt to begin to characterize general estuary characteristics that offer different sources of economic value to local communities, such as protection from storms and flooding, and help meet broader societal goals, such as mitigation for climate change. As part of an examination of estuaries across the nation, they are not intended to guide project-level decisions, or replace more localized "deep dives" that have been conducted in these estuaries. There are still many unknowns that require much more elaborate estimation procedures for both natural infrastructure and coastal blue carbon. Whether the actual benefits in the future will tend towards the lower or higher end of these estimates will require continued research and ongoing assessment. But it is certain that the realization of these benefits will depend first on conserving the wetlands that exist and then on the restoration of wetlands that could increase these benefits.

VII. Case Study 2: Pamlico Sound, NC

PAMLICO SOUND

Pamlico Sound is the largest sound, or saltwater lagoon, on the East Coast of North America.[1] Fed by the waters of the Tar-Pamlico and Neuse watersheds and bordered by Albemarle Sound in the North, Pamlico Sound extends 80 miles long and 15-20 miles wide from the southern borders of Manteo and Dare County, North Carolina to the Cape Lookout National Seashore. Its eastern edge encompasses most of the Outer Banks.[2] It is one of several interconnected estuaries known as the Albemarle-Pamlico sound system which includes Albemarle Sound, Currituck Sound, Croatan Sound, Bogue Sound, Core, Sound, and Roanoke Sound (See Figure VII-1). Together the Albemarle-Pamlico system stands as the second largest estuary in the United States, spanning over 3,000 square miles of water. Pamlico Sound comprises the southern part of the Albemarle-Pamlico system, and is separated from the Atlantic Ocean by a large unique series of barrier islands known as the Outer Banks which includes several national preserves and refuges including Pea Island National Wildlife Refuge, Cape Hatteras National Seashore, Cape Lookout National Seashore, and Swanquarter National Wildlife Refuge.[3] The average depth (5-6 feet) is relatively shallow throughout the Sound.[4] This feature makes Pamlico Sound particularly susceptible to wind and barometric pressure-driven tidal fluctuations, and historically hurricanes have caused significant flooding damage in the region.[5]

The unique ecological and geographic features of Pamlico Sound attract a great variety of wildlife. Waterfowl include swans, geese, ducks, blue herons, white ibises and snowy egrets, rare white pelicans, and occasionally American Bald Eagles.[6,7] Recreational and commercial fisheries target blue crabs, mullet, spot, croaker, and sheepshead.[8,9] The region is renowned for its oyster beds, which are open to commercial and public harvest, and extensive clamming grounds.[10] The submerged aquatic vegetation (SAV), rich oyster beds, and primary nursery areas provide expansive juvenile fish habitat, some of the most significant along the eastern coast of the United States.[11,12] In addition, wetlands, oyster reefs, and SAV improve water quality by reducing erosion and wave activity, and filtering water.[13] Seagrass meadows are considered some of the most important natural carbon sinks in marine environments.[14] The North Carolina Division of Marine Fisheries oversees commercial and recreational fishing industries within state waters.[15]

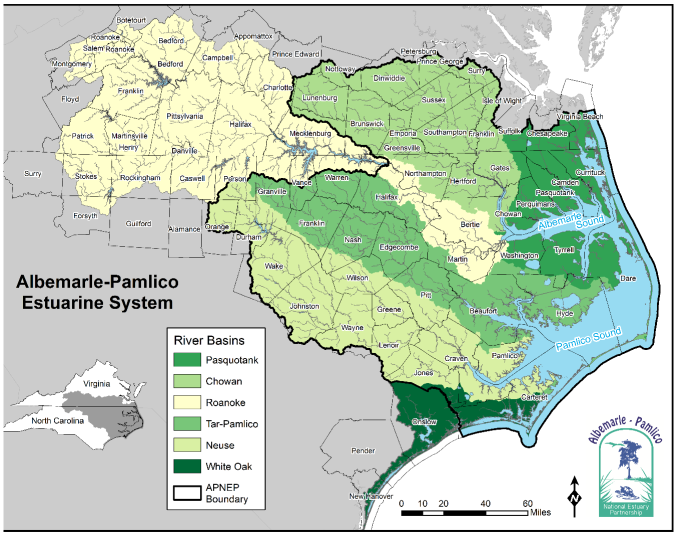


Figure VII-1. The Albemarle–Pamlico Estuarine System[16].

Environmental Policies

In 1974, the North Carolina Coastal Area Management Act declared North Carolina's coastal area to be "amongst the most valuable and biologically productive regions of the state."[17] The Albemarle-Pamlico Estuary was named an estuary of national significance by Congress in 1987 and the Albemarle-Pamlico National Estuary Partnership was a charter member of the National Estuary Program initiated in the same year.[18] Concerns over declining state fisheries in 1997 stimulated the North Carolina General Assembly to pass the Fisheries Reform Act which addresses fisheries management, habitat loss, and water quality degradation.[19] In response, the North Carolina Coastal Habitat Protection Plan (CHPP, 2004) was adopted by the Coastal Resources, Environmental Management, and Marine Fisheries Commissions in 2004. In 2015, the CHPP identified four priority habitat issues as the focus of implementation plans: oyster restoration, living shorelines, sedimentation, and metrics to assess habitat trends and management effectiveness.[20] The 2016 amended CHHP recommended improving effectiveness of existing rules and programs protecting coastal fish habitats, identifying and delineating strategic coastal habitats, enhancing and protecting habitats from adverse physical impacts (particularly estuarine shoreline), and enhancing and protecting water quality.[21] The Department of Environmental Quality is the lead steward for preservation and protection of North Carolina's natural resources and oversees the CHHP. They work in close coordination with the Albemarle-Pamlico National Estuary Partnership (APNEP), the Office of Land and Water Stewardship, the Wildlife Resources Commission, and the Division of State and Water Conservation.

Recent efforts related to climate resilience in response to Executive Order 80, signed by Governor Cooper in 2018, focus on the integration of climate adaptation and resilience planning into cabinet agency policies, programs, and operations[22]. The APNEP 10-year Comprehensive Conservation and Management Plan identifies nutrient pollution from stormwater runoff and air sources, threats to commercial and recreational fish habitat, and global climate change and sea-level rise as three key stressors facing the sound[23]. Coastal stakeholders participating in the climate resilience workshops sponsored by the state noted that nutrient runoff from stormwater, agriculture, wastewater treatment, and industrial facilities is a long-term coast-wide problem that is expected to be exacerbated by prolonged flooding and salt water intrusion[24]. Another key challenge included threats to built infrastructure. Wastewater systems, sewer systems, stormwater management, and transportation systems are expected to be impacted by salt-water intrusion, more severe and prolonged flooding, and storm surge.[25]

Socioeconomic/Cultural Status

Pamlico Sound is named after the Pamlico Indians of the Algonquian tribe who inhabited the region along the Pamlico River. The tribe was devastated by an outbreak of smallpox in 1696 and following the loss of tribal lands their presence in the region largely disappeared.[26] As Europeans colonized the region Pamlico Sound provided shipping channels for European colonists to acquire goods and supplies thus spurring a line of settlements and villages along the Outer Banks.[27] The Intracoastal

Waterway, which spans 214 miles of the Albemarle-Pamlico Sound, is still critical for shipping today.[28] Recreational and commercial fisheries are both economically and socially important to Pamlico Sound and provide employment, income, food, and recreation for residents and tourists. In 2016, recreational fisheries had a $1 billion impact on North Carolina's economy, commercial fisheries had a $180 million impact on North Carolina's economy, and saltwater fishing created almost 17,000 jobs.[29] In 2019, commercial fishermen landed more than 10 million lbs. of seafood valued at more than $15 million[30] in and around Pamlico Sound. Oysters have historically been a large and profitable fishery in Pamlico Sound, although harvest have plummeted due to habitat loss, disease, overfishing, and pollution.[31] The industry is now largely a "put and take" fishery where oyster reefs are built and populated, then harvested a few years later when oysters reach mature size, thus many restoration efforts focus on restoring and protecting the native oyster populations.[32]

Tourism is also critical to the region and Pamlico Sound is renowned for recreational watersports including windsurfing, kiteboarding, kayaking, and paddle boarding.[33] The economic impact of tourism in 2012 by the Albemarle-Pamlico's four oceanside counties—Dare, Carteret, Currituck, and Hyde—exceeded $1.37 billion.[34]

VALUE OF NATURAL INFRASTRUCTURE IN PAMLICO SOUND

NOAA defines natural infrastructure as "healthy ecosystems, including forests, wetlands, floodplains, dune systems, and reefs, which provide multiple benefits to communities, including storm protection, through wave attenuation or flood storage capacity and enhanced water services and security.[35] An estuary's capacity to protect shoreline property from climate hazards and flood risk is an important ecosystem service.

The measurement of this service is, however, complex. The value depends on how often and how severe floods will be. It depends on the value of the economic assets vulnerable to floods of different sizes and types. And it depends on the extent of lost economic activity, as well as the issue of disproportionate effects on populations which may not have the capacity to recover from flood events.

The analysis in this section uses a method that focuses on damages to real property from flooding that might be reduced by the presence of estuarine wetlands adjacent to the property. It is a very simplified perspective that is designed

Table VII-1. Summary of Findings: Pamlico Sound Estuary Natural Infrastructure Benefits

Area (Ha) of Estuarine and Marine Wetlands Offering Protective Benefits	**Number of wetlands-adjacent parcels in 100 Year Flood Zone**	**Values at Risk (Millions)**	**1% Annual Probability Storm Benefits (Millions)**		**2% Annual Probability Storm Benefits (Millions)**	
			Wetland Effect (Low) -10%	Wetland Effect (High) -20%	Wetland Effect (Low) -10%	Wetland Effect (High) -20%
62,153	**13,747**	**$17,072**	**$48.84**	**$109.88**	**$97.67**	**$219.76**

to raise awareness of natural infrastructure benefits as a prelude to incorporating these values into planning for the future of estuaries using more complete information. More detail on the methodology is available in Section IV of the main report.

For Pamlico Sound these benefits can range from $48.8 million to $109.9 million over a 30-year period for a flood that historically would occur once in 100 years. Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $97.7 million and $219.8 million (Table VII-1). These values are for damages to property exposed to flooding and do not include the damages to business sales or employment, nor the value of possible losses from effects on human health. These damage estimates should thus be considered as only partial.

The natural infrastructure benefits in Pamlico Sound are to be found throughout the area defined as the portions of four counties bordering the Sound (Carteret, Craven, Hyde, Pamlico) located within the Lower Neuse and Pamlico Hydrologic Units.[36] Parcels from the county tax records were selected based on their location within the 100-year flood zone[37] and adjacent to estuarine wetlands as defined by the National Wetlands Inventory.[38] Figure VII-2, shows the location of the estuarine wetlands as indicated by the National Wetlands Inventory from the U.S. Fish & Wildlife Service together[39] with the FEMA-designated 100- year flood zone, that is the area which has a historical probability of being flooded of 1% each year.[40] In Figure VII-3, the parcels located in the 100-year flood zone are added to the map. This spatial analysis results in the identification of 62,153 hectares (153,581 acres) of wetlands offering protection to 35,429 parcels which intersect with the selected wetlands. The parcel data was drawn from the assessors' databases of each county.

Wetlands can reduce the damage from coastal or river flooding by absorbing and slowing runoff, stabilizing riverbanks and coastlines, dissipating wave energy, and serving as a physical barrier. The benefits can be measured as the reduction in flood damages resulting from the presence of the wetlands and is a function of the location of vulnerable economic assets (buildings and land), the frequency and severity of floods, the likely extent of damages, and the possible reductions in those damages resulting from the presence of the wetlands. The exact extent of the damage that determines benefits cannot, of course, be known with precision in advance so estimates and assumptions must be used. These assumptions and the calculations used to estimate benefits are explained in Section III of the accompanying technical report.

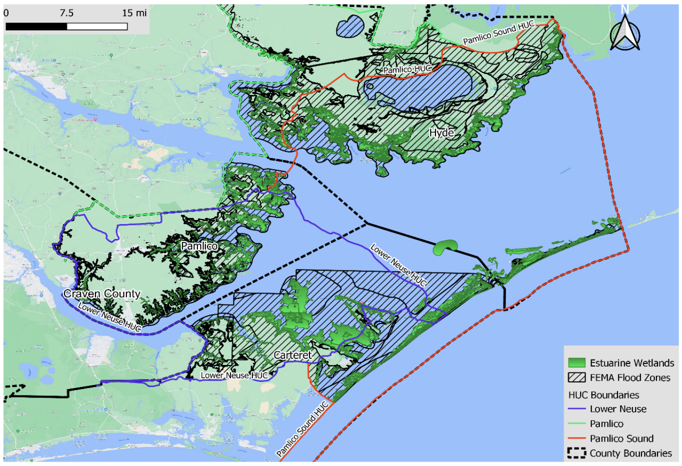


Figure VII-2 Pamlico Sound Wetlands and Flood Zones

Flood damage reductions depend on the frequency and severity of flooding as defined by the severity of flooding. A measure that combines frequency and severity is the 100-year flood zone designated by FEMA for purposes of administering the National Flood Insurance Program. This zone identifies an area affected by a flood of such severity that it only has a 1% chance of occurring each year. For this analysis, an alternate scenario is used to examine the potential effects of climate change, one of which is an increase in the frequency of severe storm events. To reflect estimation of benefits related to a changing climate, we assumed the 100-year storm becomes the 50-year storm, which means the annual probability of a storm at least this severe doubles from 1% to 2%.

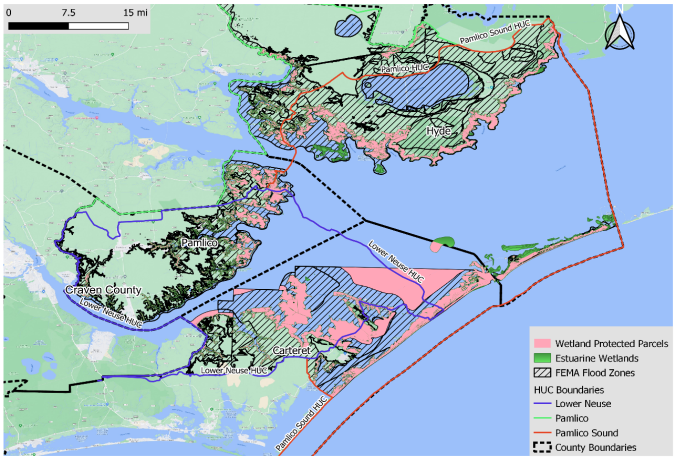


Figure VII-3 Pamlico Sound Wetlands and Parcels

To calculate the protective benefits of wetlands, we estimated the total likely damages to property from a 100-year flood first. These damages were estimated by applying flood damage factors for land and buildings to the assessed values of the property; buildings were assumed to be subject to twice the damages of land. These estimated damages were multiplied by the probability of a flood occurring over a 30-year period. For the 1% annual probability, the *cumulative* probability of a flood over 30 years is 26%. For the 2% annual probability the cumulative probability is 45%. The result is the total expected flood damage over 30 years.

Since any flood damages will occur in the future, the value of the expected damages is discounted over the 30-year time period and the results are presented in $2020, or the present value. These expected damages are the basis for calculating the reductions in flood damages that may be attributable to wetlands as described above.

The extent to which wetlands can reduce flood damages is highly variable depending greatly on the type and extent of wetlands at any given location. For purposes of this analysis the "wetlands effect" is the reduction in the dollar value of likely damages from a 100-year flood that may be attributable to the presence of wetlands—expressed as a percentage of damages. A range of 10% to 20% reduction is used based on a study of wetlands damage reductions from an actual storm in the Atlantic.[41]

Table VII-2 provides the results of the analysis for the area as a whole and for the portion of the counties located within the relevant hydrologic unit and vulnerable to flooding. The table shows the assessed values of land and buildings plus the total market value by parcel as estimated by the assessor of each county. Carteret County has the largest number of parcels and the majority of both the value at risk and the natural infrastructure benefits, accounting for about 80% of the value and benefits.

Table VII-2. Pamlico Sound Natural Infrastructure Benefits by County Area in Pamlico and Lower Neuse Hydrologic Units

					1% Annual Probability Storm Benefits (Millions)		**2% Annual Probability Storm Benefits (Millions)**	
County Area	Parcels	Buildings Value (Millions)	Land Value (Millions)	Total Value (Millions)	Wetland Effect (Low) -10%	Wetland Effect (High) -20%	Wetland Effect (Low) -10%	Wetland Effect (High) -20%
Carteret	8,760	$1,405.04	$6,845.88	$8,250.92	$22.12	$49.77	$44.24	$99.54
Craven	913	$1,759.19	$290.38	$2,049.57	$10.81	$24.33	$21.63	$48.66
Hyde	1143	$53.09	$6,105.70	$6,158.79	$14.24	$32.03	$28.48	$64.07
Pamlico	2,931	$232.14	$306.22	$538.36	$1.66	$3.75	$3.33	$7.49
TOTAL	**13,747**	**$3,449.46**	**$13,548.17**	**$16,997.63**	**$48.84**	**$109.88**	**$97.68**	**$219.76**

VALUE OF COASTAL BLUE CARBON IN PAMLICO SOUND

Over the past decades, as the relationship between greenhouse gases and climate change became clear, the scope of analyses for estuary conservation opportunities expanded to consider the role of coastal wetlands in the global carbon cycle. Coastal wetlands sequester vast amounts of the greenhouse gas carbon dioxide, and store that carbon in their soils. The carbon sequestered and stored in coastal estuaries is called coastal blue carbon.[42] Conserving and restoring estuaries rich in coastal blue carbon mitigates the impacts of climate change[43],[44] and provides additional benefits that support local communities and can bolster local economies. These benefits include providing nursery habitat for fish[45], reducing the impact of storm surge,[46],[47],[48] and improving water quality.[49],[50],[51] Researchers estimating global coastal blue carbon emissions have observed the rapid disappearance of coastal wetlands due to human activity, despite federal and regional wetland protection and planning.[52]

In this case study, coastal blue carbon values are estimated by multiplying the stock of carbon in the "emergent estuarine" land cover class of each estuary by estimates of the social cost of carbon (SCC) published by the Interagency Working Group on Social Cost of Greenhouse Gases in February 2021.[53]

SCC is "a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO_2) emissions in a given year".[54] SCC can also represent the value of damages avoided for emission reductions (i.e., the benefit of a CO_2 reduction). Whether used to measure costs or benefits, SCC values include such wide-ranging effects as global changes in economic output, human health, property damages from increased flood risk, and the value of ecosystem services.

The economic effects of releasing carbon into the atmosphere continue long into the future and increase as the total concentration of atmospheric carbon increases. Annual SCC values for this study's twenty-year period of analysis were discounted to show their value in today's dollars (present value). Values were calculated for each of four SCC scenarios using different discount rates. The "high" and "low" coastal blue carbon values presented in this summary correspond to the use of a 2.5 percent and 5.0 percent discount rate, respectively.

Land cover in the Pamlico Sound is dominated by palustrine and estuarine wetlands, including forested, scrub/shrub, and emergent (See Figure VII-4). Estuarine emergent wetland dominates the inland shoreline of the sound, with large expanses on Piney Island and the Cedar Island National Wildlife Refuge at the mouth of the Neuse River. In addition, a narrow band of estuarine emergent salt marsh extends almost the entire length of the inland shore of the Outer Banks.

Carbon Profile

In 2016, the Pamlico Sound study area contained 37,000 hectares (more than 90,000 acres) of estuarine emergent vegetation (saltmarsh, see Figure VII-5). The Coastal Carbon Research Coordination Network (RCN) database contained data from 6 cores sampling the soil beneath estuarine emergent vegetation, with values ranging from 16 to 623 metric tons of carbon per hectare in the soil and averaging 293 metric tons per hectare. The depth of core samples ranges from 57 to 125 centimeters, averaging 86 centimeters.

These figures suggest that more than 10.8 million tons of carbon dioxide equivalent (CO_2e[55]) are stored in the soil beneath the study area's 37,000 hectares of estuarine emergent vegetation. This is equivalent to the annual emissions of approximately 2 million cars.[56]

The Value of the Coastal Carbon Stock Stored in Soil

Although carbon is also stored in the biomass of the plants and continues to be sequestered over time, data limitations allow only an analysis of the value of carbon that is stored in soil. The value of the blue carbon stock stored in the soil of Pamlico Sound's estuarine emergent wetland areas is estimated as the cost to society that would be incurred if the wetlands' upper layers were disturbed or developed, and the carbon was released. These computations are described below. A more comprehensive assessment of the effects of wetland loss (and, thus, the value of conservation) would include the cessation of carbon sequestration and the emission of carbon stored in the biomass. However, sequestration rates and the amount of carbon stored in biomass vary significantly among sites, even within the same class of vegetation.[57] Reliable, site-specific estimates of carbon sequestration rates and the amount of carbon stored in biomass are not available for Pamlico Sound or the areas that are the subject of the other five case studies. For this reason, no attempt was made to estimate these values.

Figure VII-4. Map of vegetation types in Pamlico Sound

The value of restoring estuarine emergent wetland arises from the restoration of carbon sequestration, which increases over time as the salt marsh matures. The data limitations described prevent the estimation of these values.

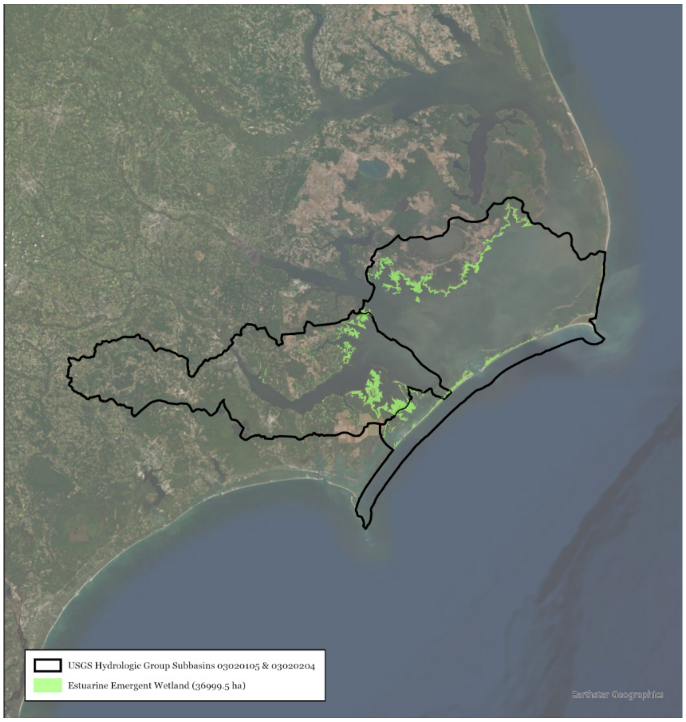


Figure VII-5. Estuarine Emergent Wetlands in the Pamlico Sound

An exponential decay function with a half-life of 7.5 years was used to estimate the annual metric tons of carbon that would be released from soil when one hectare of estuarine emergent wetland is converted to another use.[58] The results of this analysis are shown in the table below. In year 30, only 6 percent, or 18.5 metric tons of the initial store of 293 tons of CO_2e remain in each hectare of disturbed wetland soil.

SCC values are projected to increase over time corresponding to increases in the concentration of greenhouse gases. For purposes of this computation, it was assumed that the wetland was converted in 2020. The initial carbon stock (Year 2020) is 293 metric tons per hectare. Table VII-3 shows that, in the first year after conversion, 25.8 metric tons of carbon would be released, 23.5 metric tons would be released in the second year, etc. The SCCs for 2020 (See Table VII-4) were applied to carbon releases during Year 1 (assuming the wetland was converted in 2020). SCC values for 2021 would be applied to carbon released during Year 2, etc. This yields the annual social costs of carbon that would be released if the marsh were converted.

Table VII-3. Annual Carbon Released from the Soil of Converted Estuarine Emergent Wetlands (metric tons per hectare)

Year	Carbon in Soil	Cumulative Carbon Release	Annual Carbon Release
2020	293.0	0.0	0.0
2021	267.2	25.8	25.8
2022	243.7	49.3	23.5
2023	222.3	70.7	21.4
2024	202.7	90.3	19.6
2025	184.9	108.1	17.8
2026	168.6	124.4	16.3
2027	153.8	139.2	14.8
2028	140.2	152.8	13.5
2029	127.9	165.1	12.3
2030	116.6	176.4	11.3
2031	106.4	186.6	10.3
2032	97.0	196.0	9.4
2033	88.5	204.5	8.5
2034	80.7	212.3	7.8
2035	73.6	219.4	7.1
2036	67.1	225.9	6.5
2037	61.2	231.8	5.9
2038	55.8	237.2	5.4
2039	50.9	242.1	4.9
2040	46.4	246.6	4.5
2041	42.3	250.7	4.1
2042	38.6	254.4	3.7
2043	35.2	257.8	3.4
2044	32.1	260.9	3.1
2045	29.3	263.7	2.8
2046	26.7	266.3	2.6
2047	24.4	268.6	2.4
2048	22.2	270.8	2.1
2049	20.3	272.7	2.0
2050	18.5	274.5	1.8

Table VII-4. Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates

Year	2020 Dollars Per Ton of CO_2e					
	RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	$17	$6	$14	$51	$76	$152
2025	$17	$6	$17	$56	$83	$169
2030	$17	$6	$19	$62	$89	$187
2035	$17	$6	$22	$67	$96	$206
2040	$17	$6	$25	$73	$103	$225
2045	$17	$6	$28	$79	$110	$242
2050	$17	$6	$32	$85	$116	$260

This computation was performed for each of the four sets of published SCC values and each stream of annual costs was discounted to calculate its present value. Three of the four sets of published SCC values differ only with respect to the discount rates that are applied to future economic values; in Table VII-4, these values are shown in columns labeled "SCC, 5%," "SCC, 3%," and "SCC, 2.5%".[59] Present value computations for these estimates of the SCC use the discount rate upon which each estimate was based. These present values range from $3,374/hectare to $19,465/hectare of estuarine emergent marsh, with the total value for the 37,000 hectares in the estuary ranging from $124.8 million to $720.2 million.

The fourth set of published SCC values differs significantly from the other three. These values capture the potential for low-probability, high-impact outcomes from climate change and correspond to the 95th percentile of the frequency distribution of SCC estimates using a 3 percent discount rate. The present value associated with this set of SCC values is $38,679/hectare with a total value for the estuary's 37,000 hectares of $1.4 billion.

The broad range in these present value estimates is in part due to uncertainty about future economic conditions (reflected in differing discount rates) and the appropriate level of risk-taking with regard to climate policy (reflected in the set of SCC values associated with low-probability, high-impact outcomes).

Prices from the Regional Greenhouse Gas Initiative (RGGI) and Western Climate Initiative (WCI) carbon markets were also applied (with a 3% discount rate) to the future stream of carbon releases associated with the loss of one hectare of saltmarsh in Pamlico Sound. In almost all scenarios, the cost of purchasing the right to release this stream of carbon is much less than the social cost of the released carbon. Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon equals the SCC. Prices from these two carbon markets result in values that range from $1,331 per hectare to $3,744 per hectare with totals for the 37,000 hectares of salt marsh in the study area ranging from $49.2 million to $138.5 million. The results of these computations are shown in Table VII-5.

Table VII-5. Blue Carbon Values for Pamlico Sound 2020-2049 (Nominal/Net Present Value)

Annual Value	Carbon Released (t CO_2e/ ha)	Value of Released Carbon					
		RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	25.8	$156.51	$440.39	$360.98	$1,314.98	$1,959.58	$3,919.17
2021	23.5	$142.74	$401.64	$352.73	$1,222.78	$1,834.17	$3,644.83
2022	21.4	$130.18	$366.29	$321.69	$1,136.62	$1,694.21	$3,409.86
2023	19.6	$118.72	$334.06	$312.94	$1,056.16	$1,564.68	$3,168.47
2024	17.8	$108.27	$304.66	$285.40	$981.05	$1,462.66	$2,961.00
2025	16.3	$98.74	$277.85	$276.55	$910.99	$1,350.21	$2,749.23
2026	14.8	$90.06	$253.40	$252.21	$845.66	$1,246.23	$2,566.64
2027	13.5	$82.13	$231.10	$243.55	$798.30	$1,163.62	$2,381.37
2028	12.3	$74.90	$210.76	$222.12	$740.39	$1,073.56	$2,221.17
2029	11.3	$68.31	$192.22	$213.82	$686.49	$990.34	$2,059.47
2030	10.3	$62.30	$175.30	$195.01	$636.34	$913.46	$1,919.29
2031	9.4	$56.82	$159.88	$187.21	$589.70	$851.79	$1,787.83
2032	8.5	$51.82	$145.81	$179.27	$546.35	$785.37	$1,656.11
2033	7.8	$47.26	$132.98	$163.49	$506.05	$731.83	$1,541.52
2034	7.1	$43.10	$121.27	$156.21	$468.62	$674.53	$1,434.26
2035	6.5	$39.31	$110.60	$142.46	$433.86	$621.65	$1,333.95
2036	5.9	$35.85	$100.87	$135.83	$407.49	$578.75	$1,240.19
2037	5.4	$32.69	$91.99	$123.88	$377.02	$533.21	$1,147.21
2038	4.9	$29.82	$83.90	$117.89	$348.75	$491.20	$1,065.90
2039	4.5	$27.19	$76.51	$111.99	$322.54	$456.93	$990.02
2040	4.1	$24.80	$69.78	$102.14	$298.24	$420.81	$919.24
2041	3.7	$22.62	$63.64	$96.88	$275.72	$387.50	$849.53
2042	3.4	$20.63	$58.04	$88.35	$254.86	$360.20	$788.36
2043	3.1	$18.81	$52.93	$83.67	$238.63	$331.60	$728.28
2044	2.8	$17.16	$48.27	$79.14	$220.46	$305.25	$675.50
2045	2.6	$15.65	$44.03	$72.17	$203.63	$283.54	$623.79
2046	2.4	$14.27	$40.15	$68.17	$188.06	$260.94	$578.30
2047	2.1	$13.01	$36.62	$64.32	$173.66	$240.12	$533.84
2048	2.0	$11.87	$33.40	$58.66	$160.33	$222.90	$494.68
2049	1.8	$10.82	$30.46	$55.28	$149.79	$205.07	$456.50

Table VII-5. Blue Carbon Values for Pamlico Sound 2020-2049 (Nominal/Net Present Value) (cont'd)

Discounted Value	0.03	0.03	0.05	0.03	0.025	0.03
2020	$156.51	$440.39	$360.98	$1,314.98	$1,959.58	$3,919.17
2021	$138.58	$389.94	$335.93	$1,187.17	$1,789.43	$3,538.67
2022	$122.70	$345.27	$291.78	$1,071.37	$1,612.57	$3,214.12
2023	$108.65	$305.71	$270.33	$966.53	$1,452.96	$2,899.60
2024	$96.20	$270.69	$234.80	$871.65	$1,325.10	$2,630.81
2025	$85.18	$239.68	$216.68	$785.83	$1,193.39	$2,371.51
2026	$75.42	$212.22	$188.21	$708.22	$1,074.62	$2,149.52
2027	$66.78	$187.91	$173.09	$649.09	$978.92	$1,936.27
2028	$59.13	$166.38	$150.34	$584.47	$881.12	$1,753.41
2029	$52.35	$147.32	$137.83	$526.14	$793.00	$1,578.41
2030	$46.36	$130.44	$119.72	$473.50	$713.59	$1,428.13
2031	$41.05	$115.50	$109.46	$426.01	$649.19	$1,291.57
2032	$36.34	$102.27	$99.82	$383.20	$583.97	$1,161.56
2033	$32.18	$90.55	$86.70	$344.60	$530.89	$1,049.70
2034	$28.49	$80.18	$78.90	$309.81	$477.38	$948.22
2035	$25.23	$70.99	$68.53	$278.48	$429.23	$856.21
2036	$22.34	$62.86	$62.23	$253.93	$389.86	$772.84
2037	$19.78	$55.66	$54.05	$228.10	$350.42	$694.08
2038	$17.51	$49.28	$48.98	$204.85	$314.94	$626.10
2039	$15.51	$43.63	$44.32	$183.94	$285.82	$564.60
2040	$13.73	$38.64	$38.49	$165.13	$256.81	$508.96
2041	$12.16	$34.21	$34.77	$148.21	$230.71	$456.66
2042	$10.76	$30.29	$30.20	$133.01	$209.23	$411.44
2043	$9.53	$26.82	$27.24	$120.91	$187.92	$369.01
2044	$8.44	$23.75	$24.54	$108.45	$168.76	$332.30
2045	$7.47	$21.03	$21.31	$97.26	$152.94	$297.92
2046	$6.62	$18.62	$19.17	$87.20	$137.32	$268.15
2047	$5.86	$16.49	$17.23	$78.18	$123.28	$240.33
2048	$5.19	$14.60	$14.96	$70.08	$111.65	$216.21
2049	$4.59	$12.92	$13.43	$63.56	$100.21	$193.71
Net Present Value, 30 years	**$1,330.64**	**$3,744.20**	**$3,374.01**	**$12,823.88**	**$19,464.81**	**$38,679.22**

ESTUARY SUMMARY

Restoration Efforts

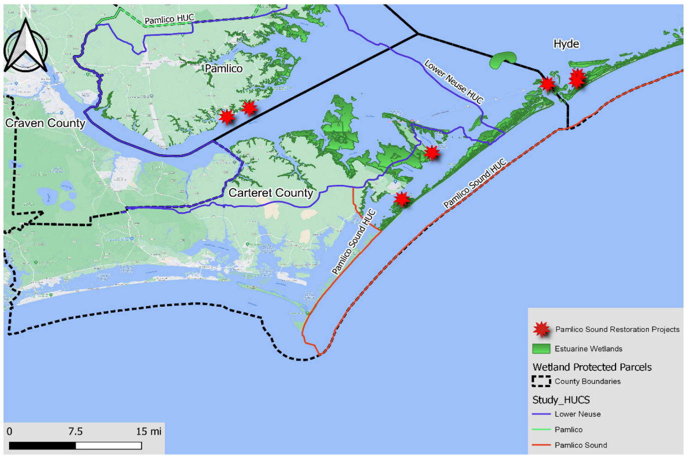


Figure VII-6 Wetlands Restoration Projects in Pamlico Soun

Wetlands restoration projects from the NOAA Restoration Atlas located in the Pamlico and Lower Neuse Hydrographic Units are shown in Figure VII-6. Most of these projects are located in Carteret County in the southwestern part of the region, outside of the study area. These are in the area where natural infrastructure benefits are highest. There were 11 projects listed in the NOAA Restoration Atlas restoring 8.3 hectares (20.6 acres). These are small projects averaging 0.7 hectares (1.9 acres) and overlap in location on Figure VII-6. Restoration projects emphasize erosion control and oyster reef construction. It should be noted that restoration in the area has been concentrated to a large extent in the White Oak Hydrographic Unit to the southwest of the study area where more than 30 projects have been undertaken.

In coordination with NOAA's Community Based Restoration Program, the North Carolina Coastal Federation also initiated construction on living shorelines in 2001. Recently with support from NOAA's coastal resilience grant program, the North Carolina Coastal Federation created a new 400-foot living shoreline in North Pamlico Sound to offset rapid salt marsh loss at 1,300 square feet per year. A 2015 NOAA study, Blue Carbon Potential of Living Shorelines, demonstrated that living shorelines provide both erosion control and sequester carbon bolstering coastal resilience.[60]

Table VII-6. NOAA Restoration Center Projects in Pamlico/Lower Neuse River

	Number of Projects
Dike/Berm	2
Bulkhead Removal	2
Erosion	7
Planting	19
Hydrological Connection	3
Oyster Restoration	16
Habitat	2

Natural Infrastructure and Coastal Blue Carbon Benefits

The estimated natural infrastructure benefits for Pamlico Sound range from $48.8 million to $109.9 million over a 30-year period for a flood that historically would occur once in 100 years. This is the present value of potential flood damages over a 30-year period.[61] Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $97.7 million and $219.8 million. These values are for damages to property exposed to flooding and do not include the damages to business sales or employment, tourism, and recreation, nor the value of possible losses from effects on human health. *These damage estimates should thus be considered conservative, that is they are likely to be low.*

The value of coastal blue carbon benefits range from $3,374/hectare to $19,465/hectare using various discount rates. The total value for the 37,000 hectares in the estuary under the three SCC scenarios ranges from $124.8 million to $720.2 million. The low-probability, high-impact climate outcome scenario resulted in a coastal blue carbon value of $1.4 billion.

Table VII-7. Natural Infrastructure and Coastal Blue Carbon Benefits Summary

Pamlico Sound	Total hectares in analysis	Estimated benefits per hectare of wetlands ($Thousands)		Total Estimated Benefits ($Millions)	
		Low estimate	High estimate	Low estimate	High Estimate
Natural Infrastructure	62,153	$0.8	$3.5	$48.8	$219.8
Coastal Blue Carbon[62]	37,000	$3.4	$19.5	$124.8	$720.2
Total				**$173.6**	**$940.0**

The broad range in these benefit estimates is due to several factors:

- variation in the "wetlands effect" arising from differences in the precise location, and quantity of wetlands between the valued assets and the water,
- uncertainty about future economic conditions (reflected in differing discount rates in the coastal blue carbon analysis), and
- assumptions about the increasing severity of storms due to climate change.

Pamlico Sound is a largely undeveloped estuary, with a small acreage of low-intensity developed land parcels and even less medium-intensity developed acres (See Figure VII-4). Table VII-7 summarizes the range of benefits from natural infrastructure and coastal blue carbon determined by this analysis. The table also includes the combination of the two ecosystem service values that were analyzed in this report. The analysis includes all areas of wetlands within the study area that provide one service or the other, as well as areas that provide both services. Because the two benefits provide complementary services, presenting a total value is appropriate. Combined, the natural infrastructure and coastal blue carbon benefits range from $173.6 to $940.0 million. The value of economic assets is relatively low compared to other estuaries assessed in this series of case studies, and the natural infrastructure flood resilience benefits are, correspondingly, several times lower than the blue carbon benefits. However, these flood resilience benefits are still substantial at about $200 million, largely because of the extent of the wetlands, and should be recognized and maintained. Pamlico Sound also contains large swaths of coastal blue carbon-rich estuary, and in terms of increasing value in the estuary over time, the benefits per hectare is larger for blue carbon. Conserving or restoring wetlands to continue to increase blue carbon benefits will provide the greatest addition to the existing value.

These estimates must be considered very preliminary and are intended to be helpful in shaping overall strategies for the future management of the wetlands resources of Pamlico Sound, strategies that account for both local goals of a healthy estuary and global goals of mitigation of climate change. They are part of a broader attempt to begin to characterize general estuary characteristics that offer different sources of economic value to local communities, such as protection from storms and flooding, and help meet broader societal goals, such as mitigation for climate change. As part of an examination of estuaries across the nation, they are not intended to guide project-level decisions, or replace more localized "deep dives" that have been conducted in these estuaries. There are still many unknowns that require much more elaborate estimation procedures for both natural infrastructure and coastal blue carbon. Whether the actual benefits in the future will tend towards the lower or higher end of these estimates will require continued research and ongoing assessment. But it is certain that the realization of these benefits will depend first on conserving the wetlands that exist and then on the restoration of wetlands that could increase these benefits.

Figure VIII1. Red mangroves (Rhizophora mangle) reflected in the water.

VIII. Case Study 3: Tampa Bay, Florida

TAMPA BAY ESTUARY

Tampa Bay, located on Florida's Gulf Coast, is an estuary system vital to both the marine life that inhabits the estuary's waters and shores and the millions of people that reside in the region. The estuary's various habitats support a broad diversity of resident and migratory wildlife. This rich biodiversity of the Bay has heavily shaped the region's community and economy throughout its history. Residents of the Tampa metropolitan area rely on jobs dependent on the health of the Bay, including fishing, boating, ecological research, and shipping to and from the region's ports.[1]

The Tampa Bay Estuary covers just over 103,000 hectares (256,000 acres) from the Hillsborough River to Anna Maria Island on the western-central peninsula of Florida and drains 2,200 square miles across the six counties it spans.[2] The estuary is extremely shallow throughout its range with an average depth of 11 feet and a maximum depth of 43 feet in the main shipping channel.[3]

The area supports two of the largest cities in Florida, St. Petersburg and Tampa, and hosts a population of approximately 2.8 million people.[4] The population in the Tampa Bay watershed has more than doubled since the 1950s when environmental issues first came to light in the estuary, with urban development accounting for 39% of the land use in the watershed followed by agriculture (20%), wetlands (17%), forested/vegetated Land (12%), mining (8%), and water (3%).[5] Rapid population growth combined with inadequate sewage treatment systems yielded major declines in the estuary's water quality in the 1960s and 1970s.[6] However, a collaborative Bay-wide management effort over the past forty years has turned Tampa Bay estuary into a great restoration success story. In 2014, these collaborative efforts achieved the goal of restoring Tampa Bay's seagrass populations to 1950's levels (15,380 acres).[7] At the same time, innovative and effective nutrient reduction efforts aimed at reducing eutrophication in the Bay have resulted in meeting water quality goals in each segment of the bay since 2005.[8] Since the early 2000's oyster restoration projects have helped to improve water quality and to provide protective services to the urban shorelines.[9]

There are four major rivers that flow into Tampa Bay: the Hillsborough, Alafia, Manatee, and Little Manatee. In total these rivers push approximately 525 billion gallons of water into the Bay every year.[10] This influx of fresh water creates the unique estuarine environment allowing mangrove forests, salt marshes, and seagrass beds to flourish. Mangrove forests, comprised of red, black, and white mangroves, are the dominant wetland vegetation in the Tampa Bay watershed.[11] Mangroves trap and cycle pollutants infiltrating the water and act as shelter and nursery habitat for fish, crustaceans, and shellfish and allow a broad diversity of marine species to flourish.[12] Additionally, they stabilize the shoreline and help protect it from storm runoff and flooding. Salt marshes comprised of rushes, sedges, and grasses provide refuge from predation for wildlife and reduce nutrient influx to the estuary.[13] In Tampa Bay *Spartina patens* and *Spartina alterniflora* are the dominant salt marsh species.[14] Three types of seagrasses (shoal, turtle, and manatee) also provide shelter and nursery habitat for marine life in addition to filtering and stabilizing sediment improving water clarity in the estuary.[15]

The Tampa Bay estuary supports a wide variety of fauna within its mangrove forests, seagrass beds, oyster reefs, and salt marshes. One quarter of the Gulf Coast's population of manatees winter in the area, over 25 species of shore birds come to nest, and important commercial and recreational fish species find habitat there year-round.[16] Over 200 species of fish reside in Tampa Bay and the estuary is abundant in small bait fish. Redfish, mullet, sheepshead, snook, and spotted seatrout are prime targets for recreational and commercial fishing in the region.[17] More than 25 species of waterbirds nest in the estuary including white ibis, great blue heron, and the reddish egret, a species of special concern in Florida and the rarest egret in the U.S.[18]

Rapid population growth and correlated declining water quality triggered Tampa Bay's environmental decline from the 1950s to 1960s.[19] Concentrated population growth and construction of municipal sewage discharges, stormwater runoff, and industrial discharge from manufacturing plants near shorelines stimulated excessive nitrogen influx into the estuary causing algae blooms and decimation of seagrass beds.[20] Seagrass bed cover was reduced by approximately 50% during the 1970s and 1980s, with particularly high reductions in areas adjacent to development.[21] Researchers estimated that the nitrogen load between the period from 1950-1980 was 500% higher than levels prior to 1950.[22] Development also destroyed critical habitat including salt marshes and mangroves resulting in the loss of approximately 44% of historic emergent coastal wetlands and 81% of historic seagrass cover by 1981.[23] Approximately half of the marsh and mangrove habitat was lost and half of the natural shoreline was developed, leading to 40% of underwater seagrasses being decimated.[24]

Today, stormwater runoff from urban and residential areas is the greatest source of nitrogen pollution in Tampa Bay accounting for more than half the nitrogen influx into the estuary.[25] Although wastewater discharge was historically a major issue, remediation in the 1970s reduced effluent discharge by more than 90%.[26] Urban development is currently a major threat to the estuary. Future development and a projected doubling of the current population by 2050 have the potential to jeopardize the environmental quality and economic stability of the region.[27] Fortunately Tampa Bay has a history of restoration success and community engagement that positions the region to manage this growth and expansion.

Environmental Policies

In 1990 Congress designated Tampa Bay an "estuary of national significance" under the National Estuary Program administered by the Environmental Protection Agency under the Clean Water Act.[28] In response the Tampa Bay Estuary Program was formed in 1991 to "build partnerships to restore and protect Tampa Bay through implementation of a scientifically sound, community-based management plan."[29] The Comprehensive Conservation and Management Plan (CCMP) for Tampa Bay identifies 39 management actions within three key priority areas needed to sustain restoration progress: Clean Waters and Sediments; Thriving Habitats and Abundant Wildlife; and an Informed, Engaged and Responsible Community.[30,31]

Seagrass acreage has been identified as a critical indicator of estuarine health in Tampa Bay and in 1996 the Tampa Bay Estuary Program developed a multi-step strategy to restore seagrass acreage to 1950's levels preceding rapid population growth.[32, 33] As seagrass is dependent upon sunlight and water clarity, the strategy focused on reducing nitrogen loads and algae blooms to improve water quality to a level that allowed sufficient sunlight for seagrass proliferation.[34] The program was hugely successful and involved collaboration from public and private sectors and the implementation of over 450 projects focusing on wastewater upgrades, stormwater improvement, habitat restoration, and public education.[35] Water clarity has been restored to historic levels, seagrass restoration goals were exceeded increasing by more than 65% since the 1980s, and nutrient loading was cut in half as a result of the program. [36,37]

Coastal habitats, including mangroves, seagrasses, and tidal marshes, have been identified as extremely productive ecosystems that act as carbon sinks in the global carbon cycle.[38] Management of this "coastal blue carbon" focuses on preserving marshes, mangroves, and seagrasses to protect sequestered atmospheric carbon dioxide in the marine system.[39] The Tampa Bay Blue Carbon Assessment, published in 2016 by Restore America's Estuaries, projected past and future climate mitigation benefits of ongoing and potential new restoration efforts in the Tampa Bay Estuary. Their models predict that coastal habitat in Tampa Bay will remove between 73,415,000 and 74,317,000 tons of carbon dioxide from the atmosphere by 2100, which equates to the removal of 15.5 million fossil-fueled vehicles from roads.[40,41] The study estimates that restoration projects conducted in the estuary removed 217,000 tons of carbon dioxide between 2006 and 2015.[42] Although this is a fraction of the potential carbon sequestration within the habitats of Tampa Bay, these restoration activities set the stage for targeting and implementing expanded restoration projects in the future to mitigate declining wetland habitat and maximize carbon sequestration.

Socioeconomic/Cultural Significance

Tampa Bay has supported a robust coastal community since the 1800s, defined more recently by rapid population growth and development.[43] The region is economically dependent on several industries including shipping, commercial fishing, and scientific research. Ocean dependent industries in Tampa Bay's three counties (Hillsborough, Pinellas, and Manatee) contributed $5.3 billion dollars to the region's GDP in 2018.[44] However, tourism is perhaps the most important industry in Tampa Bay contributing $3.6 billion to the regional economy in 2018, and employing nearly 80,000 people.[45] The tourism industry draws international and domestic visitors to experience water-based activities such as, snorkeling and diving, recreational fishing, boating, kayaking, and wildlife observation. The industry draws approximately 5 million visitors every year to experience what the Tampa Bay region has to offer. These activities all rely on a healthy Bay.

The local economy is also heavily dependent on the shipping business hosting three major ports, Port Tampa Bay, Port St. Pete, and Port Manatee. These three ports support an estimated 130,000 jobs in the region and connect the Bay area to the rest of the Gulf Coast, areas of inland Florida, and the world. The two metropolitan areas—Tampa and St. Petersburg— also include several prominent research institutions including the University of South Florida and the University of Tampa. Additionally, the area hosts MacDill Air Force Base and the U.S. Coast Guard Air Station Clearwater.[46] This combination has driven medical and technological research throughout the region, and shaped another important job sector in the Tampa Bay Estuary.

VALUE OF NATURAL INFRASTRUCTURE IN TAMPA BAY ESTUARY

NOAA defines natural infrastructure as "healthy ecosystems, including forests, wetlands, floodplains, dune systems, and reefs, which provide multiple benefits to communities, including storm protection through wave attenuation or flood storage capacity and enhanced water services and security."[47] An estuary's capacity to protect shoreline property from climate hazards and flood risk is an important ecosystem service that is usually measured by assessing the benefits of coastal natural infrastructure resulting from the ability of wetlands to reduce possible damages from floods, including flooding in the river, bay, and ocean areas within an estuary.

The measurement of this service is, however, complex. The value depends on how often and how severe floods will be. It depends on the value of the economic assets vulnerable to floods of different sizes and types. And it depends on the extent of lost economic activity, as well as the issue of disproportionate effects on populations which may not have the capacity to recover from flood events.

The analysis in this section uses a method that focuses on damages to real property from flooding that might be reduced by the presence of estuarine wetlands adjacent to the property. It is a very simplified perspective that is designed to raise awareness of natural infrastructure benefits as a prelude to incorporating these values into planning for the future of estuaries using more complete information. More detail on the methodology is available in Section IV of the main report.

Tampa Bay is the eighteenth largest metropolitan area in the U.S. by population, and the second largest in Florida after Miami-Dade. There are nearly 38,083 parcels of land within the 100-year flood zone and adjacent to wetlands, together worth over $148 million at current assessed values. The natural infrastructure benefits in terms of flood reduction can range from $902 million to $1,353 million over a 30-year period for a flood that historically would occur once in 100 years. Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $1,804 million and $2,705 million (See Table VIII-1).

Table VIII-1. Summary of Findings: Tampa Bay Estuary Natural Infrastructure Benefits

					Wetlands Effect on Flood Damages			
					1% Annual Probability Storm Benefits (Millions)		2% Annual Probability Storm Benefits (Millions)	
	Parcels	Buildings Value (Millions)	Land Value (Millions)	Total Value (Millions)	Low Estuarine Wetlands Effect	High Estuarine Wetlands Effect	Low Estuarine Wetlands Effect	High Estuarine Wetlands Effect
Estuarine Wetlands	28,653	$65,986.28	$31,365.38	$97,351.66	$360.43	$810.98	$720.87	$1,621.96
Mangroves	9,430.00	$32,797.41	$18,027.78	$50,825.19	$541.54		$1,083.09	
Total	**38,083**	**$98,783.69**	**$49,393.17**	**$148,176.85**	**$901.97**	**$1,352.52**	**$1,803.96**	**$2,705.05**

These values are for damages to property exposed to flooding and do not include the damages to business sales or employment, nor the value of possible losses from effects on human health. These damage estimates should thus be considered conservative, that is, likely to be low.

Three counties surround Tampa Bay, and there is potential for natural infrastructure benefits in all of the counties (See Figure VIII-2). But there is a distinct feature in Tampa Bay. Unlike most other estuaries in the U.S., in which the predominant wetland is salt marsh of one type or another, about 20% of the wetlands in Tampa Bay are mangroves, which have a much higher flood protection effect than salt marsh and freshwater marshlands. Because of the differences in effects on flooding, separate estimates are made for estuarine and mangrove wetlands.

Both types of wetlands along with the FEMA-designated 100- year flood zone (the area which has a historical probability of being flooded of 1% each year) are shown in Figure VIII-2. In Figure VIII-3, the parcels located in the 100-year flood zone are added to the map. This spatial analysis results in the identification of 34,377 hectares (84,965 acres) of wetlands. Of this total, 27,049 hectares (66,854 acres) were in estuarine and marine wetlands, while 7,328 hectares (18,112 acres) were mangroves. Together, these wetland areas offer protection to 38,083 parcels which intersect with the selected wetlands across the three counties. Ninety-four percent of the parcels are adjacent to estuarine and marine wetlands, while 6% are adjacent to mangroves. The parcel data, including both location and valuation, was drawn from the assessor's databases in Pinellas, Hillsborough, and Manatee counties.

The natural infrastructure benefits of the wetlands in Tampa Bay are created because wetlands can reduce the damage from coastal flooding driven by tides, wind, and storm surge or river flooding. The benefits can be measured as the reduction in flood damages resulting from the presence of the wetlands and is a function of the location of vulnerable economic assets (buildings and land), the frequency and severity of floods, the likely extent of damages, and the possible reductions in those damages resulting from the presence of the wetlands. The exact extent of the damage that determines benefits cannot, of course, be known with precision in advance so estimates and assumptions must be used.

Flood damage reductions depend on the frequency and severity of flooding, defined by the 100-year flood plain, which defines a flood of such severity that it only has a 1% chance of occurring each year. For this analysis, an alternate scenario is used to examine the potential effects of climate change, one of which is an increase in the frequency of severe storm events. To reflect estimation of benefits related to a changing climate, we assumed the 100-year storm becomes the 50-year storm, which means the annual probability of a storm at least this severe doubles from 1% to 2%.

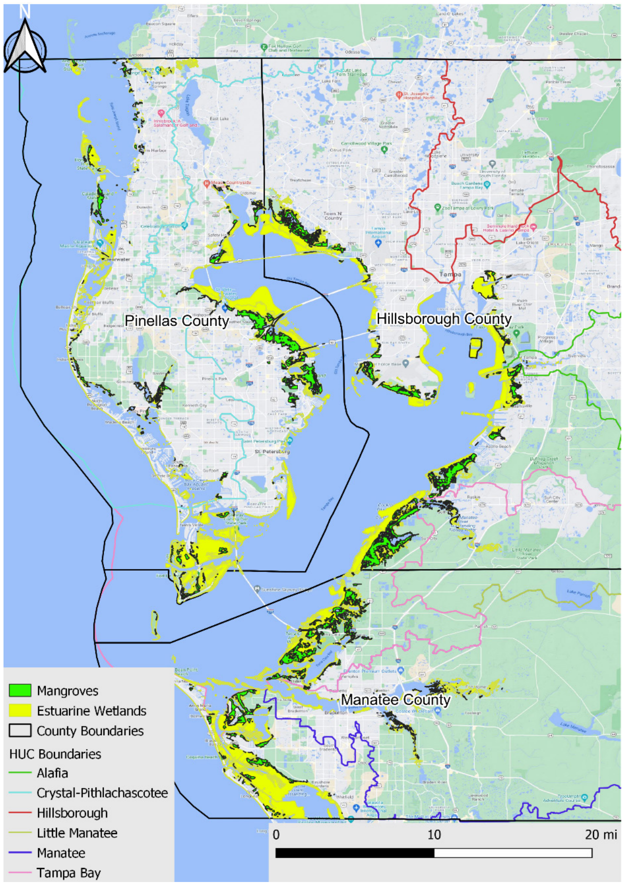


Figure VIII-2. Tampa Bay Estuarine Wetlands and Flood Zone

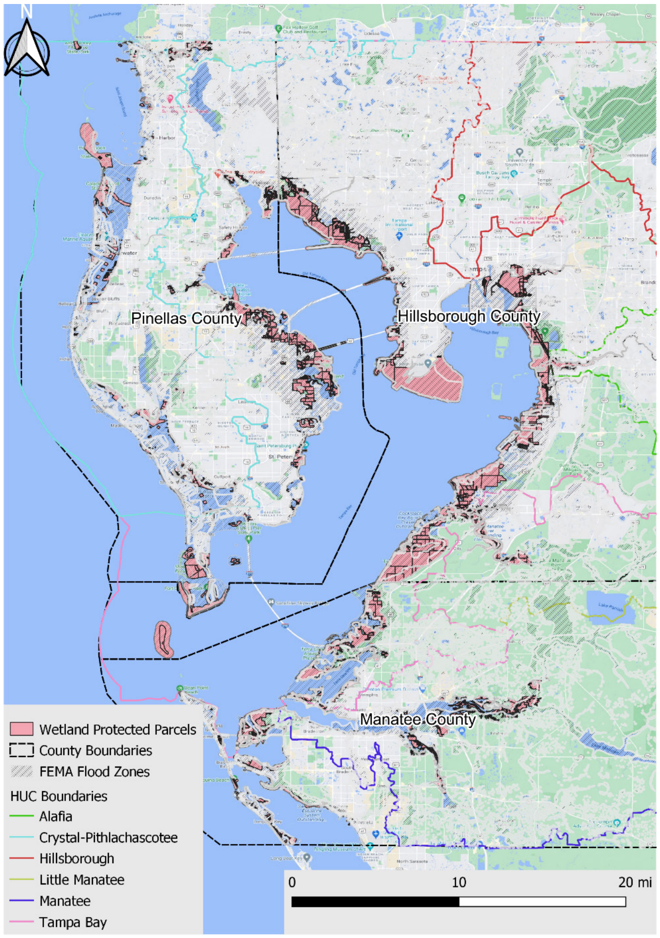


Figure VIII-3. Tampa Bay Wetlands and Parcels

To calculate the protective benefits of wetlands, we first estimated the total likely damages to property from a 100-year (1% annual) flood. These damages were estimated by applying flood damage factors for land and buildings to the assessed values of the property; buildings were assumed to be subject to twice the damages of land. These estimated damages were multiplied by the probability of a flood occurring over a 30-year period. For the 1% annual probability, the *cumulative* probability of a flood over 30 years is 26%. For the 2% annual probability the cumulative probability is 45%. The result is the total expected flood damage over 30 years. Since any flood damages will occur in the future, the value of the expected damages is discounted over the 30-year. These expected damages are the basis for calculating the reductions in flood damages that may be attributable to wetlands as describe above. The extent to which wetlands can reduce flood damages is highly variable depending greatly on the type and extent of wetlands at any given location. For purposes of this analysis the "wetlands effect" is the reduction in the dollar value of likely damages from a 100-year flood that may be attributable to the presence of wetlands—expressed as a percentage of damages. For the estuarine and marine wetlands, a range of 10% to 20% reduction is used based on studies of wetlands damage reductions from an actual storm on the Atlantic Coast.[48] For those areas protected by mangroves, an effect of a 25% reduction in damages is used based on a study similar to that for estuarine wetlands but conducted on mangroves in Collier County, Florida.[49] It should be noted that are a several locations in the three counties where mangroves and estuarine-marine wetlands are located together; in these cases the higher mangrove wetlands effect is used.

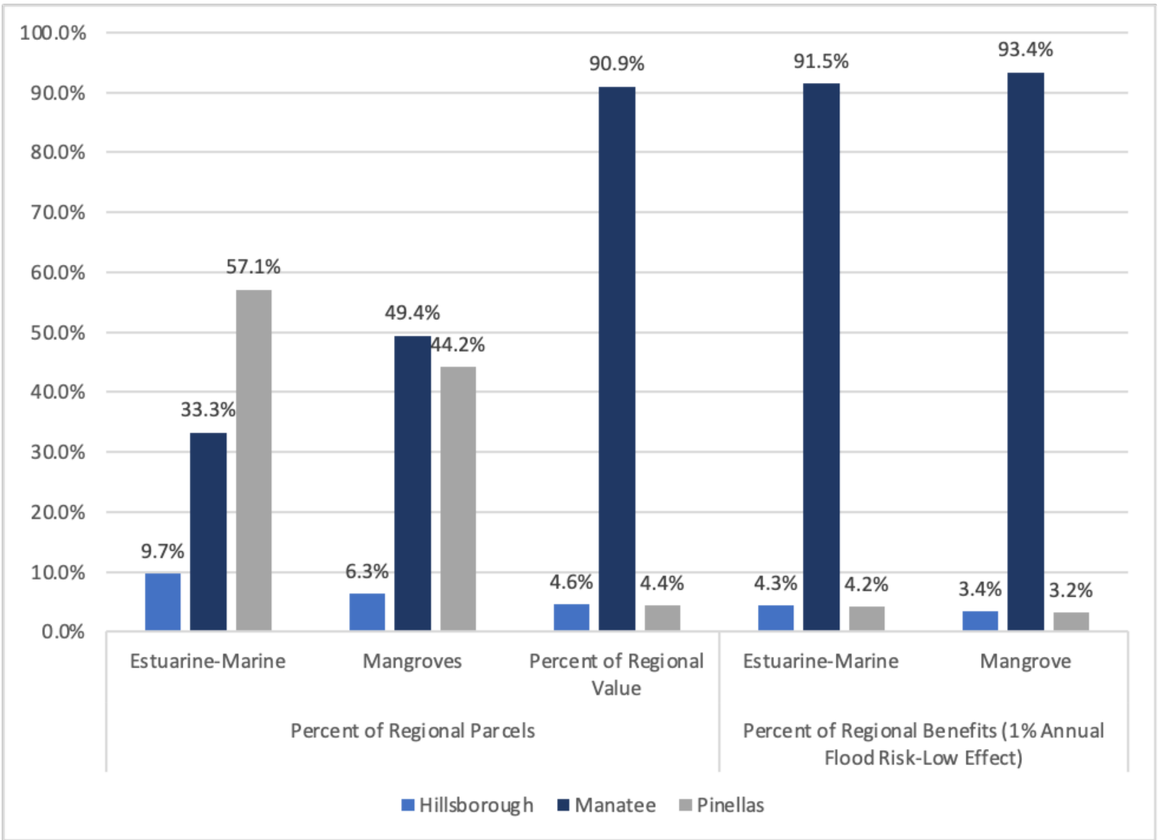
Table VIII-2 provides the results of the analysis for the area as a whole and for the counties affected. The table shows the market values of land and buildings plus the total market value by parcel as estimated by the county assessor. The largest number of parcels affected is in the northernmost county of Pinellas, followed by Hillsborough and the Manatee. But Manatee County has the largest value at risk. Table VIII-2 also shows the change in the level of flood benefits if severe flooding becomes more frequent, as explained above.

As a largely urban region, the total real estate values vulnerable to flooding are substantial. The estimated value of the 157,000 parcels vulnerable to flooding and adjacent to wetlands is in excess of $232 billion. Natural infrastructure benefits as defined above range from $1.2 billion to nearly $4.2 billion depending on the extent of the wetlands effect and on the assumption about storm severity. As shown in Figure VIII-4, Pinellas County, on the northern shore of Tampa Bay has the largest proportion of the parcels potentially benefitting from natural infrastructure, has the highest proportion of the estuarine-marine wetlands (57%) and second highest proportion of mangroves (44%) within the shoreline areas of Tampa Bay. But Manatee County on the southern shore has the highest share of real estate value, and so the highest natural infrastructure benefits. The larger percentage of mangroves in Manatee County makes that county's share of natural infrastructure benefits associated with mangroves the highest.

Table VIII-2. Tampa Bay Natural Infrastructure Benefits by County

County	Wetland Type	Parcels	Buildings Value (Millions)	Land Value (Millions)	Total Value (Millions)	1% Annual Probability Storm Benefits (Millions)		2% Annual Probability Storm Benefits (Millions)	
						Estuarine Wetland Benefits Low (10%)	*Estuarine Wetland Benefits High (20%)*	*Estuarine Wetland Benefits Low (10%)*	*Estuarine Wetland Benefits High (20%)*
Hillsborough	**Estuarine Wetlands**	1,136	$1,157.14	$984.20	$2,141.34	$8.30	$18.68	$16.60	$37.35
	Mangroves	598	$862.90	$684.80	$1,547.70	$18.40		$36.90	
	Total	1,734	$2,020.04	$1,669.00	$3,689.04	$26.70	$37.08	$53.50	$74.25
Manatee	**Estuarine Wetlands**	11,748	$62,265.58	$26,212.16	$88,477.74	$329.22	$740.75	$658.45	$1,481.51
	Mangroves	4,661	$31,008.30	$16,991.20	$47,999.50	$505.60		$1,011.20	
	Total	16,409	$93,273.88	$43,203.36	$136,477.24	$834.82	$1,246.35	$1,064.70	$2,492.71
Pinellas	**Estuarine Wetlands**	15,769	$2,563.56	$4,339.80	$6,903.36	$22.91	$51.55	$45.82	$103.10
	Mangroves	4,171	$926.20	$351.80	$1,278.00	$17.50		$35.00	
	Total	19,940	$3,489.76	$4,691.60	$8,181.36	$40.41	$69.05	$80.82	$138.10
Total	**Estuarine Wetlands**	28,653	$65,986.28	$31,536.16	$97,522.44	$360.43	$810.98	$720.87	$1,621.96
	Mangroves	9,430	$32,797.40	$18,027.80	$50,825.20	$541.50		$1,083.10	
	Total	38,083	$98,783.68	$49,563.96	$148,347.64	$901.93	$2,090.10	$1,803.97	$2,705.06

Figure VIII-4. County Shares of Parcels, Assessed Values, Natural Infrastructure Benefits



VALUE OF COASTAL BLUE CARBON IN THE TAMPA BAY ESTUARY

Over the past decades, as the relationship between greenhouse gases and climate change became clear, the scope of analyses for estuary conservation opportunities expanded to consider the role of coastal wetlands in the global carbon cycle. Coastal wetlands sequester vast amounts of the greenhouse gas carbon dioxide, and store that carbon in their soils. The carbon sequestered and stored in coastal estuaries is called coastal blue carbon.[50] Conserving and restoring estuaries rich in coastal blue carbon mitigates the impacts of climate change[51,52] and provides additional benefits that support local communities and can bolster local economies. These benefits include providing nursery habitat for fish,[53] reducing the impact of storm surge,[54,55,56] and improving water quality.[57,58,59] Researchers estimating global coastal blue carbon emissions have observed the rapid disappearance of coastal wetlands due to human activity, despite federal and regional wetland protection and planning.[60]

In this case study, coastal blue carbon values are estimated by multiplying the stock of carbon in the "emergent estuarine" land cover class of each estuary by estimates of the social cost of carbon (SCC) published by the Interagency Working Group on Social Cost of Greenhouse Gases in February 2021.[61]

SCC is "a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO_2) emissions in a given year".[62] SCC can also represent the value of damages avoided for emission reductions (i.e., the benefit of a CO_2 reduction). Whether used to measure costs or benefits, SCC values include such wide-ranging effects as global changes in economic output, human health, property damages from increased flood risk, and the value of ecosystem services.

The economic effects of releasing carbon into the atmosphere continue long into the future and increase as the total concentration of atmospheric carbon increases. Annual SCC values for this study's twenty-year period of analysis were discounted to show their value in today's dollars (present value). Values were calculated for each of four SCC scenarios using different discount rates. The "high" and "low" coastal blue carbon values presented in this summary correspond to the use of a 2.5 percent and 5.0 percent discount rate, respectively.

Land cover in Tampa Bay is dominated by urban land cover (See Figure VIII-5, black and gray shading). Relatively little estuarine emergent wetland is found in the estuary (less than 2,000 hectares); instead, mangrove is the dominant vegetation in Tampa Bay's wetlands. Mangrove dominates the shoreline of Tampa Bay, with large expanses on the southeast shore of the bay from Terra Ceia to Apollo Beach and in the interior of the bay between the Weedon Island Preserve and the St. Petersburg-Clearwater International Airport.

Carbon Profile

In 2016, the Tampa Bay study area contained 6,652 hectares (more than 16,000 acres) of mangrove (see Figure VIII-6). The Coastal Carbon Research Coordination Network (RCN) database contained data from 8 cores sampling the soil beneath mangrove cover, with values ranging from 80 to 130 metric tons of carbon per hectare in the soil and averaging 100 metric tons per hectare. All core samples were limited to a depth of 30 centimeters; this is significantly shallower than carbon samples in other sites, which ranged in average depth from 51 to 86 centimeters. However, the average soil carbon value of 100 metric tons per hectare is consistent with the values for mangrove found in the Tampa Bay Blue Carbon Assessment[63] (144.9 +/- 49.5 metric tons per hectare) funded by Restore America's Estuaries. The depth of soil beneath mangroves in Tampa Bay rarely exceeds 30 centimeters and carbon storage in Tampa Bay's mangroves are much lower than global averages "due to Tampa Bay's location near the northern limit of mangrove habitat, sandy soil, young age of the restored wetlands, presence of mosquito ditches, and recent habitat conversion from salt marshes to mangroves."[64]

It is important to note that the focus of this study on soil carbon significantly understates the amount of carbon that would be emitted with the conversion of mangrove forest. In Tampa Bay, about 70 percent of the carbon stored by mangrove is located below ground.[65] This is consistent with global studies of mangrove showing that 50 to 90 percent of the total carbon stock is in the soil carbon pool.[66]

The figures used in this analysis suggest that more than 665,000 tons of carbon dioxide equivalent (CO_2e[67]) are stored in the soil beneath the study area's 6,652 hectares of mangrove. This is equivalent to the annual emissions of approximately 145,000 cars.[68]

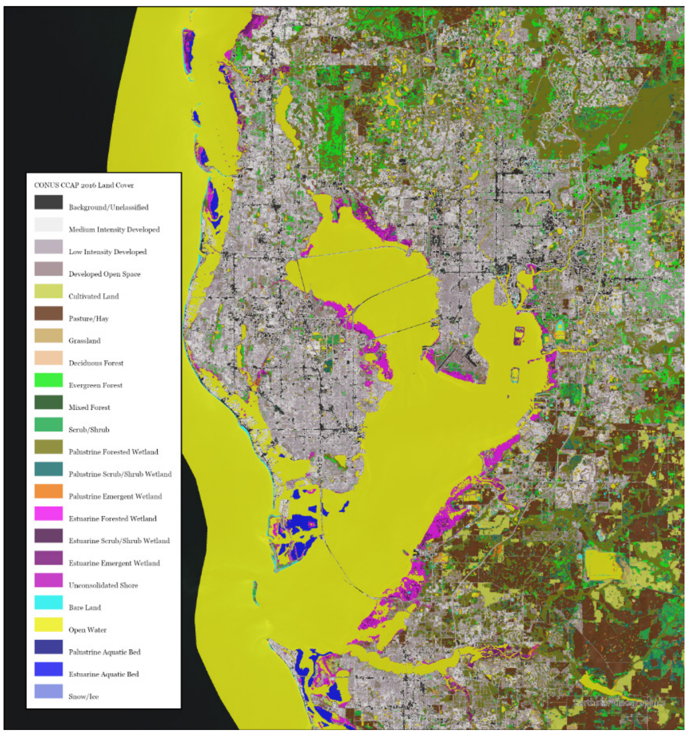


Figure VIII-5. Map of vegetation types in the Tampa Bay Estuary

Figure VIII-6. Mangrove Wetlands in the Tampa Bay Estuary

The Value of Coastal Blue Carbon Stock Stored in Soil

Although carbon is also stored in the biomass of the plants and continues to be sequestered over time, data limitations allow only an analysis of the value of carbon that is stored in soil. The value of the coastal blue carbon stock stored in the soil of Tampa Bay's mangrove wetland areas is estimated as the cost to society that would be incurred if the wetlands upper layers were disturbed or developed, and the carbon was released. These computations are described below. A more comprehensive assessment of the effects of wetland loss (and, thus, the value of conservation) would include the cessation of carbon sequestration and the emission of carbon stored in the biomass. However, sequestration rates and the amount of carbon stored in biomass vary significantly among sites, even within the same class of vegetation.[69] Reliable, site-specific estimates of carbon sequestration rates and the amount of carbon stored in biomass are not available for the Tampa Bay estuary or the areas that are the subject of the other five case studies. For this reason, no attempt was made to estimate these values.

The value of restoring mangrove wetland arises from the restoration of carbon sequestration, which increases over time as the marsh matures. The data limitations described prevent the estimation of these values.

An exponential decay function with a half-life of 7.5 years was used to estimate the annual metric tons of carbon that would be released from soil when one hectare of estuarine emergent wetland is converted to another use.[70] The results of this analysis are shown in Table VIII-3. In year 30, only 6 percent, or 6.3 metric tons, of the initial store of 100 tons of CO_2e remain in each hectare of disturbed wetland soil.

SCC values are projected to increase over time corresponding to increases in the concentration of atmospheric greenhouse gases. Annual SCC ($/metric ton) values in Table VIII-4 were applied to annual carbon release values (metric tons) to calculate the annual social cost of the carbon that is released. For purposes of this computation, it was assumed that the wetland was converted in 2020. The initial carbon stock (Year 2020) is 100 metric tons per hectare. Table VIII-3 shows that, in the first year after conversion, 8.8 metric tons of carbon would be released, 8.1 metric tons would be released in the second year, etc. The SCCs for 2020 (See Table VIII-4) were applied to carbon releases during Year 1 (assuming the wetland was converted in 2020), SCC values for 2021 would be applied to carbon released during Year 2, etc. This yields the annual social cost of the carbon that would be released if the marsh were converted.

Table VIII-3. Annual Carbon Released from the Soil of Converted Mangrove Habitat (metric tons per hectare)

Year	Carbon in Soil	Cumulative Carbon Release	Annual Carbon Release
2020	100.0	0.0	
2021	91.2	8.8	8.8
2022	83.2	16.8	8.0
2023	75.9	24.1	7.3
2024	69.2	30.8	6.7
2025	63.1	36.9	6.1
2026	57.5	42.5	5.6
2027	52.5	47.5	5.1
2028	47.9	52.1	4.6
2029	43.6	56.4	4.2
2030	39.8	60.2	3.8
2031	36.3	63.7	3.5
2032	33.1	66.9	3.2
2033	30.2	69.8	2.9
2034	27.5	72.5	2.7
2035	25.1	74.9	2.4
2036	22.9	77.1	2.2
2037	20.9	79.1	2.0
2038	19.1	80.9	1.8
2039	17.4	82.6	1.7
2040	15.8	84.2	1.5
2041	14.5	85.5	1.4
2042	13.2	86.8	1.3
2043	12.0	88.0	1.2
2044	11.0	89.0	1.1
2045	10.0	90.0	1.0
2046	9.1	90.9	0.9
2047	8.3	91.7	0.8
2048	7.6	92.4	0.7
2049	6.9	93.1	0.7
2050	6.3	93.7	0.6

Table VIII-4. Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates (selected years)

Year	2020 Dollars Per Ton of CO_2e					
	RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	$17	$6	$14.00	$51.00	$76.00	$152.00
2025	$17	$6	$15.00	$52.00	$78.00	$155.00
2030	$17	$6	$15.00	$53.00	$79.00	$159.00
2035	$17	$6	$16.00	$54.00	$80.00	$162.00
2040	$17	$6	$16.00	$55.00	$82.00	$166.00
2045	$17	$6	$17.00	$56.00	$83.00	$169.00
2050	$17	$6	$17.00	$57.00	$84.00	$173.00

This computation was performed for each of the four sets of published SCC values and each stream of annual costs was discounted to calculate its present value. Three of the four sets of published SCC values differ only with respect to the discount rates that are applied to future economic values; in Table VIII-4. Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates (selected years), these values are shown in columns labeled "SCC, 5%," "SCC, 3%," and "SCC, 2.5%".[71] Present value computations for these estimates of the SCC use the discount rate upon which each estimate was based. These present values range from $1,152/hectare to $6,643/hectare, with the total value for the 6,652 hectares in the estuary ranging from $7.7 million to $44.2 million.

The fourth set of published SCC values differs significantly from the other three. These values capture the potential for low-probability, high-impact outcomes from climate change and correspond to the 95th percentile of the frequency distribution of SCC estimates using a 3 percent discount rate. The present value associated with this set of SCC values is $13,201/hectare with a total value for the estuary's 6,652 hectares of $87.8 million.

The broad range in these present value estimates is in part due to uncertainty about future economic conditions (reflected in differing discount rates) and the appropriate level of risk-taking with regard to climate policy (reflected in the set of SCC values associated with low-probability, high-impact outcomes).

Prices from the Regional Greenhouse Gas Initiative (RGGI) and Western Climate Initiative (WCI) carbon markets were also applied (with a 3% discount rate) to the future stream of carbon releases associated with the loss of one hectare of mangrove in the Tampa Bay estuary. In almost all scenarios, the cost of purchasing the right to release this stream of carbon is much less than the social cost of the released carbon. Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon equals the SCC. Prices from these two carbon markets result in values that range from $454 per hectare to $1,278 per hectare with totals for the 6,652 hectares of mangroves in the study area ranging from $3.0 million to $8.5 million. The results of these computations are shown in Table VIII-5.

Table VIII-5. Coastal Blue Carbon Values for Tampa Bay Estuary 2020-2049 (Nominal/Net Present Value)

Annual Value	Carbon Released (t CO_2e/ha)	Value of Released Carbon					
		RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	8.8	$53.42	$150.30	$123.20	$448.80	$668.80	$1,337.60
2021	8.0	$48.72	$137.08	$120.38	$417.33	$626.00	$1,243.97
2022	7.3	$44.43	$125.01	$109.79	$387.93	$578.23	$1,163.78
2023	6.7	$40.52	$114.01	$106.80	$360.46	$534.02	$1,081.39
2024	6.1	$36.95	$103.98	$97.41	$334.83	$499.20	$1,010.58
2025	5.6	$33.70	$94.83	$94.39	$310.92	$460.82	$938.30
2026	5.1	$30.74	$86.48	$86.08	$288.62	$425.33	$875.99
2027	4.6	$28.03	$78.87	$83.12	$272.46	$397.14	$812.75
2028	4.2	$25.56	$71.93	$75.81	$252.69	$366.40	$758.08
2029	3.8	$23.31	$65.60	$72.98	$234.30	$338.00	$702.89
2030	3.5	$21.26	$59.83	$66.56	$217.18	$311.76	$655.05
2031	3.2	$19.39	$54.56	$63.89	$201.26	$290.71	$610.18
2032	2.9	$17.69	$49.76	$61.18	$186.47	$268.05	$565.23
2033	2.7	$16.13	$45.38	$55.80	$172.71	$249.77	$526.12
2034	2.4	$14.71	$41.39	$53.31	$159.94	$230.22	$489.51
2035	2.2	$13.42	$37.75	$48.62	$148.07	$212.17	$455.27
2036	2.0	$12.23	$34.43	$46.36	$139.08	$197.53	$423.27
2037	1.8	$11.16	$31.40	$42.28	$128.67	$181.98	$391.54
2038	1.7	$10.18	$28.63	$40.23	$119.03	$167.64	$363.79
2039	1.5	$9.28	$26.11	$38.22	$110.08	$155.95	$337.89
2040	1.4	$8.46	$23.82	$34.86	$101.79	$143.62	$313.73
2041	1.3	$7.72	$21.72	$33.06	$94.10	$132.25	$289.94
2042	1.2	$7.04	$19.81	$30.15	$86.98	$122.93	$269.06
2043	1.1	$6.42	$18.07	$28.56	$81.44	$113.17	$248.56
2044	1.0	$5.86	$16.48	$27.01	$75.24	$104.18	$230.55
2045	0.9	$5.34	$15.03	$24.63	$69.50	$96.77	$212.90
2046	0.8	$4.87	$13.70	$23.27	$64.19	$89.06	$197.37
2047	0.7	$4.44	$12.50	$21.95	$59.27	$81.95	$182.20
2048	0.7	$4.05	$11.40	$20.02	$54.72	$76.08	$168.83
2049	0.6	$3.69	$10.39	$18.87	$51.12	$69.99	$155.80

Table VIII-5. Coastal Blue Carbon Values for Tampa Bay Estuary 2020-2049 (Nominal/Net Present Value) (cont'd)

Discounted Value	0.03	0.03	0.05	0.03	0.025	0.03
2020	$53.42	$150.30	$123.20	$448.80	$668.80	$1,337.60
2021	$47.30	$133.08	$114.65	$405.18	$610.73	$1,207.74
2022	$41.88	$117.84	$99.58	$365.66	$550.37	$1,096.97
2023	$37.08	$104.34	$92.26	$329.87	$495.89	$989.62
2024	$32.83	$92.38	$80.14	$297.49	$452.25	$897.89
2025	$29.07	$81.80	$73.95	$268.20	$407.30	$809.39
2026	$25.74	$72.43	$64.23	$241.71	$366.76	$733.63
2027	$22.79	$64.13	$59.07	$221.53	$334.10	$660.84
2028	$20.18	$56.78	$51.31	$199.48	$300.73	$598.43
2029	$17.87	$50.28	$47.04	$179.57	$270.65	$538.71
2030	$15.82	$44.52	$40.86	$161.60	$243.55	$487.42
2031	$14.01	$39.42	$37.36	$145.40	$221.57	$440.81
2032	$12.40	$34.90	$34.07	$130.78	$199.31	$396.44
2033	$10.98	$30.90	$29.59	$117.61	$181.19	$358.26
2034	$9.72	$27.36	$26.93	$105.74	$162.93	$323.62
2035	$8.61	$24.23	$23.39	$95.04	$146.49	$292.22
2036	$7.62	$21.45	$21.24	$86.67	$133.06	$263.77
2037	$6.75	$19.00	$18.45	$77.85	$119.60	$236.89
2038	$5.98	$16.82	$16.72	$69.92	$107.49	$213.69
2039	$5.29	$14.89	$15.13	$62.78	$97.55	$192.69
2040	$4.69	$13.19	$13.14	$56.36	$87.65	$173.71
2041	$4.15	$11.68	$11.87	$50.59	$78.74	$155.86
2042	$3.67	$10.34	$10.31	$45.40	$71.41	$140.42
2043	$3.25	$9.15	$9.30	$41.27	$64.14	$125.94
2044	$2.88	$8.11	$8.37	$37.01	$57.60	$113.41
2045	$2.55	$7.18	$7.27	$33.19	$52.20	$101.68
2046	$2.26	$6.35	$6.54	$29.76	$46.87	$91.52
2047	$2.00	$5.63	$5.88	$26.68	$42.07	$82.02
2048	$1.77	$4.98	$5.11	$23.92	$38.10	$73.79
2049	$1.57	$4.41	$4.58	$21.69	$34.20	$66.11
Net Present Value, 30 years	**$454.14**	**$1,277.88**	**$1,151.54**	**$4,376.75**	**$6,643.28**	**$13,201.10**

ESTUARY SUMMARY

Restoration Efforts

Tampa Bay has been recognized internationally as a success story of restoration since it was pronounced "dead" in the late 1970s.[72]

Table VIII-6 shows the NOAA funded restoration projects in Tampa Bay. There are 144 projects shown covering 264 hectares (652 acres) in all parts of the Bay. The projects are generally very small, covering 1.8 hectares (4.5 acres). The largest number of projects (53 or 37%) were projects that featured replanting of vegetation to replace non-native species or lost vegetation. These projects accounted for 233 hectares, about 89% of all the restored area. The next most common were oyster reefs (26 projects covering 5 hectares or 12.5 acres). The wide distribution of restoration projects throughout the Bay and the focus on planting projects has most likely increased the natural infrastructure benefits in the bay. Given the long period during restoration has been underway most of these benefits are already incorporated in the estimates presented here; other projects may have effects in the future.

Table VIII-6. Restoration Projects in Tampa Bay

	Hectares	Projects
Artificial Reef	0.0	2
Berm/Dike Modification	1.2	2
Bird Habitat	7.9	8
Coral Reef	0.0	1
Debris Removal	16.2	6
Education	0.0	6
Not Specified	0.0	32
Oyster Reef	5.0	26
Planting	233.6	53
Recreation	0.0	1
Research	0.0	3
Species Enhancement	0.0	1
Stream Channel	0.0	1
(blank)	0.0	2
Grand Total	263.9	144

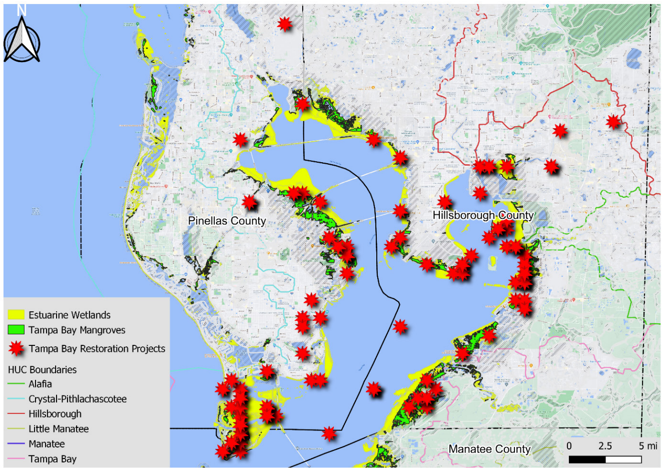


Figure VIII-7. NOAA Restoration Projects Tampa Bay

Natural Infrastructure and Coastal Blue Carbon Benefits

Tampa Bay is the eighteenth largest metropolitan area in the U.S. by population, and the second largest in Florida after Miami-Dade. There are nearly 38,083 parcels of land within the 100-year flood zone, worth over $182 million at current assessed values. The natural infrastructure benefits in terms of flood reduction can range from $902.0 million to $1,352.5 million over a 30-year period for a flood that historically would occur once in 100 years. Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $1,804.0 million and $2,705.1 million

Coastal blue carbon benefits range from $1,152/hectare to $6,643/hectare using various discount rates. The total value for the 6,652 hectares in the estuary under the three more likely SCC scenarios ranges from $7.7 million to $44.2 million. The low-probability, high-impact climate outcome scenario resulted in a total coastal blue carbon value of $87.8 million.

Table VIII-7. Natural Infrastructure and Coastal Blue Carbon Benefits Summary

Tampa Bay	Total hectares in analysis	Estimated benefits per hectare of wetlands ($Thousands)		Total Estimated Benefits ($Millions)	
		Low estimate	High estimate	Low estimate	High Estimate
Natural Infrastructure	34,377	$26.2	$78.7	$902.0	$2,705.1
Coastal Blue Carbon[73]	24,439	$1.2	$6.6	$7.7	$44.2
Total				**$909.7**	**$2,749.3**

The broad range in these benefit estimates is due to several factors:

- variation in the "wetlands affect" arising from differences in the precise location, and quantity of wetlands between the valued assets and the water,
- uncertainty about future economic conditions (reflected in differing discount rates in the coastal blue carbon analysis), and
- assumptions about the increasing severity of storms due to climate change.

Tampa Bay Estuary was unique in that it was the only estuary where mangrove habitats were examined. Globally, mangrove systems offer some of the best opportunities for shoreline protection and the storage of carbon, and generally that would indicate values leaning towards the high end of the value ranges for natural infrastructure and coastal blue carbon. However, it is notable that the level of coastal blue carbon found in the Tampa Bay soil samples was the lowest of the six U.S. estuaries that were studied (100 tons CO_2/ hectare). All core samples were limited to a depth of 30 centimeters, significantly shallower than carbon samples in other estuaries. The depth of soil beneath mangroves in Tampa Bay rarely exceeds 30 centimeters and carbon storage in Tampa Bay's mangroves are much lower than global averages "due to Tampa Bay's location near the northern limit of mangrove habitat, sandy soil, young age of the restored wetlands, presence of mosquito ditches, and recent habitat conversion from salt marshes to mangroves."[74]

Tampa Bay is an urban estuary, and has a dense concentration of economic assets that are protected by its mangroves and marshlands. As expected, the natural infrastructure benefits are larger by an order of magnitude than any of the other estuaries assessed in this study. Though currently relatively low, as the restored mangrove systems mature, their coastal blue carbon values can also be expected to increase. This study also does not account for the value of coastal blue carbon contained in other ecosystem types, such as salt marshes and sea grass beds. Future restoration efforts should consider how to maximize both the natural infrastructure and coastal blue carbon benefits in Tampa Bay.

Table VIII-7 summarizes the range of benefits from natural infrastructure and coastal blue carbon determined by this analysis. The table also includes the combination of the two ecosystem service values that were analyzed in this report. The analysis includes all areas of wetlands within the study area that provide one service or the other, as well as areas that provide both services. Because the two benefits provide complementary services, presenting a total value is appropriate. Combined, the natural infrastructure and coastal blue carbon benefits range from $0.9 to $2.7 billion. In terms of total value, natural infrastructure values in Tampa Bay far exceed the blue carbon values provided by mangroves. Those values exist now and should be recognized and maintained. However, in terms of increasing value in the estuary over time, the benefits per hectare is higher for natural infrastructure, and conserving or restoring wetlands to continue to increase natural infrastructure benefits will provide the greatest addition to the existing value.

These estimates must be considered very preliminary and are intended to be helpful in shaping overall strategies for the future management of the wetlands resources of the Tampa Bay, strategies that account for both local goals of a healthy estuary and global goals of mitigation of climate change. They are part of a broader attempt to begin to characterize general estuary characteristics that offer different sources of economic value to local communities, such as protection from storms and flooding, and help meet broader societal goals, such as mitigation for climate change. As part of an examination of estuaries across the nation, they are not intended to guide project-level decisions, or replace more localized "deep dives" that have been conducted in these estuaries such as the 2016 Tampa Bay Blue Carbon Assessment. There are still many unknowns that require much more elaborate estimation procedures for both natural infrastructure and coastal blue carbon. Whether the actual benefits in the future will tend towards the lower or higher end of these estimates will require continued research and ongoing assessment. But it is certain that the realization of these benefits will depend first on conserving the wetlands that exist and then on the restoration of wetlands that could increase these benefits.

IX. Case Study 4: Terrebonne Basin, Louisiana

TERREBONNE BASIN ESTUARY

The Barataria-Terrebonne estuary spans 6,500 square miles and encompasses a wedge-shaped region bounded on the west by the Atchafalaya River and the Bayou Lafourche on the east.[1] As the Mississippi River changes its course over time, it has often crossed over the northern boundary of the estuary.[2] The region encompasses two different estuaries, the Barataria and Terrebonne, separated by the Bayou Lafourche, which sit between the Atchafalaya and Mississippi Rivers. This region is considered the fastest disappearing land mass on earth and is estimated to lose a football field of wetlands to water every hour, largely due to hydrological modification of the estuary.[3] This analysis is specific to the Terrebonne Basin estuary, though the Terrebonne Basin is most often considered as a part of the larger Barataria-Terrebonne estuary. Terrebonne Parish, the largest of seven parishes in the Terrebonne Basin, is known for its rich Cajun culture, feasts, and southern hospitality. Its population of approximately 111,860 live primarily in the northeastern part of the parish, in and near the city of Houma which was founded in 1882 and named after the Houma Native American tribe.[4] The region was colonized by Spanish, British, and French colonists from Europe, but the Cajun culture evolved from French colonists from Nova Scotia following the Seven Years' War.[5] Today the parish is predominantly white (74%), and more than 10% of the residents speak French.[6] Black Americans comprise 17.8% of the population, and Native Americans 5.3% of the population with Asian, Pacific Islander, and Other races composing the remaining 2.9% of the population.[7]

Figure IX-1. Barataria and Terrebonne Basins.

The Barataria-Terrebonne estuary hosts a great diversity of highly fertile habitats including forests, swamps, marshes, islands, bays, bayous, and manmade levees, which yield a rich species composition in the region.[8] Over 735 species of birds, finfish, shellfish, reptiles, amphibians, and mammals have been documented within the estuary. Several threatened and endangered birds of concern use the estuary including piping plover, least tern, black skimmer, American oystercatcher, and brown pelican.[9] The system also supports millions of migrating geese and ducks and a commercial fishery that lands over 600 million pounds of fish and shellfish annually.[10] The Mandalay National Wildlife Refuge was established in 1996 to conserve and protect 1,787 hectares (ha) (4,416 acres) of freshwater marsh and pond habitat in the western Terrebonne Parish in conjunction with the North American Waterfowl Management Plan due to the importance of the region for waterfowl using the Mississippi Flyway.[11]

Oysters are the only reef building organism within the estuary. They provide shoreline protection from erosion, improve water quality through filtration, and have significant economic and cultural importance in the Terrebonne estuary.[12]

Environmental Policies

In 1987 Congress established the National Estuary Program through section 320 of the Clean Water Act. The Barataria-Terrebonne estuary complex was designated one of 28 National Estuaries in 1990 in recognition of the national significance of this estuary system. A cooperative partnership of industry and business, fisheries, farming, oil and gas, government agencies, civic organizations, academics, environmentalist, urban planners, and interested stakeholders formed a Management Conference to address concerns over habitat loss, living resource depletion, and water quality.[13,14] Their focus is on collaborative, science-based, stakeholder led, and consensus-driven planning to accomplish these goals.[15]

The Management Conference identified seven priority threats to the estuary that contribute to land loss, habitat modification, species reductions, and human and wildlife heath issues stemming from water quality.[16] The seven priority problems are: hydrologic modification, sediment reduction, habitat loss, changes in living resources, eutrophication, pathogens, and toxic substances.[17] Ultimately the management goals are to sustain the estuary's public water quality, shellfish, fish, and wildlife habitat and populations, recreational and commercial opportunities, and cultural heritage.[18]

Hydrologic modification is considered the crux of environmental issues in Barataria-Terrebonne.[19] The marsh landscape has been drastically changed through the dredging of canals, construction of levees, and cutting natural ridges. These changes have made the marsh more saline and jeopardize the stability and integrity of the estuary.[20] Navigation canals created by the oil and gas industry have also significantly modified the hydrology of the estuary. Canals allow higher salinity water to enter the marsh, encroaching on and altering wildlife habitat and forcing native plants to adapt to new conditions.[21] Canals also increase erosion and convert more marsh to open water while the dredged material alters nutrient and sediment flow in the water.[22] This sets the stage for the rapid land loss seen in the region and jeopardizes natural resources in the estuary, particularly fisheries, wildlife, and aquatic vegetation. Louisiana has lost 30% of its wetlands since the 1930s[23], and sea-level rise and loss of sediment threatens what is left. Therefore, the majority of restoration efforts focus on balancing sedimentation, reducing salt water flow into the estuary, and expanding existing marsh habitat through redistribution of sediment.

Socioeconomic/Cultural Status

The Terrebonne Basin provides a wealth of economic resources to Louisiana and the nation including an oyster, shrimp, and finfish fishery, transportation ports, and oil and gas.[24] Southern Louisiana infrastructure supports 90% of the nation's outer continental shelf oil and gas production, 23% of U.S. waterborne commerce, and 29% of the volume of commercial fisheries landings in the continental United States.[25] Louisiana is the leading provider of oysters in the nation, and oysters account for $67 million dockside sales each year.[26] In 2017, Louisiana shrimpers landed nearly 100 million pounds of shrimp valued at over $130 million[27]. The industry dates back to the 17th century with the Creoles and Arcadians, and many of the present day fleet has been passed down generationally since that time.[28] Within the industry there are several subsectors – shrimpers, dockside dealers, and processors providing a range of employment within the industry.[29] Shrimpers' distinctive food and culture also contribute to the tourism industry.[30] The region supports a strong tourism industry centered on recreational fishing and boating, swamp tours, and water sports.

The State of Louisiana maintains five of the top 12 ports by cargo volume in the United States.[31] The Houma Navigation Canal hosts the Port of Terrebonne, approximately a half mile from the Gulf Intracoastal Waterway which is a maritime commerce thoroughfare that links the economies of the Gulf States together. The Port of Terrebonne is strategically placed to absorb significant cargo flow and marine traffic from both waterways.[32] Port Fourchon is also located within Terrebonne and supports a significant portion of the area's petroleum industry traffic from offshore Gulf of Mexico oil rigs and the Louisiana Offshore Oil Port pipeline which provides over 90% of the Gulf of Mexico's deep water oil production contributing to 16-18% of the total United States oil supply.[33]

Agriculture is another important economic sector in Terrebonne. The northern parish landscape is dominated by agricultural uses with sugar cane being the dominant cash crop. Other important crops include soybeans, pecans, wheat, and corn, and the region supports a strong cattle industry.[34]

VALUE OF NATURAL INFRASTRUCUTRE IN TERREBONNE BASIN

The study area is the West Central Louisiana Hydrologic Unit, which lies to the south and west of the New Orleans metropolitan area and significantly overlaps the Terrebonne . The area is dominated by wetlands. Over one half (52%) of the area of this unit, which is comprised primarily of Terrebonne and Assumption parishes but touches parts of five other parishes, is wetlands, totaling 421,000 ha (1,040,310 acres). Of that area, 119,382 ha (296,111 acres), or 28% of the total, is estuarine wetlands. The estuarine wetlands are located in the southern portion of the hydrologic unit, generally quite distant from the developed areas around the cities of Houma and Morgan City. (Figure IX-2)

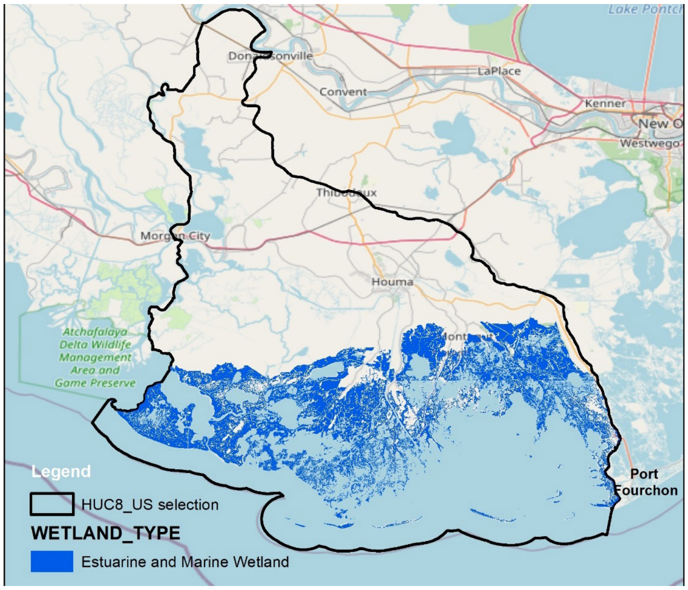


Figure IX-2 West Central Louisiana Hydrologic Unit Estuarine Wetlands

As a result of this distribution of wetlands relative to developed areas, there are only scattered properties located throughout the area analyzed in this study. Because there is so little development in this southern area and most of it is wetlands, FEMA does not designate a 100-year flood zone identified in the region covered by the wetlands. In Terrebonne Parish, the flood hazard is only designated in the northeast part of the parish around Houma. Thus, it is not possible to estimate the value of natural infrastructure flood resilience for this case study in the same manner as the other cases.

Figure IX-3 Port Fourchon

Although an estimate of the monetary value of natural infrastructure cannot be done, it is worth noting the specific natural infrastructure effects at Port Fourchon, which is located just inside the East Central Louisiana Hydrographic Unit across Bayou Lafourche from the area of the case study region. Begun in 1960 as a port facility at the mouth of Bayou Lafourche to divert the banana import trade from New Orleans, Port Fourchon today is one of the most important port facilities for petroleum in the U.S. The port is carved out of the wetlands adjacent to Bayou Lafourche. It is a base for around 400 service boats attending the oil and gas production facilities offshore Louisiana and hosts an airport, primarily for helicopters ferrying crew out to oil rigs. It is also the land terminus for a number of pipelines, the largest of which are connected to LOOP, the Louisiana Offshore Oil Port, a deep-water port located 18 miles to southwest of Port Fourchon in 110 feet of water. LOOP is designed to transfer oil from very large and ultra large oil tankers, most of which are too large for near shore ports, to pipelines and thence on to refineries. There is also a processing plant at Port Fourchon for natural gas piped ashore from offshore wells.[35]

By far the most important flood threat comes from hurricanes, which are frequent, if irregular, visitors to the area. As Figure IX-3 shows, Port Fourchon is surrounded by wetlands, and those wetlands form part of the defense against hurricane-related flooding. They absorb rain so there is little runoff, and the barrier island, on which the gas processing plant is located, provides some protection against storm surge. Surge nevertheless does come up Bayou Lafourche and threaten flood damage to the immediate shoreside facilities. But Port Fourchon was built with hurricanes in mind, so the facility is hardened against damages. With modern forecasts, there is usually time to relocate service boats, divert aircraft, and adjust structures before hurricanes arrive. Though far from immune to damage, Port Fourchon has significantly greater flood defenses than most of the properties examined in the other case studies, where the wetlands are often the only defense available.

There is one component of Port Fourchon where wetlands do play a more important flood defense role, although one that also cannot be estimated with the same methods as the other cases. This is Louisiana Highway 1, which connects Grand Isle, a densely developed barrier island to the east of Port Fourchon, with U.S. Highway 90 just east of Houma. It is also the only road in or out of Port Fourchon. Through much of its north-south length, Highway 1 sits less than two feet above sea level and lacks the levees (earthen walls that provide flood protection) common in much of Louisiana. Wind driven waves overtop the highway with some regularity, while storms can make the route impassable for extended periods. Raising Highway 1 to reduce flood risks from a 100-year flood would require elevating the highway on piles to a height of 22 feet above water level. This would protect the highway and reestablish water connections disrupted by the highway’s construction on fill.[36]

VALUE OF COSTAL BLUE CARBON IN TERREBONNE BASIN

Over the past decades, as the relationship between greenhouse gases and climate change became clear, the scope of analyses for estuary conservation opportunities expanded to consider the role of coastal wetlands in the global carbon cycle. Coastal wetlands sequester vast amounts of the greenhouse gas carbon dioxide, and store that carbon in their soils. The carbon sequestered and stored in coastal estuaries is called coastal blue carbon.[37] Conserving and restoring estuaries rich in coastal blue carbon mitigates the impacts of climate change[38,39] and provides additional benefits that support local communities and can bolster local economies. These benefits include providing nursery habitat for fish[40], reducing the impact of storm surge,[41,42,43] and improving water quality.[44,45,46] Researchers estimating global coastal blue carbon emissions have observed the rapid disappearance of coastal wetlands due to human activity, despite federal and regional wetland protection and planning.[47]

In this case study, coastal blue carbon values are estimated by multiplying the stock of carbon in the "emergent estuarine" land cover class of each estuary by estimates of the social cost of carbon (SCC) published by the Interagency Working Group on Social Cost of Greenhouse Gases in February 2021.[48]

SCC is "a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO_2) emissions in a given year".[49] SCC can also represent the value of damages avoided for emission reductions (i.e., the benefit of a CO_2 reduction). Whether used to measure costs or benefits, SCC values include such wide-ranging effects as global changes in economic output, human health, property damages from increased flood risk, and the value of ecosystem services.

The economic effects of releasing carbon into the atmosphere continue long into the future and increase as the total concentration of atmospheric carbon increases. Annual SCC values for this study's twenty-year period of analysis were discounted to show their value in today's dollars (present value). Values were calculated for each of four SCC scenarios using different discount rates. The "high" and "low" coastal blue carbon values presented in this summary correspond to the use of a 2.5 percent and 5.0 percent discount rate, respectively.

Land cover in the Terrebonne Basin is dominated by palustrine and estuarine wetlands, including forested, scrub/shrub, and emergent (See Figure IX-4). Estuarine emergent wetland covers nearly all but the northernmost portions of land south of U.S. Highway 90.

Carbon Profile

In 2016, the Terrebonne study area contained 133,462 ha (329,792 acres) of estuarine emergent vegetation (saltmarsh, see Figure IX-5). The Coastal Carbon Research Coordination Network (RCN) database contained data from 11 cores sampling the soil beneath estuarine emergent vegetation, with values ranging from 67 to 1,930 metric tons of carbon per hectare in the soil, with an average value of 280 metric tons per hectare.

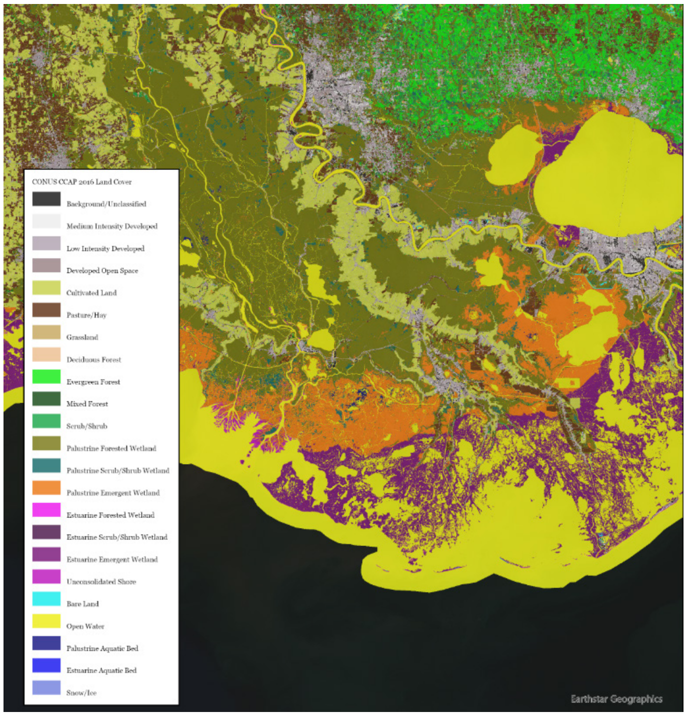


Figure IX-4. Map of vegetation types in the Terrebonne Basin

Figure IX-5. Estuarine Emergent Wetlands vegetation type in the Terrebonne Basin

The RCN data for this area had more variance than in most other case study areas. The two most extreme values (67 and 1,930 tons per hectare) are much different than others in the study area, which range from 106 to 143 metric tons per hectare. Analysts carefully studied these data points and are confident the samples are valid; for this reason, we chose to include them in this analysis. Furthermore, the core depth for the extreme high value was 125 cm and this study assumes that only the top meter of soil is disturbed during the conversion of salt marsh to another use. Further, research[50] indicates that carbon is concentrated in the top layers of soil so no adjustment was made to this value.

These figures suggest that 37.3 million tons of carbon dioxide equivalent (CO_2e[51]) are stored in the soil beneath the study area's 133,462 ha of estuarine emergent vegetation. This is equivalent to the annual emissions of approximately 8.1 million cars.[52]

The Value of Coastal Blue Carbon Stock Stored in Soil

Although carbon is also stored in the biomass of the plants and continues to be sequestered over time, data limitations allow only an analysis of the value of carbon that is stored in soil. The value of the blue carbon stock stored in the soil of the Terrebonne Basin's estuarine emergent wetland area is estimated as the cost to society that would be incurred upon the wetland's loss as carbon is emitted into the atmosphere due to the disturbance of the upper layers of soil. These computations are described below. A more comprehensive assessment of the effects of wetland loss (and, thus, the value of conservation) would include the cessation of carbon sequestration and the emission of carbon stored in the biomass. However, sequestration rates and the amount of carbon stored in biomass vary significantly among sites, even within the same class of vegetation.[53] Reliable, site-specific estimates of carbon sequestration rates and the amount of carbon stored in biomass are not available for the Terrebonne Basin or the areas that are the subject of the other five case studies. For this reason, no attempt was made to estimate these values.

The value of restoring estuarine emergent wetland arises from the restoration of carbon sequestration, which increases over time as the marsh matures. The data limitations described prevent the estimation of these values.

An exponential decay function with a half-life of 7.5 years yields was used to estimate the annual metric tons of carbon that would be released from soil when one hectare of estuarine emergent wetland is converted to another use.[54] The results of this analysis are shown in Table IX-3. In year 30, only 6 percent, or 17.7 metric tons of the initial store of 280 tons of CO2e remain in the hectare of disturbed wetland soil.

Table IX-1 Annual Carbon Released from the Soil of Converted Estuarine Emergent Wetlands (metric tons per hectare)

Year	Carbon in Soil	Cumulative Carbon Release	Annual Carbon Release
2020	280.0	0.0	
2021	255.4	24.6	24.6
2022	232.9	47.1	22.5
2023	212.4	67.6	20.5
2024	193.7	86.3	18.7
2025	176.7	103.3	17.0
2026	161.1	118.9	15.5
2027	146.9	133.1	14.2
2028	134.0	146.0	12.9
2029	122.2	157.8	11.8
2030	111.5	168.5	10.8
2031	101.6	178.4	9.8
2032	92.7	187.3	8.9
2033	84.5	195.5	8.2
2034	77.1	202.9	7.4
2035	70.3	209.7	6.8
2036	64.1	215.9	6.2
2037	58.5	221.5	5.6
2038	53.3	226.7	5.1
2039	48.6	231.4	4.7
2040	44.4	235.6	4.3
2041	40.5	239.5	3.9
2042	36.9	243.1	3.6
2043	33.7	246.3	3.2
2044	30.7	249.3	3.0
2045	28.0	252.0	2.7
2046	25.5	254.5	2.5
2047	23.3	256.7	2.2
2048	21.2	258.8	2.0
2049	19.4	260.6	1.9
2050	17.7	262.3	1.7

SCC values are projected to increase over time, corresponding to increases in the concentration of atmospheric greenhouse gases. For the purposes of this computation, it was assumed that the wetland was converted in 2020. The initial carbon stock (Year 2020) is 280 metric tons per hectare. Table IX-1 shows that, in the first year after conversion, 24.6 metric tons of carbon would be released, 22.5 metric tons would be released in the second year, etc. The SCCs for 2020 (see Table IX-2) were applied to carbon releases during Year 1 (assuming the wetland was converted in 2020). SCC values for 2021 would be applied to carbon released during Year 2, etc. This yields the annual social cost of the carbon that would be released if the marsh were converted.

This computation was performed for each of the four sets of published SCC values and each stream of annual costs was discounted to calculate its present value. Three of the four sets of published SCC values differ only with respect to the discount rates that are applied to future economic values; in Table IX-2 Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates, these values are shown in columns labeled "SCC, 5%," "SCC, 3%," and "SCC, 2.5%".[55] Present value computations for these estimates of the SCC use the discount rate upon which each estimate was based. These present values range from $3,224/hectare to $18,601/hectare. The total value for the 133,462 ha in the estuary ranges from $430 million to $2.5 billion.

Table IX-2 Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates

Year	2020 Dollars Per Ton of CO_2e					
	RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	$17	$6	$14	$51	$76	$152
2025	$17	$6	$17	$56	$83	$169
2030	$17	$6	$19	$62	$89	$187
2035	$17	$6	$22	$67	$96	$206
2040	$17	$6	$25	$73	$103	$225
2045	$17	$6	$28	$79	$110	$242
2050	$17	$6	$32	$85	$116	$260

The fourth set of SCC published values differs significantly from the other three. These values capture the potential for low-probability, high-impact outcomes from climate change and correspond to the 95th percentile of the frequency distribution of SCC estimates using a 3 percent discount rate. The present value associated with this set of SCC values is $36,963/hectare with a total value for the estuary's 133,462 ha of $4.9 billion.

The broad range in these present value estimates is in part due to uncertainty about future economic conditions (reflected in differing discount rates) and the appropriate level of risk-taking with regard to climate policy (reflected in the set of SCC values associated with low-probability, high-impact outcomes).

Prices from the Regional Greenhouse Gas Initiative (RGGI) and Western Climate Initiative (WCI) carbon markets were also applied (with a 3% discount rate) to the future stream of carbon releases associated with the loss of one hectare of saltmarsh in the Terrebonne Basin. In almost all scenarios, the cost of purchasing the right to release this stream of carbon is much less than the social cost of the released carbon. Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon equals the SCC. Prices from these two carbon markets result in values that range from $1,272 per hectare to $3,578 per hectare with totals for the 133,462 ha of salt marsh in the study area ranging from $170 million to $448 million. The results of these computations are shown in Table IX-3.

Table IX-3 Blue Carbon Values for Terrebonne Basin 2020-2049 (Nominal/Net Present Value)

Annual Value	Carbon Released (t CO_2e/ ha)	Value of Released Carbon					
		RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	24.6	$149.56	$420.85	$365.67	$1,279.83	$1,889.28	$3,748.08
2021	22.5	$136.40	$383.82	$333.49	$1,167.21	$1,750.81	$3,501.62
2022	20.5	$124.40	$350.04	$329.49	$1,089.84	$1,622.09	$3,269.52
2023	18.7	$113.45	$319.24	$300.49	$1,017.05	$1,502.46	$3,051.14
2024	17.0	$103.47	$291.14	$274.05	$948.63	$1,391.32	$2,845.88
2025	15.5	$94.36	$265.52	$269.16	$884.37	$1,307.34	$2,653.12
2026	14.2	$86.06	$242.16	$245.47	$824.08	$1,209.82	$2,472.25
2027	12.9	$78.49	$220.85	$239.86	$767.55	$1,119.35	$2,286.67
2028	11.8	$71.58	$201.41	$218.75	$714.59	$1,035.43	$2,129.20
2029	10.8	$65.28	$183.69	$199.50	$651.71	$957.61	$1,981.73
2030	9.8	$59.54	$167.52	$194.08	$606.49	$885.47	$1,843.72
2031	8.9	$54.30	$152.78	$177.00	$564.18	$818.61	$1,714.66
2032	8.2	$49.52	$139.34	$171.51	$524.62	$756.66	$1,594.04
2033	7.4	$45.16	$127.08	$156.42	$487.66	$699.28	$1,481.37
2034	6.8	$41.19	$115.89	$151.04	$453.13	$646.13	$1,376.18
2035	6.2	$37.56	$105.69	$137.75	$420.91	$596.93	$1,285.69
2036	5.6	$34.26	$96.39	$132.61	$390.85	$551.38	$1,193.49
2037	5.1	$31.24	$87.91	$120.94	$362.82	$515.59	$1,107.56
2038	4.7	$28.49	$80.17	$116.10	$336.70	$476.02	$1,027.51
2039	4.3	$25.99	$73.12	$107.02	$308.23	$436.66	$946.10
2040	3.9	$23.70	$66.68	$97.61	$285.01	$402.14	$878.46
2041	3.6	$21.61	$60.82	$92.58	$263.49	$370.31	$811.83
2042	3.2	$19.71	$55.46	$84.43	$243.55	$344.22	$753.38
2043	3.0	$17.98	$50.58	$79.96	$228.04	$316.89	$695.97
2044	2.7	$16.39	$46.13	$75.63	$210.67	$291.70	$645.53
2045	2.5	$14.95	$42.07	$68.97	$194.60	$270.96	$596.11
2046	2.2	$13.64	$38.37	$65.15	$179.72	$249.36	$552.64
2047	2.0	$12.44	$34.99	$61.46	$165.95	$229.47	$510.15
2048	1.9	$11.34	$31.91	$56.06	$153.22	$213.01	$472.73
2049	1.7	$10.34	$29.11	$52.83	$143.14	$195.97	$436.25

Table IX-3 Blue Carbon Values for Terrebonne Basin 2020-2049 (Nominal/Net Present Value) (cont'd)

Discounted Value	0.03	0.03	0.05	0.03	0.025	0.03
2020	$149.56	$420.85	$344.96	$1,256.64	$1,872.64	$3,745.28
2021	$132.43	$372.64	$321.02	$1,134.49	$1,710.04	$3,381.66
2022	$117.26	$329.95	$278.83	$1,023.84	$1,541.03	$3,071.52
2023	$103.83	$292.15	$258.33	$923.65	$1,388.49	$2,770.95
2024	$91.93	$258.68	$224.38	$832.98	$1,266.31	$2,514.08
2025	$81.40	$229.04	$207.07	$750.96	$1,140.44	$2,266.29
2026	$72.07	$202.80	$179.86	$676.80	$1,026.94	$2,054.15
2027	$63.82	$179.57	$165.41	$620.29	$935.48	$1,850.36
2028	$56.51	$159.00	$143.67	$558.54	$842.03	$1,675.61
2029	$50.03	$140.78	$131.72	$502.79	$757.81	$1,508.38
2030	$44.30	$124.65	$114.41	$452.49	$681.93	$1,364.77
2031	$39.23	$110.37	$104.60	$407.11	$620.39	$1,234.26
2032	$34.73	$97.73	$95.40	$366.19	$558.06	$1,110.03
2033	$30.75	$86.53	$82.86	$329.31	$507.33	$1,003.12
2034	$27.23	$76.62	$75.39	$296.07	$456.20	$906.15
2035	$24.11	$67.84	$65.49	$266.12	$410.18	$818.22
2036	$21.35	$60.07	$59.46	$242.67	$372.57	$738.55
2037	$18.90	$53.19	$51.65	$217.98	$334.87	$663.28
2038	$16.74	$47.09	$46.81	$195.77	$300.97	$598.33
2039	$14.82	$41.70	$42.35	$175.78	$273.14	$539.54
2040	$13.12	$36.92	$36.79	$157.80	$245.41	$486.38
2041	$11.62	$32.69	$33.23	$141.64	$220.48	$436.40
2042	$10.29	$28.95	$28.86	$127.11	$199.94	$393.18
2043	$9.11	$25.63	$26.03	$115.55	$179.58	$352.64
2044	$8.07	$22.69	$23.45	$103.64	$161.28	$317.56
2045	$7.14	$20.09	$20.37	$92.94	$146.15	$284.71
2046	$6.32	$17.79	$18.32	$83.34	$131.22	$256.26
2047	$5.60	$15.75	$16.46	$74.71	$117.81	$229.67
2048	$4.96	$13.95	$14.30	$66.97	$106.69	$206.62
2049	$4.39	$12.35	$12.83	$60.74	$95.76	$185.12
Present Value, 30 years	**$1,271.60**	**$3,578.07**	**$3,224.31**	**$12,254.90**	**$18,601.18**	**$36,963.08**

ESTUARY SUMMARY

Restoration Efforts

The Terrebonne Basin is part of the vast complex of wetlands in the lower Mississippi River, that is both one of the largest wetland complexes in the world and one of the most threatened. The loss of wetland areas has been underway for decades driven by sediment starvation, channelization, and conversion.[56] The response to these losses has been a major combined effort from the federal and state governments to combine funding from multiple sources to restore or protect over 19,263 ha (47,600 acres) of wetlands and 60 miles of barrier islands[57] (See Figure IX-6).

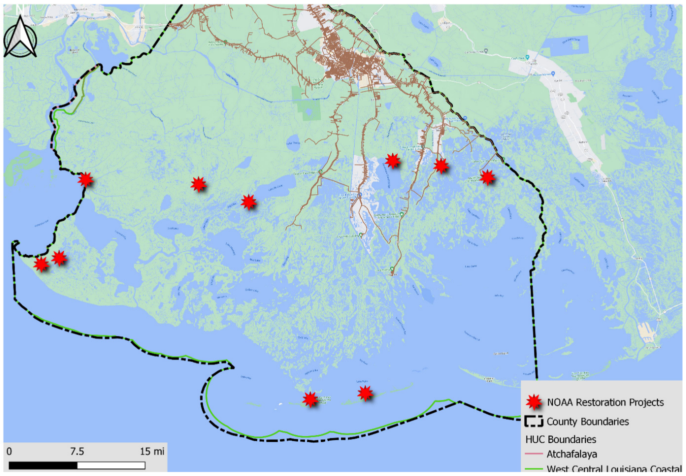


Figure IX-6 Terrebonne Region Restoration Projects

The largest of the wetland restoration programs is the federal Coastal Wetlands Resource Planning Protection and Restoration Act, enacted by Congress in 1990. This program has supported over 40 projects either within Terrebonne Parish or in multiple parishes including Terrebonne (See Table IX-4). Terrebonne parish alone was the location of thirty-four of these projects. About half of the projects were for marsh and barrier island restoration. These projects restored over 9,914 ha (24,500 acres) of wetland (See Table IX-5). About half of the projects by type are for vegetative (herbivory) control and marsh creation, although many projects have multiple effects.

Table IX-4 CWPPRA Restoration Projects by Type and Location as of 2021

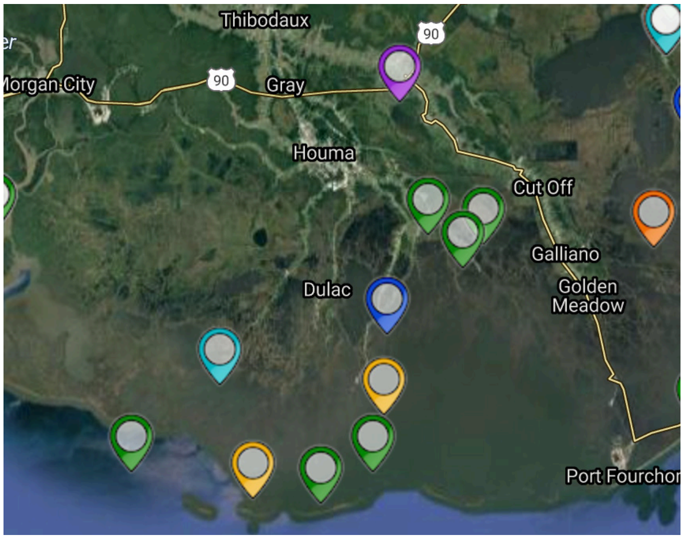
	Terrebonne	Terrebonne & Others	Grand Total
Barrier Island Restoration	9		9
Demonstration	5	4	9
Freshwater Diversion	1	1	2
Herbivory Control		1	1
Hydrologic Restoration	6	1	7
Invasives Control		1	1
Marsh Creation	11		11
Monitoring		1	1
Water Diversion	1		1
(blank)	1		1
Total	34	9	43

Table IX-5 Acreage of CWPPRA Restoration Projects by Type and Location

	Terrebonne	Terrebonne & Others	Grand Total
Barrier Island Restoration	2,199		2,199
Demonstration			
Freshwater Diversion	202	988	1,190
Herbivory Control		14,963	14,963
Hydrologic Restoration	2,175	199	2,374
Invasives Control		26	26
Marsh Creation	3,502		3,502
Monitoring			
Water Diversion	266		266
(blank)	64		64
Total	8,408	16,176	24,584

Terrebonne is also one of the focal areas of the Deepwater Horizon Oil Spill Restoration Plans in Louisiana (See Figure IX-7).[58] The Deepwater Horizon mobile drilling unit exploded in April of 2010 releasing approximately 134 million gallons of oil. The Louisiana Deepwater Horizon Oil Spill Restoration Plans identify projects in this estuary to respond to the effects of the oil spill. These projects include a nutrient reduction project, a marsh creation project, an oyster restoration project, two dune and island restoration projects, three artificial reef projects, and three other projects related to recreation enhancements within the Terrebonne Basin[59] (See Figure IX-7).

Figure IX-7 Planned and Completed Deepwater Horizon-Related Projects in Terrebonne Basin



Legend
Purple marker: Nutrient Reduction
Green Marker: Enhance Recreational Opportunities
Yellow Marker: Restoration
Dark Blue Marker: Marsh Creation
Light Blue Marker: Oyster Restoration

Natural Infrastructure and Coastal Blue Carbon Benefits

The Terrebonne Basin estuary is rich in contradictions. It has large swaths of sparsely populated wetlands along with the highest rate of land loss in Louisiana, increasing the urgency for restoration efforts. Having adapted long-ago to the frequent storms, flooding, and land-loss that characterize the region, most economic assets, that in other estuaries would be located along the shore, have moved inland. Those that remain near the shore have adapted to these conditions. For instance, Port Fourchon has significantly greater flood defenses than most of the properties examined in the other case studies.

The expansive range of salt marshes provide an environment rich in coastal blue carbon values, the largest of any found in the six estuaries studied in this project. Much of that value is due to the sheer amount of wetlands, 133,462 ha (over 300,000 acres). Though the level of coastal blue carbon found in the Terrebonne soil samples was the second highest, at 280 tons CO_2/hectare. The value of this coastal blue carbon ranges from $3,224/hectare to $18,601/hectare. The total value for the 133,462 ha under the three SCC scenarios in the estuary ranges from $430 million to $2.5 billion. The low-probability, high-impact climate outcome scenario resulted in a total coastal blue carbon value of $4.9 billion.

The broad range in these benefit estimates is due to multiple factors:

- uncertainty about future economic conditions (reflected in differing discount rates in the coastal blue carbon analysis), and
- and the appropriate level of risk-taking with regard to climate policy and the range of potential future impacts from climate change (choice of scenarios).

While Terrebonne Basin is far from an urban estuary, it is still a "working" estuary, supporting marine transportation, and oil and gas production, as well as oyster, shrimp, and finfish fisheries that rely on the health of the ecosystem for their continued existence. Restoration efforts that continue to improve the health and stability of the fragile Gulf ecosystems through diversions and marsh creation will continue to add valuable blue carbon to the list of economic benefits that the estuary provides to the community.

Figure X-1. Wetlands at Sunset. San Pablo Bay, Vallejo, CA.

X. Case Study 5: San Pablo Bay, CA

SAN PABLO BAY

San Pablo Bay is a tidal estuary and sub-embayment of North San Francisco Bay in Northern California.[1] It spans an area of approximately 90 sq mi. and is nestled within the San Francisco Bay metropolitan area, home to over 7 million people.[2] The population is ethnically very diverse; approximately half of the residents are Hispanic, Asian, African American, or Pacific Islander.[3]

San Pablo Bay is comprised of a channel-shoal system which is characteristically shallow but dissected by a single deep-water channel through the middle of the Bay allowing ships access to the ports of Sacramento, Stockton, Benicia, and Martinez.[4] It is fed by four tributaries: the Sacramento, San Joaquin, Petaluma, and Napa Rivers, and its undeveloped shore lands are defined by large intertidal mudflats interspersed with salt marshes.[5, 6] Wind-waves play a significant role in shaping these mudflats by resuspending sediment and increasing suspended sediment within the water column.[7] Sediment type varies by habitat type with fine, mud sediment dominating the shoals and sandy sediment collecting in and around deep channels.[8] More than 90% of the shallow tidal flats are covered in mud and this mud will occasionally cover sandy channels as well.[9] The mudflats are inundated by tides twice daily saturating the Bay with nutrients supporting a large community of marine invertebrates.[10]

The wetlands surrounding San Pablo Bay were once one of the largest tidal marsh complexes on the Pacific Coast of North America but approximately 85% of San Pablo Bay's tidal marshes have been significantly altered by anthropogenic activities including hydraulic mining, salt production, diking, draining, filling, agriculture, and development. Hydraulic mining operations coinciding with the California gold rush in the 1850s injected large amounts of sediment into the San Francisco Bay Estuary and into the mid-1900s the marshes were diked, filled, and drained to support commercial development.[11] Construction of a reservoir and land reclamation projects from 1910 to 1975 decimated tidal marsh in the area, decreasing the Bay's sediment trapping efficiency and significantly altering the sediment balance in the estuary.[12, 13] Modern forecasting indicates that while some mature salt marshes may be able to trap sediment eroding from mudflats, young salt marshes will likely drown due to sea level rise and intertidal mudflat migration making the Bay vulnerable to significant habitat alteration.[14] Sea level rise is one of the greatest threats to coastal areas across the globe, and particularly impacts estuarine environments.[15] Predictive modeling of sea level rise in San Pablo Bay demonstrates that sea level rise will slowly drown the estuarine environment as it exceeds the accretion rate of mudflats.[16] Therefore, salt marsh conservation and restoration is critical to keeping sedimentation and habitat stability in balance in San Pablo Bay.

Rapid development starting in the mid-1800's transformed the landscape but today, San Pablo Bay still contains a variety of habitat including open bay waters, salt marshes, intertidal mudflats, upland habitats, and restored wetlands.[17] Over 300 species of wildlife can be found in the greater San Francisco Bay estuary encompassing San Pablo Bay.[18] Many of these species visit the Bay as a stopping point during their Pacific migration.[19] San Pablo Bay is a primary wintering ground for the canvasback duck and a renowned location where thousands of canvasbacks congregate each year.[20] San Pablo also hosts a migratory staging ground for many species of waterfowl. Several resident faunal species are included on the federal Endangered Species List including California brown pelicans, California clapper rail, and the salt marsh harvest mouse. In fact, the region hosts the largest remaining continuous patch of pickleweed-dominated tidal marsh (*Sarcocornia pacifica*), the primary habitat of the endangered salt marsh harvest mouse.[21]

Recreational fishing is popular in San Pablo Bay. Within the San Pablo Bay watershed there are 26 recognized native fish species.[22] Striped bass (non-native invasive species), surfperch, sturgeon, and starry flounder are some of the prime target species for recreational fishermen. The winter season is known for prime white sturgeon fishing, particularly in the north Bay. Commercial fisheries are located primarily in the larger San Francisco Bay, which hosts a large offshore Dungeness crab fleet in the fall season as well as salmon trollers throughout the summer and fall. Although it used to be a working port for the southern squid purse seiners, the fleet moved north in response to a severe El Nino event in 2016.[23] The commercial fishing fleet does not typically operate out of San Pablo Bay. One exception is herring spawns. Large aggregations of Pacific herring (*Clupea harengus pallasi)* spawning at China Camp and Point Richmond once supported a modest commercial fleet, and recreational fishing off the piers in the Bay.[24] However, a long downward trend, starting in the late 1980s, with a few notable spikes in biomass in 1995, 2005, and 2010, has diminished substantially, with the fleet currently catching a few hundred tons each year.[25]

Environmental Policies

Significant loss of tidal wetlands launched collaborative conservation efforts in the 1960s by non-profit organizations, local grassroots groups, and government entities.[26] In 1999, the *Baylands Ecosystem Habitat Goals* set a goal of achieving and maintaining 100,000 acres of tidal marsh. Following this, the San Francisco Bay Conservation and Development Commission adopted a goal of restoring 26,305 ha (65,000 acres) of diked land.[27] As of 2015, approximately 12,500 acres had been restored with an additional 30,000 acres of restoration underway.[28] The larger San Francisco Bay region is identified as one of the Waterfowl Habitat Areas of Major Concern under the North American Waterfowl Management Plan.[29] The US Fish and Wildlife Service and the California Department of Fish and Game jointly oversee the northern marshes of the Bay. The Nature Conservancy and California State Coastal Conservancy have been instrumental in acquiring additional wetland units for conservation. In 1974 the San Pablo Bay National Wildlife Refuge was established which encompasses much of the northern shore of the Bay, and it is owned and managed by the U.S. Fish and Wildlife Service for the purpose of conserving, restoring, and protecting the wetlands for endangered species and migratory bird habitat.[30] The Refuge now encompasses 19,965 acres of wetlands in northern San Pablo Bay. It allows waterfowl hunting per its 2018 Waterfowl Hunting Plan which allows ducks, geese, and coots to be hunted on the refuge during the season. Recreational fisheries are managed under the San Pablo Bay National Wildlife Refuge Recreational Sport Fishing Plan.[31] Ten species are monitored under this plan including the white sturgeon, two species of surfperch, and the invasive striped bass.[32] The Napa-Sonoma Marshes Wildlife Area managed by the California Department of Fish and Game also protects part of the San Pablo Bay estuary within its 15,200 acres of baylands, tidal sloughs, and wetland habitat.[33] The wildlife area restricts development and manages usage to recreational activities including hunting, fishing, bird watching, and hiking.[34]

Socioeconomic/Cultural Status

Historically, Ohlone, Miwok, and Patwin Native American tribes inhabited the San Pablo Bay and larger San Francisco region until the watershed was colonized by Spanish settlers in the late 1700s.[35, 36] Disease, cultural assimilation, and imposed substandard living conditions decimated the Native American population in the region. However, native populations declined precipitously after the Gold Rush and Mexican War because of violent conflicts with the rapidly increasing American population.[37] Today the population surrounding San Pablo Bay mirrors the ethnic diversity of the larger San Francisco Bay area. Economically, the San Francisco Bay area has become very strong due to its large presence of some of the nation's biggest technology companies. The median San Francisco household income is $96,677 per year which nearly doubles the national household income according to the U.S. census bureau.[38] That wealth is also present in many of the communities that border the eastern shores of the Bay such as Pinole, Hercules, and Rodeo. However, remnants of wartime industries dominate the communities on the southern shore of San Pablo Bay including Richmond/North Richmond, as the city was home to four Kaiser shipyards that housed the most productive wartime shipbuilding operations during World War II.[39] Mare Island Naval Shipyard dominates the shoreline in Vallejo. The southern shore of San Pablo Bay still hosts heavy-industry including Chevron, Shell, and Phillips 66 oil refineries, manufacturing, commercial shipping, and rail transportation.[40] Communities near these heavy industries, such as San Pablo and North Richmond, have median household incomes that are about half of those in San Francisco ($47,459 and $50,568 in 2017 respectively[41]). The northern and western boundaries of the bay are comprised primarily of open-space, agricultural land, parks, and wildlife and wetlands reserves, including the San Pablo Bay National Wildlife Refuge, China Camp State Park, and the San Francisco Bay National Estuarine Research Reserve.

VALUE OF NATURAL INFRASTRUCTURE IN SAN PABLO BAY

NOAA defines natural infrastructure as "healthy ecosystems, including forests, wetlands, floodplains, dune systems, and reefs, which provide multiple benefits to communities, including storm protection through wave attenuation or flood storage capacity and enhanced water services and security."[42] An estuary's capacity to protect shoreline property from climate hazards and flood risk is an important ecosystem service. The measure of this service is, however, complex. The value depends on how often and how severe floods will be. It depends on the value of the economic assets vulnerable to floods of different sizes and types. And it depends on the extent of lost economic activity, as well as the issue of disproportionate effects on populations which may or may not have the capacity to recover from flood events.

The analysis in this section uses a method that focuses on damages to real property from flooding that might be reduced by the presence of estuarine wetlands adjacent to the property. It is a very simplified perspective that is designed to raise awareness of natural infrastructure benefits as a prelude to incorporating these values into planning for the future of estuaries using more complete information.

San Pablo Bay lies at the point where the San Francisco Bay transitions between bay and the lower part of the Sacramento/San Joaquin River complex. The area studied for natural infrastructure is comprised of areas within seven counties that are located within the San Pablo Hydrographic Unit as defined by the U.S. Geological Survey.[43] Parcels from the county tax records were selected based on their location within the 100-year flood zone[44] and adjacent to estuarine wetlands as defined by the National Wetlands Inventory[45].

There are over 2,800 parcels of land meeting this condition, worth just under $3.3 billion at current assessed values. The natural infrastructure benefits in terms of flood reduction can range from $15.4 million to $34.4 million over a 30-year period for a flood that historically would have a 1% chance of occurring each year. Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $30.0 million and $68.7 million (See Table X-1).

These values are for damages to property exposed to flooding and do not include the damages to business sales or employment, nor the value of possible losses from effects on human health. These damage estimates should thus be considered conservative, that is likely to be low relative to the actual full economic costs of flooding.

The natural infrastructure benefits in San Pablo Bay are to be found in all counties surrounding the Bay except for San Francisco, where the fully developed shoreline has only small amounts of wetland (See Figure X-2). Parcels on the shoreline located within the flood zone and adjacent to estuarine wetlands are shown in Figure X-3. The parcels in the northeastern part of San Pablo Bay in Napa and Solano counties are located within the San Pablo Bay National Wildlife Refuge, and thus are owned by the federal government, and have no recorded values and so are excluded from the benefit estimates presented here.

The natural infrastructure benefits of the wetlands in San Pablo Bay are created because wetlands can reduce the damage from flooding, whether from coastal flooding driven by tides, wind, and storm surge or river flooding. The benefits can be measured as the reduction in flood damages resulting from the presence of the wetlands and is a function of the location of vulnerable economic assets (buildings and land), the frequency and severity of floods, the likely extent of damages, and the possible reductions in those damages resulting from the presence of the wetlands. The exact extent of the damage that determines benefits cannot, of course, be known with precision in advance so estimates and assumptions must be used. These assumptions and the calculations used to estimate benefits are explained in Section III of the accompanying technical report.

Flood damage reductions depend on the frequency and severity of flooding, defined by the 100-year flood plain, which defines a flood of such severity that it only has a 1% chance of occurring each year. For this analysis, an alternate scenario is used to examine the effects of climate change, one of which is to increase the frequency of severe storm events. To reflect estimation of benefits related to a changing climate, we assumed the 100-year storm becomes the 50-year storm, which means the annual probability of a storm at least this severe doubles from 1% to 2%.

Table X-1. Summary of Findings: San Pablo Bay Estuary Natural Infrastructure Benefits

			1% Annual Probability Storm Benefits (Millions)		**2% Annual Probability Storm Benefits (Millions)**	
Estuarine and Maine Wetlands Area (Ha)	Number of wetlands-adjacent parcels in 100 Year Flood Zone	Values at Risk (Millions)	Wetland Effect (Low) -10%	Wetland Effect (High) -20%	Wetland Effect (Low) -10%	Wetland Effect (High) -20%
29,872	**2,862**	**$3,298.71**	**$15.40**	**$34.41**	**$30.00**	**$68.71**

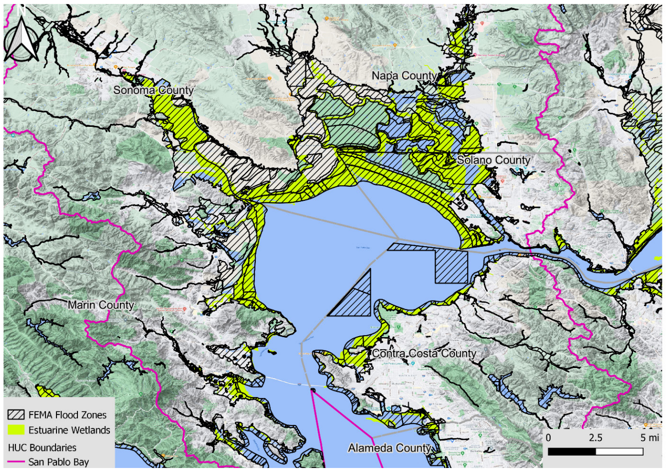


Figure X-2. San Pablo Bay Estuarine Wetlands and FEMA Flood Zones

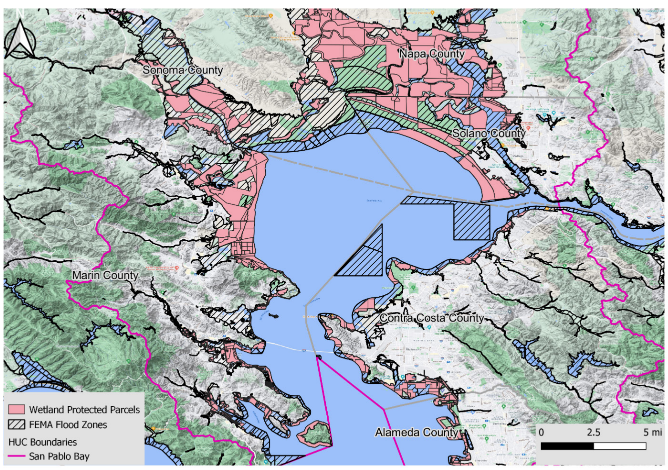


Figure X-3. San Pablo Bay Estuarine Wetlands and Adjacent Parcels

To calculate the protective benefits of wetlands, we estimated the total likely damages to property from a 100-year flood first. These damages were estimated by applying flood damage factors for land and buildings to the assessed values of the property; buildings were assumed to be subject to twice the damages of land. These estimated damages were multiplied by the probability of a flood occurring over a 30-year period. For the 1% annual probability, the *cumulative* probability of a flood over 30 years is 26%. For the 2% annual probability the *cumulative* probability is 45%. The result is the total expected flood damage over 30 years. Since any flood damages will occur in the future, the value of the expected damages is discounted over the 30-year time period and the results are presented in $2020, or the present value. These expected damages are the basis for calculating the reductions in flood damages that may be attributable to wetlands as described above.

The extent to which wetlands can reduce flood damages is highly variable depending greatly on the type and extent of wetlands at any given location. For purposes of this analysis the "wetlands effect" is the reduction in the dollar value of likely damages from a 100-year flood that may be attributable to the presence of wetlands—expressed as a percentage of damages. A range of 10% to 20% reduction is used based on a study of wetlands damage reductions from an actual storm on the Atlantic coast.[46] It should be noted that this estimate was derived from an analysis of a storm with a strong surge-based flood.

Table X-2. San Pablo Bay Natural Infrastructure Benefits by County

					1% Annual Probability Storm Benefits (Millions)		**2% Annual Probability Storm Benefits (Millions)**	
County	Parcels	Buildings Value (Millions)	Land Value (Millions)	Total Value (Millions)	Wetland Effect Low -10%	Wetland Effect High -20%	Wetland Effect Low -10%	Wetland Effect High -20%
Alameda	690	$451.4	$189.4	$640.8	$2.5	$5.6	$4.5	$11.1
Contra Costa	245	$1,198.5	$184.7	$1,383.2	$8.5	$19.0	$16.9	$38.1
Marin	1,546	$546.7	$586.0	$1,132.7	$4.0	$8.9	$7.9	$17.8
Napa	154	$14.4	$38.0	$52.5	$0.1	$0.3	$0.2	$0.5

Such a storm is much less likely in a location such as San Pablo Bay, so the natural benefits there are likely to be towards the low end of the estimated values.

Table X-2 provides the results of the analysis for the area as a whole and for the portions of the counties within the San Pablo Hydrographic Units that are also adjacent to wetlands.[47] The largest number of parcels affected is in Marin County, but highest values and highest flood damage reduction benefits occur on the southern shore of San Pablo Bay in Contra Costa County. Most of the value at risk in this county is in buildings. The flood benefits in the counties with the smallest number of parcels (Napa, Sonoma, and Solano) are larger for land than buildings.

VALUE OF COASTAL BLUE CARBON IN SAN PABLO BAY

Over the past decades, as the relationship between greenhouse gases and climate change became clear, the scope of analyses for estuary conservation opportunities expanded to consider the role of coastal wetlands in the global carbon cycle. Coastal wetlands sequester vast amounts of the greenhouse gas carbon dioxide, and store that carbon in their soils. The carbon sequestered and stored in coastal estuaries is called coastal blue carbon.[48] Conserving and restoring estuaries rich in coastal blue carbon mitigates the impacts of climate change[49][50] and provides additional benefits that support local communities and can bolster local economies. These benefits include providing nursery habitat for fish[51], reducing the impact of storm surge,[52][53][54] and improving water quality.[55][56][57] Researchers estimating global coastal blue carbon emissions have observed the rapid disappearance of coastal wetlands due to human activity, despite federal and regional wetland protection and planning.[58]

In this case study, coastal blue carbon values are estimated by multiplying the stock of carbon in the "emergent estuarine" land cover class of each estuary by estimates of the social cost of carbon (SCC) published by the Interagency Working Group on Social Cost of Greenhouse Gases in February 2021.[59]

SCC is "a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO_2) emissions in a given year".[60] SCC can also represent the value of damages avoided for emission reductions (i.e., the benefit of a CO_2 reduction). Whether used to measure costs or benefits, SCC values include such wide-ranging effects as global changes in economic output, human health, property damages from increased flood risk, and the value of ecosystem services.

The economic effects of releasing carbon into the atmosphere continue long into the future and increase as the total concentration of atmospheric carbon increases. Annual SCC values for this study's twenty-year period of analysis were discounted to show their value in today's dollars (present value). Values were calculated for each of four SCC scenarios using different discount rates. The "high" and "low" coastal blue carbon values presented in this summary correspond to the use of a 2.5 percent and 5.0 percent discount rate, respectively.

Land cover in the San Pablo Bay estuary is dominated by evergreen and deciduous forest (See Figure X-4). Estuarine emergent wetland is nearly continuous surrounding the bay with one notable exception; it is almost completely absent along the heavily developed southeastern shoreline extending from the Point Pinole Regional Shoreline to the city of Vallejo. Large expanses of estuarine emergent wetland also extend about 10 miles inland along the Petaluma River and about 10 miles inland along the Napa River (including the Napa Slough).

Carbon Profile

In 2016, the San Pablo Bay study area contained 8,451 hectares (more than 20,000 acres) of estuarine emergent vegetation (saltmarsh, see Figure X-5). The Coastal Carbon Research Coordination Network (RCN) database contained data from 10 cores sampling the soil beneath estuarine emergent vegetation, with values ranging from 85 to 274 metric tons of carbon per hectare in the soil, with an average value of 163 metric tons per hectare. The depth of core samples ranges from 55 to 125 centimeters, averaging 85 centimeters.

These figures suggest that more than 1.4 million tons of carbon dioxide equivalent (CO_2e[61]) are stored in the soil beneath the study area's 8,451 hectares of estuarine emergent vegetation. This is equivalent to the annual emissions of approximately 300,000 cars.[62]

The Value of Coastal Blue Carbon Stock Stored in Soil

Although carbon is also stored in the biomass of the plants and continues to be sequestered over time, data limitations allow only an analysis of the value of carbon that is stored in soil. The value of the blue carbon stock stored in the soil of San Pablo Bay's estuarine emergent wetland areas is estimated as the cost to society that would be incurred if the wetlands upper layers were disturbed or developed, and the carbon was released. These computations are described below. A more comprehensive assessment of the effects of wetland loss (and, thus, the value of conservation) would include the cessation of carbon sequestration and the emission of carbon stored in the biomass. However, sequestration rates and the amount of carbon stored in biomass vary significantly among sites, even within the same class of vegetation.[63] Reliable, site-specific estimates of carbon sequestration rates and the amount of carbon stored in biomass are not available for the San Pablo Bay estuary or the areas that are the subject of the other five case studies. For this reason, no attempt was made to estimate these values.

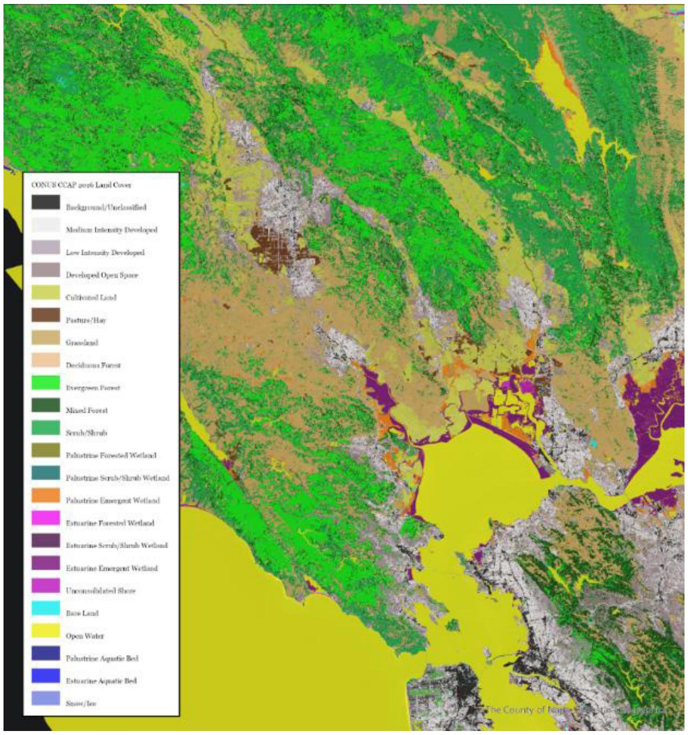


Figure X-4. Map of vegetation types in the San Pablo Bay Estuary

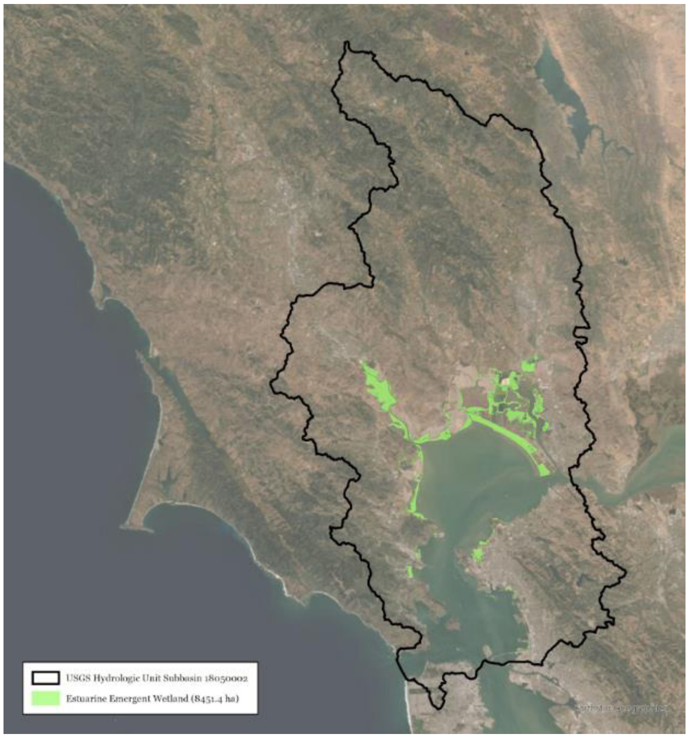


Figure X-5. Estuarine Emergent Wetlands in the San Pablo Bay Estuary

The value of restoring estuarine emergent wetland arises from the restoration of carbon sequestration, which increases over time as the marsh matures. The data limitations described prevent the estimation of these values.

An exponential decay function with a half-life of 7.5 years was used to estimate the annual metric tons of carbon that would be released from soil when one hectare of estuarine emergent wetland is converted to another use.[64] The results of this analysis are shown in Table X-3. In year 30, only 6 percent, or 10.3 metric tons of the initial store of 163 tons of CO_2e remain in each hectare of disturbed wetland soil.

SCC values are projected to increase over time corresponding to increases in the concentration of atmospheric greenhouse gases. For the purposes of this computation, it was assumed that the wetland was converted in 2020. The initial carbon stock (Year 2020) is 163 metric tons per hectare. Table X-3 shows that, in the first year after conversion, 14.3 metric tons of carbon would be released, 13.1 metric tons would be released in the second year, etc. The SCCs for 2020 (See Table X-4) were applied to carbon releases during Year 1 (assuming the wetland was converted in 2020), SCC values for 2021 would be applied to carbon released during Year 2, etc. This yields the annual social costs of the carbon that would be released if the marsh were converted.

Table X-3. Annual Carbon Released from the Soil of Converted Estuarine Emergent Wetlands (metric tons per hectare)

Year	Carbon in Soil	Cumulative Carbon Release	Annual Carbon Release
2020	163.0	0.0	
2021	148.7	14.3	14.3
2022	135.6	27.4	13.1
2023	123.6	39.4	11.9
2024	112.8	50.2	10.9
2025	102.8	60.2	9.9
2026	93.8	69.2	9.0
2027	85.5	77.5	8.3
2028	78.0	85.0	7.5
2029	71.1	91.9	6.9
2030	64.9	98.1	6.3
2031	59.2	103.8	5.7
2032	54.0	109.0	5.2
2033	49.2	113.8	4.7
2034	44.9	118.1	4.3
2035	40.9	122.1	4.0
2036	37.3	125.7	3.6
2037	34.0	129.0	3.3
2038	31.1	131.9	3.0
2039	28.3	134.7	2.7
2040	25.8	137.2	2.5
2041	23.6	139.4	2.3
2042	21.5	141.5	2.1
2043	19.6	143.4	1.9
2044	17.9	145.1	1.7
2045	16.3	146.7	1.6
2046	14.9	148.1	1.4
2047	13.6	149.4	1.3
2048	12.4	150.6	1.2
2049	11.3	151.7	1.1
2050	10.3	152.7	1.0

Table X-4. Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates

Year	2020 Dollars Per Ton of CO_2e					
	RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	$17	$6	$14	$51	$76	$152
2025	$17	$6	$17	$56	$83	$169
2030	$17	$6	$19	$62	$89	$187
2035	$17	$6	$22	$67	$96	$206
2040	$17	$6	$25	$73	$103	$225
2045	$17	$6	$28	$79	$110	$242
2050	$17	$6	$32	$85	$116	$260

This computation was performed for each of the four sets of published SCC values and each stream of annual costs was discounted to calculate its present value. Three of the four sets of published SCC values differ only with respect to the discount rates that are applied to future economic values; in Table X-4. Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates, these values are shown in columns labeled "SCC, 5%," "SCC, 3%," and "SCC, 2.5%".[65] Present value computations for these estimates of the SCC use the discount rate upon which each estimate was based. These present values range from $1,877/hectare to $10,829/hectare of estuarine emergent marsh, with the total value for the 8,451 hectares in the estuary ranging from $15.9 million to $91.5 million.

The fourth set of published SCC values differs significantly from the other three. These values capture the potential for low-probability, high-impact outcomes from climate change and correspond to the 95th percentile of the frequency distribution of SCC estimates using a 3 percent discount rate. The present value associated with this set of SCC values is $21,518/hectare with a total value for the estuary's 8,451 hectares of $181.8 million.

The broad range in these present value estimates is in part due to uncertainty about future economic conditions (reflected in differing discount rates) and the appropriate level of risk-taking with regard to climate policy (reflected in the set of SCC values associated with low-probability, high-impact outcomes).

Prices from the Regional Greenhouse Gas Initiative (RGGI) and Western Climate Initiative (WCI) carbon markets were also applied (with a 3% discount rate) to the future stream of carbon releases associated with the loss of one hectare of saltmarsh in the San Pablo Bay estuary. In almost all scenarios, the cost of purchasing the right to release this stream of carbon is much less than the social cost of the released carbon. Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon equals the SCC. Prices from these two carbon markets result in values that range from $740 per hectare to $2,083 per hectare with totals for the 8,451 hectares of salt marsh in the study area ranging from $6.3 million to $17.6 million. The results of these computations are shown in Table X-5.

Table X-5. Blue Carbon Values for San Pablo Bay Estuary 2020-2049 (Nominal/Net Present Value)

Annual Value	Carbon Released (t CO_2e/ha)	Value of Released Carbon					
		RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	14.3	$87.07	$245.00	$200.82	$731.54	$1,090.14	$2,180.29
2021	13.1	$79.41	$223.44	$196.23	$680.25	$1,020.37	$2,027.67
2022	11.9	$72.42	$203.77	$178.96	$632.32	$942.51	$1,896.96
2023	10.9	$66.05	$185.84	$174.09	$587.56	$870.45	$1,762.67
2024	9.9	$60.23	$169.49	$158.77	$545.77	$813.70	$1,647.24
2025	9.0	$54.93	$154.57	$153.85	$506.80	$751.14	$1,529.44
2026	8.3	$50.10	$140.97	$140.31	$470.45	$693.30	$1,427.86
2027	7.5	$45.69	$128.56	$135.49	$444.11	$647.34	$1,324.79
2028	6.9	$41.67	$117.25	$123.57	$411.89	$597.24	$1,235.67
2029	6.3	$38.00	$106.93	$118.95	$381.90	$550.94	$1,145.71
2030	5.7	$34.66	$97.52	$108.49	$354.01	$508.17	$1,067.73
2031	5.2	$31.61	$88.94	$104.15	$328.06	$473.87	$994.60
2032	4.7	$28.83	$81.11	$99.73	$303.94	$436.91	$921.32
2033	4.3	$26.29	$73.98	$90.95	$281.52	$407.13	$857.57
2034	4.0	$23.98	$67.47	$86.90	$260.70	$375.25	$797.90
2035	3.6	$21.87	$61.53	$79.25	$241.36	$345.83	$742.10
2036	3.3	$19.94	$56.11	$75.56	$226.69	$321.97	$689.93
2037	3.0	$18.19	$51.18	$68.91	$209.74	$296.63	$638.21
2038	2.7	$16.59	$46.67	$65.58	$194.02	$273.26	$592.98
2039	2.5	$15.13	$42.57	$62.30	$179.43	$254.20	$550.76
2040	2.3	$13.80	$38.82	$56.82	$165.92	$234.10	$511.39
2041	2.1	$12.58	$35.40	$53.89	$153.39	$215.57	$472.60
2042	1.9	$11.47	$32.29	$49.15	$141.78	$200.38	$438.58
2043	1.7	$10.47	$29.45	$46.55	$132.75	$184.47	$405.15
2044	1.6	$9.54	$26.86	$44.03	$122.64	$169.81	$375.79
2045	1.4	$8.70	$24.49	$40.15	$113.28	$157.74	$347.02
2046	1.3	$7.94	$22.34	$37.93	$104.62	$145.16	$321.71
2047	1.2	$7.24	$20.37	$35.78	$96.61	$133.58	$296.98
2048	1.1	$6.60	$18.58	$32.63	$89.19	$124.00	$275.20
2049	1.0	$6.02	$16.94	$30.75	$83.33	$114.08	$253.96

Table X-5. Blue Carbon Values for San Pablo Bay Estuary 2020-2049 (Nominal/Net Present Value) (cont'd)

Discounted Value	**0.03**	**0.03**	**0.05**	**0.03**	**0.025**	**0.03**
2020	$87.07	$245.00	$200.82	$731.54	$1,090.14	$2,180.29
2021	$77.09	$216.93	$186.88	$660.44	$995.49	$1,968.61
2022	$68.26	$192.08	$162.32	$596.02	$897.10	$1,788.06
2023	$60.44	$170.07	$150.39	$537.70	$808.30	$1,613.09
2024	$53.52	$150.59	$130.62	$484.91	$737.17	$1,463.55
2025	$47.39	$133.34	$120.54	$437.17	$663.90	$1,319.30
2026	$41.96	$118.06	$104.70	$394.00	$597.83	$1,195.81
2027	$37.15	$104.53	$96.29	$361.10	$544.58	$1,077.17
2028	$32.89	$92.56	$83.63	$325.15	$490.18	$975.45
2029	$29.13	$81.96	$76.68	$292.70	$441.16	$878.09
2030	$25.79	$72.57	$66.60	$263.41	$396.98	$794.49
2031	$22.83	$64.25	$60.89	$237.00	$361.15	$718.52
2032	$20.22	$56.89	$55.53	$213.18	$324.87	$646.19
2033	$17.90	$50.37	$48.23	$191.70	$295.34	$583.96
2034	$15.85	$44.60	$43.89	$172.35	$265.58	$527.51
2035	$14.04	$39.49	$38.12	$154.92	$238.78	$476.32
2036	$12.43	$34.97	$34.62	$141.27	$216.89	$429.94
2037	$11.00	$30.96	$30.07	$126.90	$194.94	$386.13
2038	$9.74	$27.42	$27.25	$113.96	$175.21	$348.31
2039	$8.63	$24.27	$24.66	$102.33	$159.01	$314.09
2040	$7.64	$21.49	$21.42	$91.86	$142.87	$283.14
2041	$6.76	$19.03	$19.34	$82.45	$128.35	$254.05
2042	$5.99	$16.85	$16.80	$73.99	$116.40	$228.89
2043	$5.30	$14.92	$15.16	$67.26	$104.54	$205.29
2044	$4.70	$13.21	$13.65	$60.33	$93.89	$184.86
2045	$4.16	$11.70	$11.86	$54.11	$85.08	$165.74
2046	$3.68	$10.36	$10.67	$48.51	$76.39	$149.18
2047	$3.26	$9.17	$9.58	$43.49	$68.58	$133.70
2048	$2.89	$8.12	$8.32	$38.98	$62.11	$120.28
2049	$2.56	$7.19	$7.47	$35.36	$55.75	$107.77
Present Value, 30 years	**$740.25**	**$2,082.95**	**$1,877.01**	**$7,134.10**	**$10,828.55**	**$21,517.79**

ESTUARY SUMMARY

Restoration Efforts

The area around San Pablo Bay is the site of multiple restoration projects. The NOAA Restoration Atlas notes 52 completed projects through early 2021, covering 1,775 hectares (4,386 acres). The California EcoAtlas notes 103 completed projects. These projects are located throughout the San Pablo Bay on both the northern and southern shores, including that portion of Marin County in the lower San Pablo Hydrologic Unit. (Figure X-6)

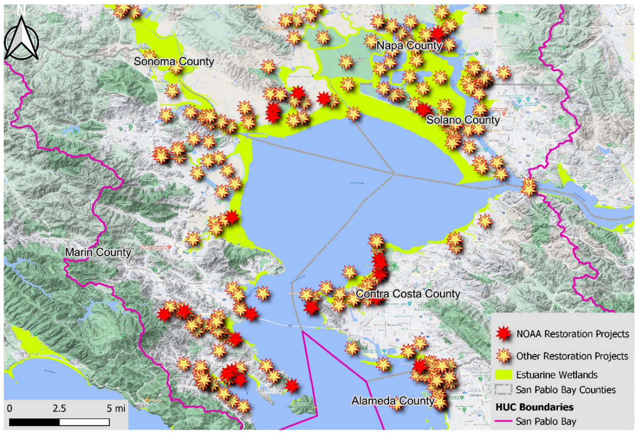


Figure X-6. Restoration Projects in San Pablo Bay

The projects listed in the NOAA Restoration Atlas include a variety of restoration approaches; projects related to tidal wetlands comprise 40% (21 projects of the total) but almost 95% of the area of the restoration projects (See Table X-6). Similar detail is not available for the projects listed in the California Eco Atlas. But this source does show that in addition to the 103 completed restoration projects, there are 70 projects underway in April 2021, two in the permitting phase, and 124 either proposed or in the planning phase. This makes for nearly 300 restoration projects in the San Pablo Bay area.

Table X-6 NOAA Restoration Projects in San Pablo Bay

	Number of Projects	Hectares
Beach	1	0
Beach, Rocky Shoreline, Tidal Wetland	1	0.0
Beach, Tidal Wetland	1	4.5
Dune	1	8.9
Freshwater Wetland	1	0.0
Freshwater Wetland, Upland	1	37.2
In-Stream	4	2.3
In-Stream, Riparian Zone (Non-Wetland)	1	0.6
Oyster Reef/Shell Bottom	3	0.0
Oyster Reef/Shell Bottom, Softbottom Mud/Sand	1	0.8
Oyster Reef/Shell Bottom, Submerged Aquatic Vegetation	2	16.6
Oyster Reef/Shell Bottom, Tidal Wetland	1	16.6
Oyster Reef/Shell Bottom, Tidal Wetland, Water Column	1	2.4
Riparian Zone (Non-Wetland)	2	2.1
Rocky Shoreline	1	0.0
Softbottom Mud/Sand, Submerged Aquatic Vegetation	1	2.4
Submerged Aquatic Vegetation	4	3.9
Temp - (Same As Previous Habitat), Tidal Wetland	1	0.0
Tidal Wetland	18	1675.1
Upland	1	1.5
Not Available	5	0.0
Total	52	1775.0

Natural Infrastructure and Coastal Blue Carbon Benefits

The natural infrastructure benefits for San Pablo Bay in terms of flood reduction can range from $15.4 million to $34.4 million over a 30-year period[66] for a flood that historically would occur once in 100 years. Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $30.0 million and $68.8 million. These values are for damages to property exposed to flooding and do not include the damages to business sales or employment, nor the value of possible losses from effects on human health. These damage estimates should thus be considered conservative, that is likely to be low.

The value of coastal blue carbon benefits ranges from $1,877/hectare to $10,829/hectare using various discount rates. The total value for the 8,451 hectares in the estuary under the three more likely SCC scenarios ranges from $15.9 million to $91.5 million. The low-probability, high-impact climate outcome scenario resulted in a coastal blue carbon value of $181.8 million.

The broad range in these benefit estimates is due to several factors:

- variation in the "wetlands effect" arising from differences in the precise location, and quantity of wetlands between the valued assets and the water,
- uncertainty about future economic conditions (reflected in differing discount rates in the coastal blue carbon analysis), and
- assumptions about the increasing severity of storms due to climate change.

Comparing the natural infrastructure benefits with the coastal blue carbon benefits results in some interesting observations. San Pablo Bay is essentially an urban estuary, surrounded by one of the largest metropolitan areas in the country. Relatively small areas of remaining wetlands provide somewhat similar infrastructure and coastal blue carbon benefits, as measured by this analysis. The values of urban assets protected by coastal habitats can be large if the assets are fronted by wetlands. In San Pablo Bay, however, much of the economic assets are located right along the shoreline, and the wetlands are mostly located in areas that do not front development (See Figure X-3). San Pablo Bay hosts only 8,451 ha (3,420 acres) of saltmarsh, which results in lower blue carbon values than other estuaries studied in this series of assessments, though expansive non-tidal wetlands add additional carbon benefits. Maintaining and protecting those values is an important consideration in the planning and siting of future restoration projects.

Table X-7 summarizes the range of benefits from natural infrastructure and coastal blue carbon determined by this analysis. The table also includes the combination of the two ecosystem service values that were analyzed in this report. The analysis includes all areas of wetlands within the study area that provide one service or the other, as well as areas that provide both services. Because the two benefits provide complementary services, presenting a total value is appropriate. Combined, the natural infrastructure and coastal blue carbon benefits range from $31.3 to $160.2 million. In terms of total value, blue carbon values in San Pablo Bay are greater than those provided by natural infrastructure, likely due to the large expanses of conserved and restored wetlands on the northern and western shores.

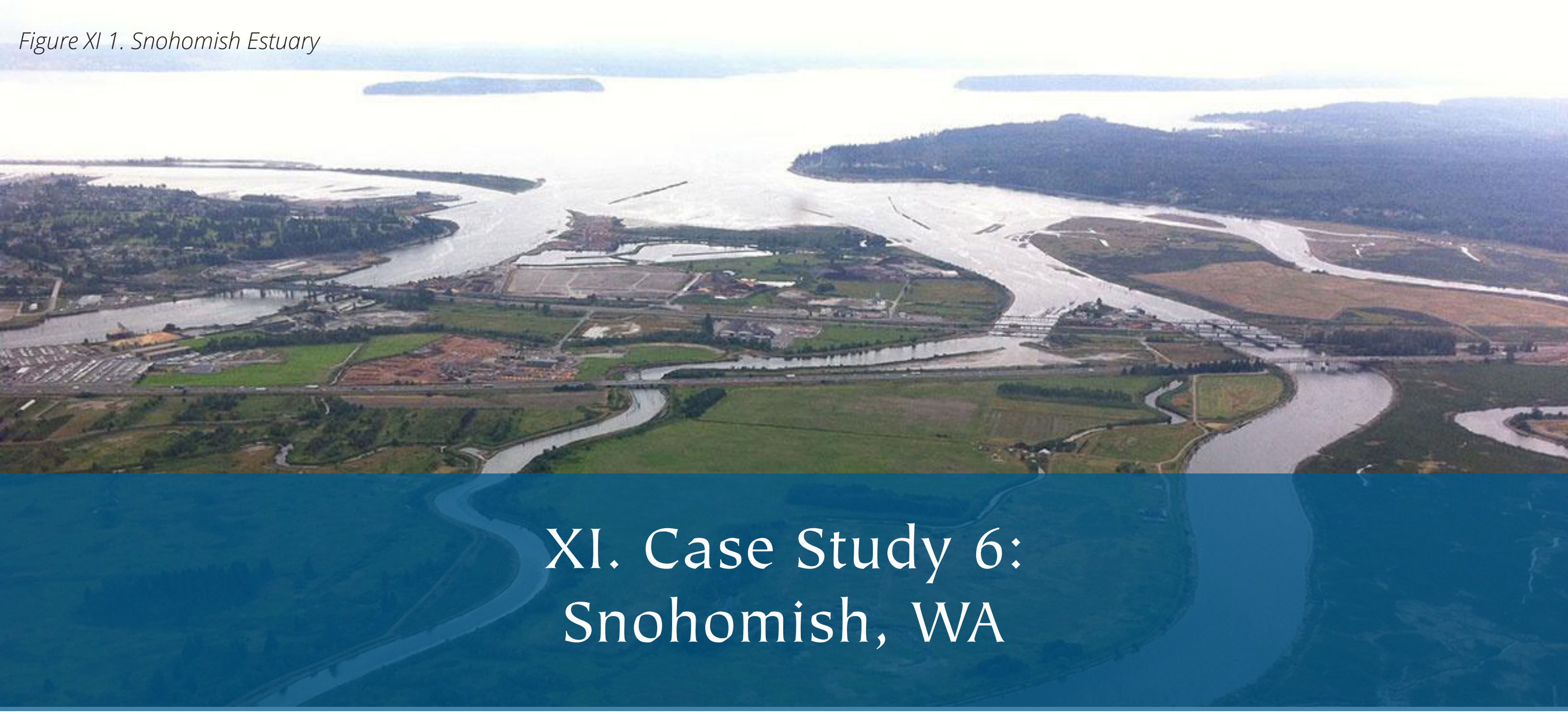
Table X-7. Natural Infrastructure and Coastal Blue Carbon Benefits Summary

San Pablo Bay	Total hectares in analysis	Estimated benefits per hectare of wetlands ($Thousands)		Total Estimated Benefits ($Millions)	
		Low estimate	High estimate	Low estimate	High Estimate
Natural Infrastructure	29,872	$.5	$2.3	$15.4	$68.7
Coastal Blue Carbon[67]	8,451	$1.9	$10.8	$15.9	$91.5
Total				**$31.3**	**$160.2**

Those values exist now, and should be recognized and maintained. In terms of increasing value in the estuary over time, the benefits per hectare is highest for coastal blue carbon, and conserving or restoring wetlands to continue to increase these benefits will provide the greatest addition to the existing value.

These estimates must be considered very preliminary and are intended to be helpful in shaping overall strategies for the future management of the wetlands resources of San Pablo Bay, strategies that account for both local goals of a healthy estuary and global goals of mitigation of climate change. They are part of a broader attempt to begin to characterize general estuary characteristics that offer different sources of economic value to local communities, such as protection from storms and flooding, and help meet broader societal goals, such as mitigation for climate change. As part of an examination of estuaries across the nation, they are not intended to guide project-level decisions, or replace more localized "deep dives" that have been conducted in these estuaries. There are still many unknowns that require much more elaborate estimation procedures for both natural infrastructure and coastal blue carbon. Whether the actual benefits in the future will tend towards the lower or higher end of these estimates will require continued research and ongoing assessment. But it is certain that the realization of these benefits will depend first on conserving the wetlands that exist and then on the restoration of wetlands that could increase these benefits.

Figure XI 1. Snohomish Estuary



XI. Case Study 6: Snohomish, WA

THE SNOHOMISH ESTUARY

Snohomish County is the 3rd largest county in Washington, with a population of 822,000. It lies on the eastern shore of Puget Sound and is just north of Seattle and King County. The largest city is Everett, with a population of 111,000. Most of the county is within the Seattle metropolitan area. The shoreline bordering Puget Sound extends approximately 70 km (43 miles).

The Snohomish Estuary lies near Everett, Washington just north of Seattle at the confluence of the Snohomish River and Possession Sound (See Figure XI-1). The Snohomish, Skykomish, and Snoqualmie Rivers and their tributaries conjoin to form the Snohomish basin and span approximately 1,856 square miles, forming the second largest estuary in Puget Sound. Historically, the estuary consisted of a suite of forested wetlands, scrub-shrub wetlands, and emergent tidal wetland.[1] However, human development, and associated clearing and draining of these wetland habitats, drastically changed the landscape over time. The modern Snohomish Estuary includes significant agricultural lands, comprising approximately 5% of the basin and dominating the floodplains of the Snohomish, as well as palustrine wetlands, and a small area of planted forest.[2,3] It also encompasses some remnant emergent and forested wetlands, large-scale regenerating wetlands (Smith Island and Ebey Island), and drained wetland regions.[4]

The Snohomish Estuary provides critically important spawning and rearing habitat for salmon, steelhead, and trout and is one of the most productive systems in Puget Sound. Eelgrass beds in the Snohomish Estuary are some of the most extensive in Puget Sound and provide critical habitat for waterfowl, a food-base for fish and shellfish, and shelter for marine wildlife including salmon[5]. The region is biologically diverse with the area providing habitat to over 350 different species of birds, mammals, plants, and fish including blue heron, eagles, and osprey. Nine species of salmonids depend on the river system: Chinook, coho, chum, sockeye, pink, steelhead, and cutthroat, rainbow, and bull trout all utilize the estuary at some point in their life cycle.[6] Chinook salmon was listed as threatened on the Endangered Species Act (ESA) in 1999 by NOAA, the U.S. Fish and Wildlife Service added bull trout to the list as threatened in the same year, and coho salmon have since been listed as a species of concern under the ESA.[7]

These listings prompted the development of a regional recovery plan and the Ecological Analysis for Salmonid Conservation (2004) identified Chinook salmon (*Oncorhynchus tshawytscha*), bull trout char (*Salvelinus confluentus*), and coho salmon (*Oncorhynchus kisutch*) as indicator species to represent the status of all anadromous salmonids in the Snohomish River Basin based on their diverse habitat requirements and occupation of the full geographic range of the basin. Two distinct, naturally spawning Chinook salmon populations co-exist in the Snohomish Estuary, the Skykomish Chinook and the Snoqualmie Chinook, and both populations are estimated at less than 10% of their historic population size.[8] This decline has been attributed to loss and destruction of salmon rearing habitat along main streams, within the estuary, and the nearshore environment.[9] While the Snohomish Estuary has sufficient high-quality spawning habitat to support returning adults, juvenile rearing habitat has been significantly limited by disconnected floodplain habitat.[10] Since the mid-1800s, early European settlers harvested timber, ditched tributaries, diked, and drained thousands of acres of delta habitat. Restoring habitat connectivity has been a major focus of conservation efforts, and in recent years the salmon population has been slowly increasing in numbers due to restoration efforts focusing on levee removal.

Socioeconomic/Cultural Status

Snohomish County has three major geographic and economic areas. The city of Everett and its suburbs is the largest part of the county economy, with the Boeing fabrication facilities for larger aircraft located in the city. There are many firms supplying goods and services to Boeing in the Everett area. The economic activity along the shorelines of Everett makes up nearly one third of the county economy, but only two percent of population and housing. Snohomish County hosts the fifth largest port on the West Coast in export value, the highest percentage of jobs tied to international trade which comprise 60% of the workforce, and a manufacturing hub with the largest concentration of jobs in the western United States.[11] As is typical of much of the urban coast of the U.S. employment is concentrated near the shoreline and population spreads out inland. The upper parts of the Snohomish watershed are an evolving mix of suburbs, agriculture, and forests.

Stretching north and east from Everett are large agricultural areas covering the river plains leading up to the mountains and forests that make up the eastern one third of the county. The northern part of the county is primarily agricultural land with the small city of Stanwood at the mouth of the Stillaguamish acting as a service center for the Port Susan Bay area and a connection to Camano Island and Island County. In 2019, the U.S. Census Bureau reported a population of 822,083 people for Snohomish County,[12] an increase of 18% since 2009. Of that population, 77% of the population was white, 12% Asian, 10.6% Latino, 3.8% Black, and 1.6% Native American or Alaskan Native.[13] The median household income is $82,751 and 7.5% of the population is estimated to be in poverty.[14]

There are three federally recognized Native American tribes in Snohomish County: the Sauk-Suiattle, the Stillaguamish, and the Tulalip.[15] The Tulalip Tribe, in particular, plays an important role in the resource use and management of the Snohomish Estuary. In 2013, the Tulalip Tribe and Snohomish County adopted a Memorandum of Understanding to agree to coordinated long-range planning and information sharing.[16] As such, the Tulalip Tribe co-manage salmon, and other wildlife resources, within the Snohomish Estuary.[17]

Industrialization was rapid in nearby Everett from the late 1800s through the 1900s. By 1912 the city claimed 10 sawmills, 12 shingle mills, a smelter, an arsenic plant, and 95 manufacturing plants.[18] Diking began in the Snohomish Estuary in the 1860's as the forestry and farming industries expanded into the region.[19] The creation of dikes and levees, deforestation, and urbanization of the land around the estuary dramatically changed how the ecosystem functioned and disconnected approximately 90% of the estuary from tidal influence (ESRP, 2020). Early industrialization also brought significant pollution to the estuary which has persisted to this day. Byproducts of pulp and paper mills infused carcinogens and sediments into the water. Over thirty years of environmental monitoring started in the 1980's revealed high levels of metals (arsenic, mercury, zinc, copper, lead), polycyclic aromatic hydrocarbons (PAHs), semivolatile organic compounds (SVOCs) including phenol, total polychlorinated biphenyls (PCBs), and Polybrominated diphenyl ethers (PBDEs) in the water which depress fish reproduction and transfer to other organisms through the trophic cycle.[20] Additionally, bacterial contaminants leaking from faulty septic systems, pet waste, agricultural and storm water runoff compound the water quality issues in the estuary.[21]

In addition to local anthropogenic impacts, global climate change also threatens the Snohomish Estuary. The State of the Knowledge of Climate Change in Puget Sound (2015) report[22] identified the following major local impacts and vulnerabilities from climate change: Dramatic decreases in snowpack will completely alter the hydrologic regime of the region. Changes to river flow timing and magnitude threatens salmon runs and agricultural viability. Increased average annual temperatures will impact the economy and flood production through elevated stream temperatures, introduction of new plant diseases and pests, and reduced water flows for irrigation, municipal use, and salmon populations. Sea level rise and ocean acidification are readily impacting tidal marshes, floodplains, groundwater levels, and wells that supply water to some neighborhoods.[23] Flooding, high sediment loads, and increasing water temperatures also specifically threaten the salmon populations in the Snohomish Estuary.[24]

VALUE OF NATURAL INFRASTRUCTURE IN THE SNOHOMISH ESTUARY

NOAA defines natural infrastructure as "healthy ecosystems, including forests, wetlands, floodplains, dune systems, and reefs, which provide multiple benefits to communities, including storm protection through wave attenuation or flood storage capacity and enhanced water services and security."[25] An estuary's capacity to protect shoreline property from climate hazards and flood risk is an important ecosystem service. The measurement of this service is, however, complex. The value depends on how often and how severe floods will be. It depends on the value of the economic assets vulnerable to floods of different sizes and types. And it depends on the extent of lost economic activity, as well as the issue of disproportionate effects on populations which may not have the capacity to recover from flood events.

The analysis in this section uses a method that focuses on damages to real property from flooding that might be reduced by the presence of estuarine wetlands adjacent to the property. It is a very simplified perspective that is designed to raise awareness of natural infrastructure benefits as a prelude to incorporating these values into planning for the future of estuaries using more complete information. More detail on the methodology is available in Section IV of the main report.

The analysis for the Snohomish Estuary shows that these benefits can range from $0.7 million to $1.7 million over a 30-year period for a flood that historically would occur once in 100 years. Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $1.5 million and $3.4 million (Table XI-1). These values are for damages to property exposed to flooding and do not include the damages to business sales or employment, nor the value of possible losses from effects on human health. These damage estimates should thus be considered conservative, that is likely to be lower than actual values.

Table XI-1 Summary of Findings: Snohomish Estuary Natural Infrastructure Benefits

			1% Annual Probability Storm Benefits (Millions)		2% Annual Probability Storm Benefits (Millions)	
Area (Ha) of Estuarine and Marine Wetlands Offering Protective Benefits	Number of wetlands-adjacent parcels in 100 Year Flood Zone	Values at Risk (Millions)	Wetland Effect Low (10%)	Wetland Effect High (20%)	Wetland Effect Low (10%)	Wetland Effect High (20%)
906	**243**	**$132.4**	**$0.7**	**$1.7**	**$1.5**	**$3.4**

The natural infrastructure benefits in the Snohomish Estuary are to be found primarily in the lower part of the estuary near the mouth of the river. There estuarine and marine wetlands lie adjacent to parts of the cities of Everett, Marysville, and the Tulalip Reservation. This area is shown in Figure XI-2, which shows the location of the estuarine wetlands as indicated by the National Wetlands Inventory from the U.S. Fish & Wildlife Service.[26] This class of wetlands and the FEMA-designated 100- year flood zone, that is the area which has a historical probability of being flooded of 1% each year are shown in Figure XI-2. In Figure XI-3, the parcels located in the 100-year flood zone are added to the map. Parcels from the county tax records were selected based on their location within the 100-year flood zone[27] and adjacent to estuarine wetlands as defined by the National Wetlands Inventory.[28] This spatial analysis results in the identification of 906 hectares (2,238 acres) of wetlands offering protection to 243 parcels which intersect with the selected wetlands. The parcel data was drawn from the Snohomish County Assessor's database.

Wetlands can reduce the damage from coastal or river flooding by absorbing and slowing runoff, stabilizing riverbanks and coastlines, dissipating wave energy, and serving as a physical barrier. The benefits can be measured as the reduction in flood damages resulting from the presence of the wetlands and is a function of the location of vulnerable economic assets (e.g., buildings and land), the frequency and severity of floods, the likely extent of damages, and the possible reductions in those damages resulting from the presence of the wetlands. The exact extent of the damage that determines benefits cannot, of course, be known with precision in advance so estimates and assumptions must be used. These assumptions and the calculations used to estimate benefits are explained in the accompanying technical report.

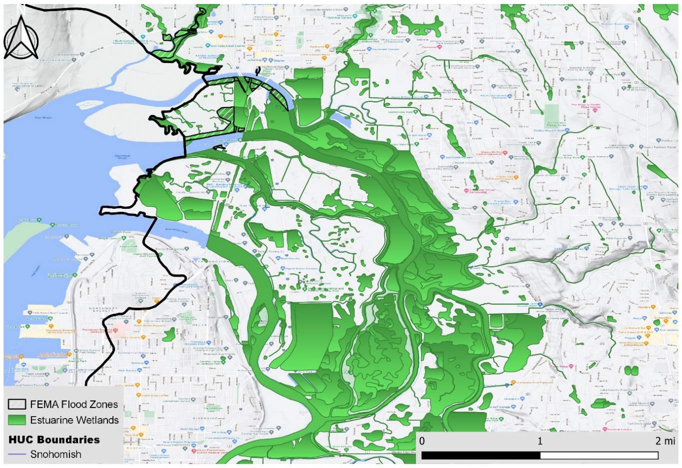


Figure XI-2. Snohomish Estuarine Wetlands and Flood Zone Parcels

Flood damage reductions depend on the frequency and severity of flooding. A measure that combines frequency and severity is the 100-year flood zone designated by FEMA for purposes of administering the National Flood Insurance Program. This zone identifies the area affected by a flood that has a 1% chance of occurring each year. For this analysis, an alternate scenario is used to examine the effects of climate change, one of which is an increase the frequency of severe storm events. To reflect estimation of benefits related to a changing climate, we assumed the 100-year storm becomes the 50-year storm, which means the annual probability of a storm at least this severe doubles from 1% to 2%.

To calculate the protective benefits of wetlands, we estimated the total likely damages to property from a 100-year flood first. These damages were estimated by applying flood damage factors for land and buildings to the assessed values of the property; buildings were assumed to be subject to twice the damages of land. These estimated damages were multiplied by the probability of a flood occurring over a 30-year period. For the 1% annual probability, the *cumulative* probability of a flood over 30 years is 26%. For the 2% annual probability the cumulative probability is 45%. The result is the total expected flood damage over 30 years. Since any flood damages will occur in the future, the value of the expected damages is discounted over the 30-year time period and the results are presented in $2020, or the present value. These expected damages are the basis for calculating the reductions in flood damages that may be attributable to wetlands as described above.

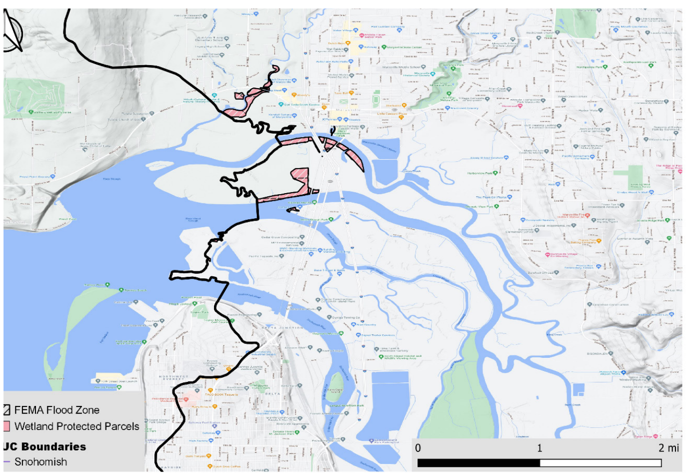


Figure XI-3. Snohomish Estuary Wetlands and Adjacent Parcels

The extent to which wetlands can reduce flood damages is highly variable depending greatly on the type and extent of wetlands at any given location. For purposes of this analysis the "wetlands effect" is the reduction in the dollar value of likely damages from a 100-year flood that may be attributable to the presence of wetlands—expressed as a percentage of damages. A range of 10% to 20% reduction is used based on studies of wetlands damage reductions from an actual storm on the Atlantic coast.[29] This estimate of the possible effects of wetland on reducing flood damages was made using a storm with a level of storm surge-induced flooding that is unlikely to occur within Puget Sound. Therefore, the most likely benefits will be at the lower end of the range estimated.

Table XI-2 provides the results of the analysis for the area as a whole and for the municipalities affected.[30] The table shows the market values of land and buildings plus the total market value by parcel as estimated by the Assessor. Across the area examined, the bulk of the assessed values are in land rather than buildings. Twenty percent of the parcels are vacant land; the rest have improvements (buildings). The large proportion of land value reflects the fact that all the parcels are, by definition, adjacent to the shoreline. The largest number of parcels affected is in Marysville, with 127 parcels.

Table XI-2 Snohomish Estuary Natural Infrastructure Benefits by Municipality

					1% Annual Probability Storm Benefits (Millions)		**2% Annual Probability Storm Benefits (Millions)**	
Municipality	Parcels	Buildings Value (Millions)	Land Value (Millions)	Total Value (Millions)	Wetland Effect Low (10%)	Wetland Effect High (20%)	Wetland Effect Low (10%)	Wetland Effect High (20%)
Everett	10	$7.81	$35.97	$43.79	$0.26	$0.58	$0.52	$1.16
Marysville	127	$9.39	$12.93	$22.33	$0.17	$0.38	$0.34	$0.76
Tulalip	18	$0.39	$35.41	$35.80	$0.17	$0.38	$0.34	$0.76
Unknown	88	$0.90	$29.55	$30.45	$0.15	$0.33	$0.30	$0.67
TOTAL	**243**	**$18.50**	**$113.86**	**$113.86**	**$0.74**	**$1.68**	**$1.49**	**$3.35**

The estimated natural infrastructure benefits for the 100-year storm range in total from $0.7 million to $1.7 million. This is the present value of potential flood damages over a 30-year period.[31] The largest benefits accrue to the parcels in Everett. The estimated wetland benefits for Marysville and the Tulalip Reservation are approximately the same. This is despite the fact that the buildings value in Marysville is substantially higher than in the affected section of the Tulalip Reservation. The land value is much higher in the Tulalip parcels than those in Marysville. But in this analysis, buildings are assumed to be likely to endure much larger damages from flooding than land, so the benefits to Tulalip and Marysville reflect this difference in assumed damage extents.

Table XI-2 also shows the change in the level of flood benefits if severe flooding becomes more frequent, as explained above. The distribution among the municipalities remains the same, but the total wetlands benefits increase to between $1.5 million and $3.4 million present value over 30 years. This means that the range of wetlands benefits for the Snohomish Estuary ranges from a low of $0.7 million to $3.4 million.

VALUE OF BLUE CARBON IN THE SNOHOMISH ESTUARY

Over the past decades, as the relationship between greenhouse gases and climate change became clear, the scope of analyses for estuary conservation opportunities expanded to consider the role of coastal wetlands in the global carbon cycle. Coastal wetlands sequester vast amounts of the greenhouse gas carbon dioxide, and store that carbon in their soils. The carbon sequestered and stored in coastal estuaries is called coastal blue carbon.[32] Conserving and restoring estuaries rich in coastal blue carbon mitigates the impacts of climate change[33,34] and provides additional benefits that support local communities and can bolster local economies. These benefits include providing nursery habitat for fish[35], reducing the impact of storm surge,[36,37,38] and improving water quality.[39,40,41] Researchers estimating global coastal blue carbon emissions have observed the rapid disappearance of coastal wetlands due to human activity, despite federal and regional wetland protection and planning.[42]

In this case study, coastal blue carbon values are estimated by multiplying the stock of carbon in the "emergent estuarine" land cover class of each estuary by estimates of the social cost of carbon (SCC) published by the Interagency Working Group on Social Cost of Greenhouse Gases in February 2021.[43]

SCC is "a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO_2) emissions in a given year".[44] SCC can also represent the value of damages avoided for emission reductions (i.e., the benefit of a CO_2 reduction). Whether used to measure costs or benefits, SCC values include such wide-ranging effects as global changes in economic output, human health, property damages from increased flood risk, and the value of ecosystem services.

The economic effects of releasing carbon into the atmosphere continue long into the future and increase as the total concentration of atmospheric carbon increases. Annual SCC values for this study's twenty-year period of analysis were discounted to show their value in today's dollars (present value). Values were calculated for each of four SCC scenarios using different discount rates. The "high" and "low" coastal blue carbon values presented in this summary correspond to the use of a 2.5 percent and 5.0 percent discount rate, respectively.

Land cover in the Snohomish Estuary is diverse, with the western portion of the watershed dominated by urban land cover classes and large expanses of evergreen forest in the east (See Figure XI-4). Wetland classes appear along the mouth of the Snohomish River, with estuarine wetland (forested, scrub/shrub and emergent) dominant to the west of I-5 and palustrine wetland (forested, scrub/shrub and emergent) dominant to the east of I-5, with large areas of palustrine emergent wetland. It is worth noting that salinity levels are used to differentiate between estuarine and palustrine wetland; increasing salinity and sea levels associated with climate change are likely to result in significant changes to the amount and composition of wetlands in the Snohomish Estuary.

Carbon Profile

In 2016, the Snohomish study area contained 189 hectares (467 acres) of estuarine emergent vegetation (saltmarsh, see Figure XI-5). The Coastal Carbon Research Coordination Network (RCN) database contained data from 10 cores sampling the soil beneath estuarine emergent vegetation, with values ranging from 77 to 155 metric tons of carbon per hectare in the soil, with an average value of 113 metric tons per hectare. The depth of core samples ranges from 45 to 84 centimeters, averaging 62 centimeters.

These figures suggest that more than 21,000 tons of CO_2e[45] are stored in the soil beneath the study area's 189 hectares of estuarine emergent vegetation. This is equivalent to the annual emissions of approximately 4,500 cars.[46]

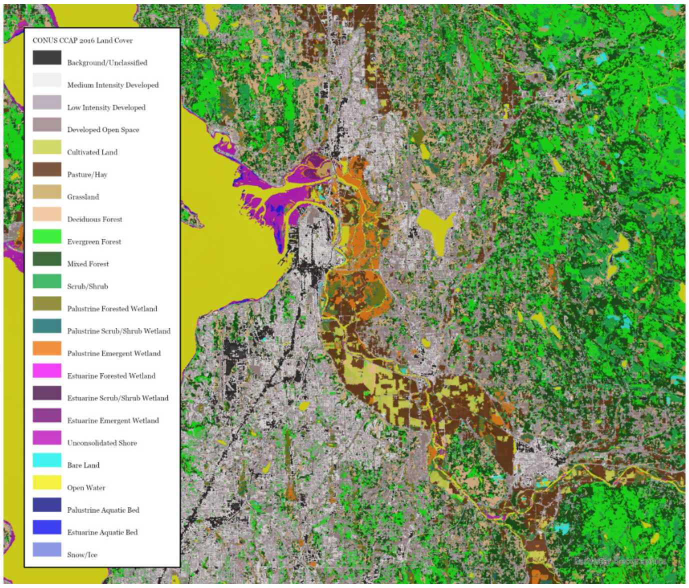


Figure XI-4. Map of vegetation types in Snohomish Estuary

The Value of Coastal Blue Carbon Stock Stored in Soil

Although carbon is also stored in the biomass of the plants and continues to be sequestered over time, data limitations allow only an analysis of the value of carbon that is stored in soil. The value of the blue carbon stock stored in the soil of the Snohomish Estuary's estuarine emergent wetland areas is estimated as the cost to society that would be incurred if the wetlands upper layers were disturbed or developed, and the carbon was released. These computations are described below. A more comprehensive assessment of the effects of wetland loss (and, thus, the value of conservation) would include the cessation of carbon sequestration and the emission of carbon stored in the biomass. However, sequestration rates and the amount of carbon stored in biomass vary significantly among sites, even within the same class of vegetation.[47] Reliable, site-specific estimates of carbon sequestration rates and the amount of carbon stored in biomass are not available for the Snohomish Estuary or the areas that are the subject of the other five case studies. For this reason, no attempt was made to estimate these values.

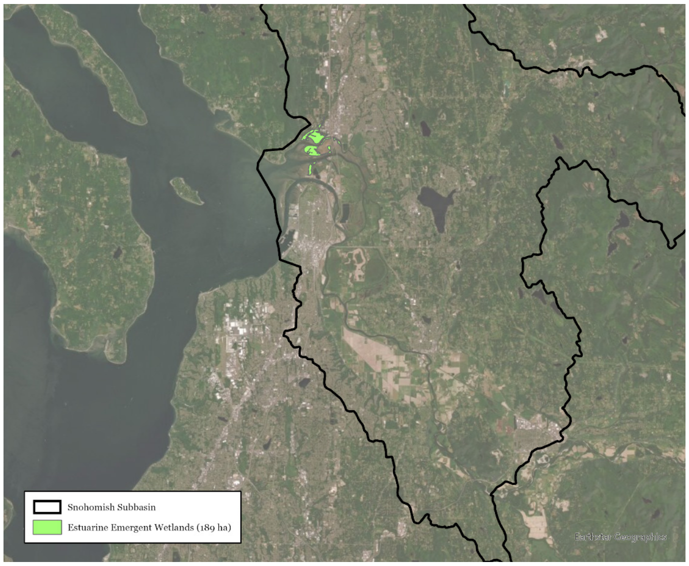


Figure XI-5. Estuarine Emergent Wetlands vegetation type in the Snohomish Estuary

The value of restoring estuarine emergent wetland arises from the restoration of carbon sequestration, which increases over time as the marsh matures. The data limitations described prevent the estimation of these values.

An exponential decay function with a half-life of 7.5 years was used to estimate the annual metric tons of carbon that would be released from soil when one hectare of estuarine emergent wetland is converted to another use.[48] The results of this analysis are shown in Table XI-3. In year 30, only 6 percent, or 7.1 metric tons, of the initial store of 113 tons of CO2e remain in the hectare of disturbed wetland soil.

Table XI-3 Annual Carbon Released from the Soil of Converted Estuarine Emergent Wetlands (metric tons per hectare)

Year	Carbon in Soil	Cumulative Carbon Release	Annual Carbon Release
2020	113.0	0.0	
2021	103.1	9.9	9.9
2022	94.0	19.0	9.1
2023	85.7	27.3	8.3
2024	78.2	34.8	7.5
2025	71.3	41.7	6.9
2026	65.0	48.0	6.3
2027	59.3	53.7	5.7
2028	54.1	58.9	5.2
2029	49.3	63.7	4.8
2030	45.0	68.0	4.3
2031	41.0	72.0	4.0
2032	37.4	75.6	3.6
2033	34.1	78.9	3.3
2034	31.1	81.9	3.0
2035	28.4	84.6	2.7
2036	25.9	87.1	2.5
2037	23.6	89.4	2.3
2038	21.5	91.5	2.1
2039	19.6	93.4	1.9
2040	17.9	95.1	1.7
2041	16.3	96.7	1.6
2042	14.9	98.1	1.4
2043	13.6	99.4	1.3
2044	12.4	100.6	1.2
2045	11.3	101.7	1.1
2046	10.3	102.7	1.0
2047	9.4	103.6	0.9
2048	8.6	104.4	0.8
2049	7.8	105.2	0.8
2050	7.1	105.9	0.7

SCC values are projected to increase over time, corresponding to increases in the concentration of atmospheric greenhouse gases. Annual SCC ($/metric ton) values in Table XI-4 were applied to annual carbon release values (metric tons) to calculate the annual social cost of the carbon that is released. For purposes of this computation, it was assumed that the wetland was converted in 2020. The initial carbon stock (Year 2020) is 113 metric tons per hectare. Table XI-3 shows that, in the first year after conversion, 9.9 metric tons of carbon would be released, 9.1 metric tons would be released in the second year, etc. The SCCs for 2020 (see Table XI-4) were applied to carbon releases during Year 1 (assuming the wetland was converted in 2020). SCC values for 2021 would be applied to carbon released during Year 2, etc. This yields the annual social cost of the carbon that would be released if the marsh were converted.

Table XI-4 Market Price of Carbon Credits and Interim (2021) Values of the Social Cost of Carbon (SCC) with Discount Rates

Year	2020 Dollars Per Ton of CO_2e					
	RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	$17	$6	$14	$51	$76	$152
2025	$17	$6	$17	$56	$83	$169
2030	$17	$6	$19	$62	$89	$187
2035	$17	$6	$22	$67	$96	$206
2040	$17	$6	$25	$73	$103	$225
2045	$17	$6	$28	$79	$110	$242
2050	$17	$6	$32	$85	$116	$260

This computation was performed for each of the four sets of published SCC values and each stream of annual costs was discounted to calculate its present value. Three of the four sets of published SCC values differ only with respect to the discount rates that are applied to future economic values; in Table XI-4, these values are shown in columns labeled "SCC, 5%," "SCC, 3%," and "SCC, 2.5%".[49] Present value computations for these estimates of the SCC use the discount rate upon which each estimate was based. These present values range from $1,301/hectare to $7,507/hectare. The total value for the 189 hectares in the estuary ranges from $246,000 to $1.4 million.

A fourth set of published SCC values differs significantly from the other three. These values capture the potential for low-probability, high-impact outcomes from climate change and correspond to the 95th percentile of the frequency distribution of SCC estimates using on a 3 percent discount rate. The present value associated with this set of SCC values is $14,917/hectare with a total value for the estuary's 189 hectares of $2.8 million.

The broad range in these present value estimates is in part due to uncertainty about future economic conditions (reflected in differing discount rates) and the appropriate level of risk-taking with regard to climate policy (reflected in SCC values associated with low-probability, high-impact outcomes).

Prices from the Regional Greenhouse Gas Initiative (RGGI) and Western Climate Initiative (WCI) carbon markets were also applied (with a 3% discount rate) to the future stream of carbon releases associated with the loss of one hectare of saltmarsh in Snohomish. In almost all scenarios, the cost of purchasing the right to release this stream of carbon is much less than the social cost of the released carbon. Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon equals the SCC. Prices from these two carbon markets result in values that range from $513 per hectare to $1,444 per hectare with totals for the 189 hectares of salt marsh in the study area ranging from $97,000 to $273,000. The results of these computations are shown in Table XI-5.

Table XI-5 Blue Carbon Values for Snohomish Estuary 2020-2049 (Nominal/Net Present Value)

Annual Value	Carbon Released (t CO2e/ ha)	Value of Released Carbon					
		RGGI	WCI	SCC, 5%	SCC, 3%	SCC, 2.5%	SCC, High Impact
2020	9.9	$60.36	$169.84	$139.22	$507.14	$755.74	$1,511.49
2021	9.1	$55.05	$154.90	$136.03	$471.58	$707.38	$1,405.68
2022	8.3	$50.20	$141.27	$124.06	$438.36	$653.40	$1,315.07
2023	7.5	$45.79	$128.83	$120.69	$407.32	$603.44	$1,221.97
2024	6.9	$41.76	$117.50	$110.07	$378.36	$564.10	$1,141.95
2025	6.3	$38.08	$107.16	$106.66	$351.34	$520.73	$1,060.28
2026	5.7	$34.73	$97.73	$97.27	$326.14	$480.63	$989.87
2027	5.2	$31.67	$89.13	$93.93	$307.88	$448.77	$918.41
2028	4.8	$28.89	$81.28	$85.66	$285.54	$414.04	$856.63
2029	4.3	$26.35	$74.13	$82.46	$264.76	$381.94	$794.27
2030	4.0	$24.03	$67.61	$75.21	$245.42	$352.29	$740.20
2031	3.6	$21.91	$61.66	$72.20	$227.43	$328.51	$689.51
2032	3.3	$19.98	$56.23	$69.14	$210.71	$302.89	$638.71
2033	3.0	$18.23	$51.28	$63.05	$195.17	$282.24	$594.51
2034	2.7	$16.62	$46.77	$60.24	$180.73	$260.14	$553.15
2035	2.5	$15.16	$42.66	$54.94	$167.32	$239.75	$514.46
2036	2.3	$13.83	$38.90	$52.38	$157.15	$223.21	$478.30
2037	2.1	$12.61	$35.48	$47.78	$145.40	$205.64	$442.44
2038	1.9	$11.50	$32.36	$45.47	$134.50	$189.44	$411.08
2039	1.7	$10.49	$29.51	$43.19	$124.39	$176.22	$381.82
2040	1.6	$9.56	$26.91	$39.39	$115.02	$162.29	$354.52
2041	1.4	$8.72	$24.54	$37.36	$106.34	$149.45	$327.63
2042	1.3	$7.95	$22.38	$34.07	$98.29	$138.92	$304.04
2043	1.2	$7.25	$20.41	$32.27	$92.03	$127.89	$280.87
2044	1.1	$6.62	$18.62	$30.52	$85.02	$117.72	$260.52
2045	1.0	$6.03	$16.98	$27.83	$78.53	$109.35	$240.57
2046	0.9	$5.50	$15.49	$26.29	$72.53	$100.64	$223.03
2047	0.8	$5.02	$14.12	$24.81	$66.97	$92.61	$205.88
2048	0.8	$4.58	$12.88	$22.62	$61.83	$85.96	$190.78
2049	0.7	$4.17	$11.75	$21.32	$57.77	$79.09	$176.06

Table XI-5 Blue Carbon Values for Snohomish Estuary 2020-2049 (Nominal/Net Present Value) **(cont'd)**

Discounted Value	0.03	0.03	0.05	0.03	0.025	0.03
2020	$60.36	$169.84	$139.22	$507.14	$755.74	$1,511.49
2021	$53.45	$150.39	$129.56	$457.85	$690.12	$1,364.74
2022	$47.32	$133.16	$112.53	$413.19	$621.91	$1,239.58
2023	$41.90	$117.90	$104.26	$372.76	$560.36	$1,118.28
2024	$37.10	$104.39	$90.55	$336.17	$511.04	$1,014.61
2025	$32.85	$92.44	$83.57	$303.07	$460.25	$914.61
2026	$29.09	$81.85	$72.58	$273.14	$414.44	$829.00
2027	$25.75	$72.47	$66.75	$250.33	$377.53	$746.75
2028	$22.80	$64.17	$57.98	$225.41	$339.82	$676.23
2029	$20.19	$56.82	$53.16	$202.91	$305.83	$608.74
2030	$17.88	$50.31	$46.17	$182.61	$275.21	$550.78
2031	$15.83	$44.54	$42.21	$164.30	$250.37	$498.11
2032	$14.02	$39.44	$38.50	$147.79	$225.22	$447.98
2033	$12.41	$34.92	$33.44	$132.90	$204.74	$404.83
2034	$10.99	$30.92	$30.43	$119.48	$184.11	$365.70
2035	$9.73	$27.38	$26.43	$107.40	$165.54	$330.21
2036	$8.62	$24.24	$24.00	$97.93	$150.36	$298.06
2037	$7.63	$21.46	$20.84	$87.97	$135.15	$267.68
2038	$6.75	$19.01	$18.89	$79.01	$121.46	$241.47
2039	$5.98	$16.83	$17.09	$70.94	$110.23	$217.74
2040	$5.30	$14.90	$14.85	$63.68	$99.04	$196.29
2041	$4.69	$13.19	$13.41	$57.16	$88.98	$176.12
2042	$4.15	$11.68	$11.65	$51.30	$80.69	$158.68
2043	$3.68	$10.34	$10.51	$46.63	$72.47	$142.32
2044	$3.25	$9.16	$9.46	$41.83	$65.09	$128.16
2045	$2.88	$8.11	$8.22	$37.51	$58.98	$114.90
2046	$2.55	$7.18	$7.39	$33.63	$52.96	$103.42
2047	$2.26	$6.36	$6.64	$30.15	$47.54	$92.69
2048	$2.00	$5.63	$5.77	$27.03	$43.06	$83.39
2049	$1.77	$4.98	$5.18	$24.51	$38.65	$74.71
Present Value, 30 years	**$513.18**	**$1,444.01**	**$1,301.24**	**$4,945.73**	**$7,506.91**	**$14,917.24**

ESTUARY SUMMARY

Restoration Efforts

Snohomish County and the Snohomish Estuary are part of a large network of estuaries that link the rivers flowing from the Olympic Mountains to the west and the Cascades to the east to Puget Sound. Salmon stocks of various species are a defining feature of the environment and economy of Puget Sound, a region that was ideally suited for anadromous fish. Declines in salmon stocks led to the creation of a state Salmon Recovery Program in 1999. Estuary restoration in the Snohomish River has been a part of this overall recovery program. Restoration projects in the Snohomish Estuary region are shown in Figure XI-6.

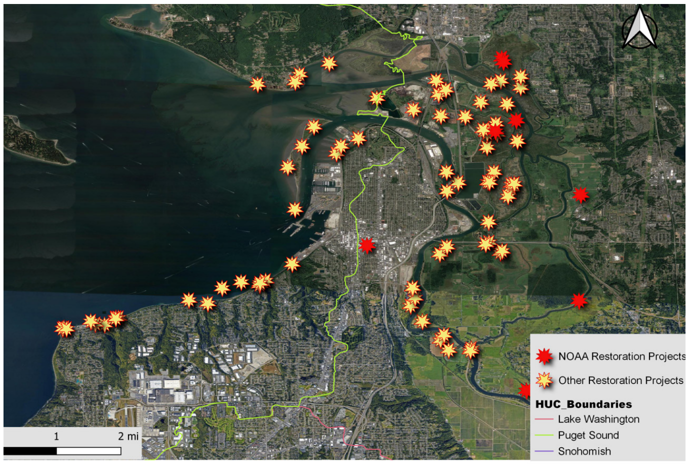


Figure XI-6 Restoration Projects in the Snohomish Estuary

The NOAA Restoration Atlas notes seven projects, primarily in the upper parts of the Snohomish River and its tributaries. Most projects shown in Figure XI-6 are taken from the Salmon Recovery Portal administered by the Washington State Recreation and Conservation Office.[50]

Fifty-four restoration projects are listed in the Salmon Recovery Portal (Table XI-6). Of these, over half (33) are various forms of hydrologic reconnection projects designed to restore natural flows within the estuary and to open space for salmon during the parts of their life cycle they spend in the estuary.

Table XI-6 Snohomish Estuary Restoration Projects

Restoration Type	Number of Projects
Beach nourishment	1
Bulkhead replacement	1
Debris Removal	2
Dike Maintenance	1
Habitat	10
Hydrologic Reconnection	33
Island Creation	1
Marsh Restoration	2
Shoreline Restoration	1
Tidal Marsh	2
Not Specified	21
Total	75

Natural Infrastructure and Coastal Blue Carbon Benefits

The natural infrastructure benefits for Snohomish Estuary in terms of flood reduction can range from $0.7 million to $1.7 million over a 30-year period[51] for a flood that historically would occur once in 100 years. Climate change may double the risk of a severe flood occurring, in which case benefits would increase to between $1.5 million and $3.4 million. These values are for damages to property exposed to flooding and do not include the damages to business sales or employment, tourism and recreation, nor the value of possible losses from effects on human health. *These damage estimates should thus be considered conservative, that is they are likely to be low.*

The value of coastal blue carbon benefits ranges from $1,301/hectare to $7,507/hectare using various discount rates. The total value for the 189 hectares in the estuary under the three more likely SCC scenarios ranges from $246,000 to $1.4 million. The low-probability, high-impact climate outcome scenario resulted in a coastal blue carbon value of $2.8 million.

Table XI-7. Natural Infrastructure and Coastal Blue Carbon Benefits Summary

Snohomish	Total hectares in analysis	Estimated benefits per hectare of wetlands		Total Estimated Benefits ($Millions)	
		Low estimate	High estimate	Low estimate	High Estimate
Natural Infrastructure	906	$773	$3,753	$0.7	$3.4
Coastal Blue Carbon[52]	189	$1,301	$7,507	$0.2	$1.4
Total				$0.9	$4.8

The broad range in these benefit estimates is due to several factors:

- variation in the "wetlands effect" arising from differences in the precise location, and quantity of wetlands between the valued assets and the water,
- uncertainty about future economic conditions (reflected in differing discount rates in the coastal blue carbon analysis), and
- assumptions about the increasing severity of storms due to climate change.

The lands surrounding the Snohomish Estuary are a mix of the more developed cities of Everett and Marysville to the South and North respectively, and restored freshwater and brackish floodplains of the Snohomish River to the East (See Figure XI-4), and the region has hosted several blue carbon and natural infrastructure analyses. In 2014, Restore America's Estuaries (RAE) published *Coastal Blue Carbon Opportunity Assessment for the Snohomish Estuary*[53], a first-of-its-kind assessment to quantify the climate mitigation benefits of restoration of an estuary. **The two studies use the same carbon cores to answer two different questions and should not be compared to one another, but rather should be considered to complement each other.** The 2014 RAE Study measured carbon storage and sequestration rates in the Snohomish Estuary, incorporated sea-level-rise impacts on estuary habitats, and determined the carbon capture benefit of restoring tidal wetlands. The 2014, analysis looked at carbon stores in multiple landcover types and represented a "first assessment of carbon fluxes over multiple decades for historic drained and future restoring wetlands."[54] This study looks at a single point in time, a snapshot, of one vegetation type, measures the soil carbon, and puts an economic value on it. This study uses the same carbon soil samples as the 2014, but the methodology treats them differently. For instance, the 2014 study considered carbon in only the first 30 cm of soil, whereas this study considers the carbon in the first 100 cm of soil. The blue carbon methods in this study were standardized so they could be applied in six estuaries across the country. As the 2014 study was a "first assessment of carbon fluxes over multiple decades", this study is also a "first assessment" of coastal blue carbon values over multiple estuaries in the U.S.

Table XI-7 summarizes the range of benefits from natural infrastructure and coastal blue carbon determined by this analysis. The table also includes the combination of the two ecosystem service values that were analyzed in this report. The analysis includes all areas of wetlands within the study area that provide one service or the other, as well as areas that provide both services. Because the two benefits provide complementary services, presenting a total value is appropriate. Combined, the natural infrastructure and coastal blue carbon benefits range from $0.9 million to $4.8 million. In terms of total value, natural infrastructure values in Snohomish Estuary are greater than those provided by coastal blue carbon, likely due to the very small area of emergent estuarine vegetation. Those values exist now, and should be recognized and maintained. In terms of increasing value in the estuary over time, the benefits per hectare is highest for coastal blue carbon, and conserving or restoring wetlands to continue to increase these benefits will provide the greatest addition to the existing value.

These estimates must be considered very preliminary and are intended to be helpful in shaping overall strategies for the future management of the wetlands resources of the Snohomish Estuary, strategies that account for both local goals of a healthy estuary and global goals of mitigation of climate change. They are part of a broader attempt to begin to characterize general estuary characteristics that offer different sources of economic value to local communities, such as protection from storms and flooding, and help meet broader societal goals, such as mitigation for climate change. As part of an examination of estuaries across the nation, they are not intended to guide project-level decisions, or replace more localized "deep dives" that have been conducted in these estuaries. There are still many unknowns that require much more elaborate estimation procedures for both natural infrastructure and coastal blue carbon. Whether the actual benefits in the future will tend towards the lower or higher end of these estimates will require continued research and ongoing assessment. But it is certain that the realization of these benefits will depend first on conserving the wetlands that exist and then on the restoration of wetlands that could increase these benefits.

XII. Conclusions and Discussion

This study had two main purposes, the first was to update our understanding of the contribution of estuary regions to the economies of the United States and of the coastal states in the continental U.S. The second was to expand our understanding of the economic values of estuarine wetlands by examining the values provided by reduction in flood damages (the natural infrastructure function) and by storing carbon dioxide that would exacerbate climate change if released to the atmosphere (the coastal blue carbon function). The first task was accomplished by examining the economic characteristics of twenty-one estuary regions. The second was accomplished by examining the natural infrastructure and coastal blue carbon values in six different estuaries.

THE ECONOMIC CONTRIBUTIONS OF ESTUARIES TO THE U.S. ECONOMY

The twenty-one regions examined are comprised of 380 counties bordering the Atlantic, Gulf of Mexico, Pacific, and Great Lakes. These regions together comprised 4% of the land area of the U.S. but from that 4% come 47% of the output of the U.S. economy ($8.8 trillion in gross domestic product), 39% of the employment (59.4 million jobs) and 40% of the population (130 million people) in 2018. Also, according to 2018 data, eight of the ten largest metropolitan areas were located in estuary regions. This concentration of economic activity and population in a small land area makes estuaries among the most economically valuable areas of the country, but that concentration also implies the potential for significant stresses on the environmental quality and ecosystem health of estuaries.

The size of the regions varies tremendously in both land area and economic size. The largest estuary region economies are associated with the major metropolitan areas of New York, Los Angeles, Chicago, Seattle, and Houston. But when adjusted for area, other estuary regions become significantly more important. This is particularly true of the Delaware River and Gulf of Mexico regions.

Economic growth over the period from 2009 to 2018 in the estuary regions overall followed national trends during the expansion period following the end of the Great Recession, but growth in both the economy and population tended to be fastest in the regions of the south Atlantic states from North Carolina to Florida, and in the Gulf of Mexico. Growth was slowest in the Great Lakes region, particularly in areas such as Lake Superior and Lake Ontario, away from major cities. In this, the estuary regions were also similar to the U.S. as a whole.

All economic activity in estuaries has an effect on estuary resources like water quality, but some economic activity is more directly related to the estuaries and coastal waters such as coastal tourism, recreation, and commercial fishing. These sectors provided 3.1 million jobs in 2018 and contributed $301.9 billion to the U.S. economy. As with the overall regional economy, these sectors tend to be largest in the major urban areas such as the estuary regions of the New York Bight and Southern California. But these industries are more important to the local economy in less urban areas such as the coastal areas of North and South Carolina.

The pattern of economic and population growth within the estuary regions was also examined. Faster growth near the ocean or Great Lake can have greater direct effects on coastal and marine ecosystems, while faster growth in the upstream parts of estuary regions have more indirect effects from issues such as runoff that magnify as they travel down the rivers and streams of estuaries. Population changes within the regions were relatively small over 2009-2018, but Georgia and South Carolina saw increased populations in their near shore areas and employment shifted towards the shore in the Gulf of Mexico regions. But growth shifted to inland parts of the estuaries in the major urban areas such as New York, Chicago, and Los Angeles.

The patterns of growth observed from 2009-2018 should not be assumed to simply continue. Two forces have the potential to substantially alter the size and characteristics of estuary regions. One force will be the combined effects of the many changes in the technology of jobs, particularly those in urbanized areas, resulting from the COVID-19 Pandemic. The large-scale shift of certain types of work away from centralized locations for an extended period opens a range of possible changes in the pattern of residence/work arrangements that could be very different from the past. The second force is climate change. This includes both the risks that the consequences of climate change, such as sea level rise, might have for all uses of the estuary shorelines and the response to those risks undertaken by all users of those shores. That the estuary regions will continue to be a key part of the U.S. economy is highly likely, but an update to this study at the end of the current decade may find very different economic circumstances in the estuary regions.

> ***This concentration of economic activity and population in a small land area makes estuaries among the most economically valuable areas of the country, but that concentration also implies the potential for significant stresses on the environmental quality and ecosystem health of estuaries.***

CASE STUDY CONCLUSIONS: ECONOMIC BENEFITS OF NATURAL INFRASTRUCTURE AND COASTAL BLUE CARBON

Climate change presents many challenges to estuaries and coastal ecological and economic systems. The central challenges today are to manage and adapt to the changes that are already well underway while preparing for, and attempting to prevent future threats. Wetlands in estuaries can play a key role in meeting both these challenges, and that role has economic values that are only now beginning to be understood.

To illustrate these values, and to demonstrate how preliminary estimates of values can be established, this study examined the role of specific types of wetlands in reducing damages from flooding in estuaries and storing carbon in the soils that could offset carbon releases from other sources.
This was done through case studies of six estuaries:

- Great Egg Harbor, New Jersey
- Pamlico Sound and the Lower Neuse River, North Carolina
- Tampa Bay, Florida
- Terrebonne Basin, Louisiana
- San Pablo Bay, California
- Snohomish River Estuary, Washington

There are two important features to values of natural infrastructure and blue carbon. The first is that these are stocks of value derived from the ability of wetlands to avoid future economic damages. The value is based on ecosystem services produced by the wetlands. This value is a form of natural capital, and derived from a future flow of benefits and expressed as a present value estimated for a future period in time. Because the value is realized in the future, future values are adjusted to present values through discount rates.

Secondly, and most important, the values estimated in these case studies are entirely dependent keeping existing wetlands intact, and thereby preventing or reducing future economic losses. The reduction or elimination of flood losses and the avoided release of carbon stores into the atmosphere are what determine the basic values. It is worth noting that wetlands both sequester carbon, i.e., remove it from the atmosphere, and store it in their soils.

However, this study only assesses the storage values of wetlands and does not include sequestration benefits. The rate of carbon storage and the extent of future flooding are both highly complex, variable across local areas, and subject to variation as a result of climate change. Therefore, any estimates of these values contain uncertainty,

Table XII-1. Summary of Natural Infrastructure and Blue Carbon Benefits by Case Study – Total Value in $Millions

	Wetlands Area (Hectares)		***Natural Infrastructure***		***Coastal Blue Carbon***		***Total Natural Infrastructure and Blue Carbon***	
	Natural Infrastructure	**Coastal Blue Carbon**	**Lowest Estimate**	**Highest Estimate**	**Lowest Estimate**	**Highest Estimate**	**Lowest Estimate**	**Highest Estimate**
			Total ($Millions)					
Great Egg Harbor	3,600	24,439	$34.1	$153.6	$63.6	$366.9	$97.7	$520.5
Pamlico Sound	62,153	37,000	$48.8	$219.8	$124.8	$720.2	$173.6	$940.0
Tampa Bay	34,377	6,652	$902.0	$2,705.1	$7.7	$44.2	$909.7	$2,749.3
Terrebonne Basin	N/A[2]	133,462	N/A	N/A	$430.0	$2,482.6	$430.0	$2,482.6
San Pablo Bay	29,872	8,451	$15.4	$68.7	$15.9	$91.5	$31.3	$160.2
Snohomish Estuary	906	189	$0.7	$3.4	$0.2	$1.4	$0.9	$4.8
TOTAL	**130,908**	**210,193**	**$1,001.0**	**$3,150.6**	**$642.2**	**$3,706.8**	**$1,946.0**	**$8,118.7**

and can be best expressed as lying with a range defined by the optimistic and pessimistic assumptions about the future.

Table XII-1 and Table XII-2 summarize the results from the six case studies. The differences between the low and high estimates in each estuary are explained in Chapter III and explored in detail in the individual case studies (Chapters V through XI). The value estimates are presented on both a total basis (Table XII-1) and adjusted for area on a per hectare basis (Table XII-2). All estimates are for the eight-digit Hydrological Unit that defines watershed as designated by the U.S. Geological Survey. Results are shown for natural infrastructure and blue carbon values separately and combined. Estuaries are listed geographically from the Northeast, clockwise to the Northwest. The rank ordering by size and value is indicated by the colors of the cells.

Allowing for the assumptions and simplified methods used in the analysis, it is clear that natural infrastructure and coastal blue carbon values in these six estuaries are quite significant, ranging in total (across all six estuaries studied) from a low estimate of approximately $1.9 billion to a high estimate of approximately $8.0 billion over a 30-year period. Whether the natural infrastructure or blue carbon values are higher varies across the six estuaries studied.

It is important to look at both per hectare and total values for each estuary. Per hectare values (high and low) for coastal blue carbon generally exceed those for natural infrastructure, except for Great Egg Harbor and Tampa Bay.[1] But when total values are examined, natural infrastructure values for both San Pablo and Snohomish become greater than coastal blue carbon values because there are more wetlands protecting assets than storing carbon. Conversely, the total value for Great Egg Harbor coastal blue carbon is greater than the natural infrastructure value, because while the per hectare value is higher for natural infrastructure, there are more wetlands storing blue carbon than protecting economic assets. These differences are primarily driven by the extent and location of development within the estuaries. Highly developed estuary regions will tend to have larger flood benefits either because the value of protected assets is high, as is the

Table XII-2. Summary of Natural Infrastructure and Blue Carbon Benefits by Case Study – Value per Hectare in $Thousands

	Wetlands Area (Hectares)		Natural Infrastructure		Coastal Blue Carbon	
	Natural Infrastructure	Coastal Blue Carbon	Lowest Estimate	Highest Estimate	Lowest Estimate	Highest Estimate
			Dollars Per Hectare ($Thousands)			
Great Egg Harbor	3,600	24,439	$9.6	$42.7	$2.6	$15.0
Pamlico Sound	62,153	37,000	$0.8	$3.5	$3.4	$19.5
Tampa Bay	34,377	6,652	$26.2	$78.7	$1.2	$6.6
Terrebonne Basin	N/A	133,462	N/A	N/A	$3.2	$18.6
San Pablo Bay	29,872	8,451	$0.5	$2.3	$1.9	$10.8
Snohomish Estuary	906	189	$0.8	$3.8	$1.3	$7.5

case with Tampa Bay, or more economic assets located behind wetlands, as is the case with San Pablo and Snohomish. Less developed regions, like Pamlico Sound and Terrebonne Basin, tend to have more functional wetlands sequestering and storing carbon, resulting in substantial coastal blue carbon benefits.

It is not surprising that large urban areas such as Tampa Bay have large natural infrastructure values and large unbroken stretches of salt marsh such as in Terrebonne will have large coastal blue carbon values. But there are significant economic values even in relatively small estuaries. The Snohomish River is the smallest of the estuaries examined at 906 hectares (2,200 acres) of natural infrastructure valued wetlands and only 190 hectares (470 acres) of coastal blue carbon wetlands. The Snohomish estuary wetlands have combined values ranging from approximately $900 thousand to $4.8 million, with natural infrastructure accounting for 88% of the low estimates and 72% of the high estimates. On the other end of the spectrum, Terrebonne Basin is the largest of the estuaries examined at 133,462 hectares (329,792 acres) of coastal blue carbon valued wetlands and zero hectares of wetlands that provide natural infrastructure, as defined by the methodology in this report. The Terrebonne Basin wetlands have values ranging from approximately $.4 billion to $2.2 billion, all values (100%) from coastal blue carbon. This analysis shows that regions with intact wetlands are likely to have *both* benefits, and that the overall values are significant and the exact distribution in any region requires region-specific assessment.

CASE STUDY CONCLUSIONS: WETLANDS RESTORATION PROJECTS IN THE CASE STUDY AREAS

In addition to estimating the coastal blue carbon and natural infrastructure benefits, each of the case studies summarized past efforts at restoring wetlands. Data was primarily drawn from the NOAA Restoration Atlas, supplemented by local sources of data as detailed in each of the case studies. Projects covered the period from 1970 to 2020. Only projects shown as completed were included in the analysis; projects listed in planning or in permitting were not included.

Table XII-3 shows the number of projects by case study area and the areas (in hectares) that the projects restored and/or protected. Many projects are intended to accomplish both purposes, but the list is restricted to those projects reported as restoration. There are additional restoration projects discussed in each case study beyond what is presented in the tables below. However, those projects do not list the area restored, and so are not included in Table XII-3 or Table XII-4. See each case study for additional detail on restoration data and its sources. There are a total of 287 projects reported where the area is also reported (See Table XII-3).

Table XII-3. Restoration Projects by Case Study

Case Study	Projects	Hectares Restored	Hectares Protected	Acres Restored	Acres Protected
Great Egg Harbor	14	216	-	533	-
Pamlico Sound	36	238	1	587	2
San Pablo Bay*	52	718	-	1,775	-
Snohomish**	7	322	166	796	410
Tampa Bay	144	264	315	652	778
Terrebonne	34	3,403	-	8,408	-
All Case Studies	287	5,160	482	12,751	1,190

* *Does not include 175 completed or under way projects with no area data*
** *Does not include 75 Salmon Recovery Projects with no area data*

The largest number of projects are shown in San Pablo Bay, followed by Tampa Bay. Terrebonne Basin has, by far, the largest area restored, according to sources that provide restoration acreage, at 3,403 hectares (8,408 acres).

The differences among the case study estuaries are significantly diminished when the projects are adjusted by the average size. Table XII-4 shows that the average size of restoration projects varies considerably, from a low of 1.8 hectares (4.5 acres) in Tampa Bay to a high of 100.1 hectares (247.3 acres) in Terrebonne. Snohomish River Estuary projects also show a higher average size than other estuaries, but this figure excludes state salmon recovery projects for which area is not reported.

The benefits of wetlands for natural infrastructure and coastal blue carbon were generally not a factor in deciding on past projects, though they may have been considered as co-benefits. For example, Tampa Bay had 144 restoration projects, but at an average size of 1.8 hectares (4.6 acres), so the natural infrastructure benefits of these projects are not likely to be large. This discrepancy between past projects and future natural infrastructure and coastal blue carbon benefits is simply a matter of historical focus on other purposes, primarily enhancing habitat, for fisheries and other types of environmental benefits. Looking to the future, the existence of the large economic benefits associated with natural infrastructure and coastal blue carbon suggests a need for expanding the scale of restoration through the use of larger projects or a larger number of small projects.

IMPLICATIONS AND LIMITATIONS

The six case studies included as part of this report used a consistent methodology to assess the values of natural infrastructure flood resilience and coastal blue carbon. Using a consistent methodology has benefits and presents challenges. Benefits include the ability to look across the case studies and begin to discern similar patterns across the different analyses, this information can be used to support national strategies for the future management of U.S. estuaries. More work is needed before this can effectively drive sustainable policy, as the sample size is too small to make any broad characterizations. However it does provide a basis to start thinking about what criteria in estuaries needs to be present to drive certain types of value, and why measuring and monitoring that value is important. Connecting the contributions of estuaries to the U.S. economy, as detailed in Section V, along with the contributions estuaries make to our health and wellbeing—by providing protection from storms and mitigating the effects of climate change—begins to provide a sense of the total value of the Nation's estuaries, and begins to lay out the potential tradeoffs between the two. An additional, and more practical benefit of the consistent methodology is that it allows for multiple estuaries to be assessed within a reasonable timeframe and cost.

Table XII-4. Average Size of Restoration and Protection Projects by Case Study

Case Study	Average Hectares Restored	Average Hectares Protected	Average Acres Restored	Average Acres Protected
Great Egg Harbor	15.4	-	38.1	-
Pamlico Sound	6.6	0.0	16.3	0.1
San Pablo Bay	13.8	-	34.1	-
Snohomish	46.0	23.7	113.7	58.6
Tampa Bay	1.8	2.2	4.5	5.4
Terrebonne	100.1	-	247.3	-
All Case Studies	18.0	1.7	44.4	4.1

The challenges with using a consistent methodology include limitations on understanding details that are needed for project-siting and management decisions. This study is not intended to drive on the ground, project-level, or siting decisions. Several of the estuaries that were selected for case studies already have assessments of varying degrees of their benefits, developed at a much more local and usable scale. Concerns that the existence of different values for the same service are warranted, however this project explicitly recognizes those concerns, while also recognizing there is room and use for both approaches.

Decisionmakers need a more accurate picture of the economic values connected to America's estuary regions, and how restoration and conservation can increase those values. This will be particularly critical in the future, as climate change creates the possibility of significant changes in the values estimated in this report. Increased storm intensities and frequencies due to climate change will likely increase the value of natural infrastructure and flood resilience. The need to greatly increase removal of carbon dioxide from the atmosphere will augment the value of coastal blue carbon. At the same time, sea level rise and other climate-related threats may play the opposite role, reducing the value of natural infrastructure and coastal blue carbon benefits by degrading existing wetlands.

The coastal blue carbon values can provide needed context and insights into emerging efforts to develop carbon markets, integrate blue carbon values into the Nationally Determined Contributions (NDCs) required by the Paris Agreement, to which the U.S. has recently become a party. While the NDCs require a much more stringent approach to assessing the stocks of carbon in coastal soils, this report provides a first look, an indication on whether undertaking the more comprehensive assessment is worthwhile. It also sheds insights on the social cost of carbon. In every case study, in almost all scenarios, the cost of purchasing the right to release the stream of carbon by converting wetlands is much less than the social cost of the released carbon. Achieving a socially optimal solution requires that emission caps be set at a level where the market price of carbon equals the social cost of carbon.

The case studies also shed light on where to look to find certain types of benefits that estuaries provide. The natural infrastructure flood resilience benefits are greatest in the areas that contain the highest levels of economic assets, but placement of the wetlands is key. To maximize these values, estuaries between those economic assets and the oncoming wind and water must be conserved or restored. Conversely, natural infrastructure flood resilience benefits are relatively low in the absence of concentrations of economic assets. Terrebonne basin estuary did not have enough potentially impacted parcels that bordered buildings or homes to measure, yet it was by far the richest source of blue carbon benefits in terms of total value, second only to Pamlico Sound in terms of blue carbon benefits per hectare.

To those experienced in assessing and understanding the value of the benefits provided by coastal habitats like estuaries these concepts may seem obvious. However, they are often overlooked in broader planning and budgeting processes. Restoration investment decisions should not be driven by the potential for economic return, but it should be considered as part of the equation. Continued investment in the assessment and monitoring of the ecosystem services provided by our nation's estuaries can improve decisions and allow for future potential benefits to be included in current efforts to restore America's estuaries.

Appendices

ENDNOTES

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2 https://coast.noaa.gov/states/fast-facts/hurricane-costs.html
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4 https://www.lamar.edu/_files/documents/resilience-recovery/grant/recovery-and-resiliency/hurric2.pdf
5 https://www.pewtrusts.org/en/research-and-analysis/articles/2020/10/01/repeatedly-flooded-properties-will-continue-to-cost-taxpayers-billions-of-dollars). The cost of flooding in 2019 alone was estimated to be between $15 and $29 billion (https://www.ncdc.noaa.gov/billions/summary-stats/US/2019
6 For this study, Alaska and Hawaii are excluded.
7 This report uses the term "coastal blue carbon" to differentiate carbon sequestration and storage in estuary habitats, including salt marshes, mangroves, and sea grass beds, from those in the open ocean.
8 Because the estuarine wetlands are located in the southern portion of the hydrologic unit, and are generally quite distant from the developed areas around the cities of Houma and Morgan City, it is not possible to estimate the value of natural infrastructure flood resilience for this case study in the same manner as the other case studies. See Section IX. Terrebonne Basin Case Study for more information.
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56 Source: NOAA Fisheries These are state totals. States such as Pennsylvania and New York with both ocean/estuary shores and Great Lakes shores are reported together.
57 Commercial fisheries landings are the weight of, or revenue from, fish that are caught, brought to shore, processed, and sold for profit.
58 It should be noted that in almost all years the largest fisheries landings values are in Alaska. Some of the fish caught off Alaska are landed in Puget Sound.
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62 The Bureau of Labor Statistics annual data is an average of 12 monthly observations reported by employers. Zip Code Business Patterns measures employment during the week of March 15 each year

as March tends to be the month closest to the annual average (that is, the least disturbed by seasonal trends).

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66 Using a discount rate of 2.5%.
67 Coastal Blue Carbon values for this table are taken from the more likely SCC scenarios, and do not include the low-probability, high-impact climate outcome scenario.

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30 The "Unknown" category reflects missing data in the Assessor database. The benefits in this case study are shown at the municipality level because all the benefits will be realized within one county.
31 Using a discount rate of 2.5%.
32 This report uses the term "coastal blue carbon" to differentiate carbon sequestration and storage in estuary habitats from those in the open ocean.
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Conclusions and Discussion

1 As discussed above, natural infrastructure benefits were not estimated for Terrebonne because of the unique features of that estuary.

2 Because the estuarine wetlands are located in the southern portion of the hydrologic unit, and are generally quite distant from the developed areas around the cities of Houma and Morgan City, it is not possible to estimate the value of natural infrastructure flood resilience for this case study in the same manner as the other case studies. See Section IX. Terrebonne Basin Case Study for more information.

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DATA TABLES

Table XII-1. Population, Employment and GDP State by Region

State	Region	Population	Percent of State	Employment	Percent of State	GDP ($ Millions)	Percent of State
Alabama	Eastern Gulf	622,766	12.7%	245,128	12.3%	$24,137.84	10.6%
California	Estuary Regions	29,228,973	74.1%	13,539,749	76.8%	$2,352,556.22	75.1%
	Central Northern CA	11,372,056	28.8%	5,476,059	31.1%	$1,149,763.80	36.7%
	Southern California	17,856,917	45.3%	8,063,690	45.7%	$1,202,792.42	38.4%
Connecticut	New York Bight	2,235,936	62.6%	980,292	58.7%	$152,121.21	52.9%
Delaware	Delaware River	949,495	100.0%	438,923	100.0%	$62,764.70	100.0%
District of Columbia	Chesapeake Bay	684,498	100.0%	771,742	100.0%	$123,981.60	100.0%
Florida	Estuary Regions	15,781,264	74.3%	6,357,787	71.6%	$715,398.67	64.7%
	Eastern Gulf	1,905,581	9.0%	589,040	6.6%	$54,013.58	4.9%
	Florida Atlantic	9,417,048	44.3%	3,855,608	43.4%	$449,018.67	40.6%
	Southern Gulf	4,458,635	21.0%	1,913,139	21.5%	$212,366.42	19.2%
Georgia	Georgia	583,773	5.6%	246,682	5.5%	$26,182.07	4.2%
Illinois	Lake Michigan	5,927,338	46.6%	2,931,748	48.9%	$500,396.52	56.5%
Indiana	Lake Michigan	765,442	11.4%	288,891	9.4%	$35,075.44	9.2%
Louisiana	Central Gulf	2,747,135	59.0%	1,124,270	58.4%	$160,269.42	62.4%
Maine	Gulf of Maine	1,002,159	74.8%	477,298	76.8%	$46,873.32	69.2%
Maryland	Chesapeake Bay	3,980,817	66.0%	1,694,954	62.8%	$228,831.05	53.6%
Massachusetts	Estuary Regions	4,387,609	63.7%	2,141,223	58.9%	$296,854.81	49.8%
	Gulf of Maine	3,800,290	55.2%	1,896,065	52.1%	$272,195.29	45.6%
	New York Bight	587,319	8.5%	245,158	6.7%	$24,659.52	4.1%
Michigan	Estuary Regions	6,094,113	61.0%	2,585,814	59.3%	$339,886.85	63.3%
	Lake Erie	4,030,628	40.4%	1,832,400	42.0%	$261,872.44	48.8%
	Lake Huron	700,942	7.0%	229,579	5.3%	$23,145.59	4.3%
	Lake Michigan	1,173,833	11.8%	459,493	10.5%	$48,634.37	9.1%
	Lake Superior	188,710	1.9%	64,342	1.5%	$6,234.45	1.2%
Minnesota	Lake Superior	215,960	3.9%	105,412	3.6%	$10,070.20	2.6%

Mississippi	Central Gulf	391,293	13.1%	147,529	13.0%	$15,335.37	13.2%
New Hampshire	Gulf of Maine	433,366	32.0%	198,193	29.8%	$23,504.23	26.8%
New Jersey	Estuary Regions	6,646,251	74.8%	2,804,160	68.7%	$367,467.29	57.9%
	Delaware River	1,555,027	17.5%	638,160	15.6%	$73,342.47	11.6%
	New York Bight	5,091,224	57.3%	2,166,000	53.0%	$294,124.83	46.3%
New York	Estuary Regions	16,505,618	84.5%	8,001,270	83.8%	$1,306,526.41	73.7%
	Lake Erie	1,049,522	5.4%	518,862	5.4%	$54,715.97	3.1%
	Lake Ontario	1,508,961	7.7%	637,909	6.7%	$66,074.89	3.7%
	New York Bight	13,947,135	71.4%	6,844,499	71.7%	$1,185,735.55	66.9%
North Carolina	North Carolina	1,084,914	10.5%	369,789	8.2%	$34,139.11	5.8%
Ohio	Lake Erie	2,566,844	22.0%	1,278,808	23.5%	$153,212.10	22.0%
Oregon	Oregon Washington	1,633,649	39.1%	837,696	42.9%	$95,594.01	37.7%
Pennsylvania	Estuary Regions	3,862,692	30.2%	1,797,910	30.3%	$257,254.85	31.8%
	Delaware River	3,586,720	28.0%	1,675,882	28.3%	$245,447.81	30.3%
	Lake Erie	275,972	2.2%	122,028	2.1%	$11,807.04	1.5%
Rhode Island	New York Bight	1,056,611	100.0%	471,060	100.0%	$53,624.90	100.0%
South Carolina	South Carolina	1,234,419	24.3%	549,984	25.8%	$55,808.98	22.5%
Texas	Estuary Regions	6,763,555	23.6%	3,103,216	24.6%	$504,439.26	27.4%
	Central Gulf	339,257	1.2%	145,680	1.2%	$20,686.49	1.1%
	Western Gulf	6,424,298	22.4%	2,957,536	23.5%	$483,752.77	26.2%
Virginia	Chesapeake Bay	4,985,987	66.3%	2,276,347	66.2%	$305,214.85	49.8%
Washington	Estuary Regions	5,633,227	74.9%	2,643,744	76.9%	$437,173.09	71.3%
	Oregon Washington	784,896	10.4%	264,852	7.7%	$30,318.29	4.9%
	Puget Sound	4,848,331	64.4%	2,378,892	69.2%	$406,854.80	66.4%
Wisconsin	Estuary Regions	2,066,332	35.6%	1,005,980	71.6%	$124,068.16	35.5%
	Lake Michigan	1,986,511	34.2%	976,272	68.8%	$121,229.98	34.7%
	Lake Superior	79,821	1.4%	29,708	2.8%	$2,838.18	0.8%

Table XIII-2. Population, Employment and GDP Region by State

Region	State	Population	Percent of Region	Employment	Percent of Region	GDP ($Millions)	Percent of Region
Gulf of Maine		5,235,815		2,571,556		$342,572.83	
Gulf of Maine	Maine	1,002,159	19.1%	477,298	18.6%	$46,873.32	13.7%
Gulf of Maine	Massachusetts	3,800,290	72.6%	1,896,065	73.7%	$272,195.29	79.5%
Gulf of Maine	New Hampshire	433,366	8.3%	198,193	7.7%	$23,504.23	6.9%
New York Bight		22,918,225		10,707,009		$1,710,266.01	
New York Bight	Connecticut	2,235,936	9.8%	980,292	9.2%	$152,121.21	8.9%
New York Bight	Massachusetts	587,319	2.6%	245,158	2.3%	$24,659.52	1.4%
New York Bight	New Jersey	5,091,224	22.2%	2,166,000	20.2%	$294,124.83	17.2%
New York Bight	New York	13,947,135	60.9%	6,844,499	63.9%	$1,185,735.55	69.3%
New York Bight	Rhode Island	1,056,611	4.6%	471,060	4.4%	$53,624.90	3.1%
Delaware River		6,091,242		2,752,965		$381,554.98	
Delaware River	Delaware	949,495	15.6%	438,923	15.9%	$62,764.70	16.4%
Delaware River	New Jersey	1,555,027	25.5%	638,160	23.2%	$73,342.47	19.2%
Delaware River	Pennsylvania	3,586,720	58.9%	1,675,882	60.9%	$245,447.81	64.3%
Chesapeake Bay		9,651,302		4,743,043		$658,027.50	
Chesapeake Bay	District of Columbia	684,498	7.1%	771,742	16.3%	$123,981.60	18.8%
Chesapeake Bay	Maryland	3,980,817	41.2%	1,694,954	35.7%	$228,831.05	34.8%
Chesapeake Bay	Virginia	4,985,987	51.7%	2,276,347	48.0%	$305,214.85	46.4%
North Carolina		1,084,914		369,789		$34,139.11	
North Carolina	North Carolina	1,084,914	100%	369,789	100%	$34,139.11	100%
South Carolina		1,234,419		549,984		$55,808.98	
South Carolina	South Carolina	1,234,419	100%	549,984	100%	$55,808.98	100%
Georgia		583,773		246,682		$26,182.07	
Georgia	Georgia	583,773	100%	246,682	100%	$26,182.07	100%

Florida Atlantic		9,417,048		3,855,608		$449,018.67	
Florida Atlantic	Florida	9,417,048	100%	3,855,608	100%	$449,018.67	100%
Southern Gulf		4,458,635		1,913,139		$212,366.42	
Southern Gulf	Florida	4,458,635	100%	1,913,139	100%	$212,366.42	100%
Eastern Gulf		2,528,347		834,168		$78,151.43	
Eastern Gulf	Alabama	622,766	24.6%	245,128	29.4%	$24,137.84	30.9%
Eastern Gulf	Florida	1,905,581	75.4%	589,040	70.6%	$54,013.58	69.1%
Central Gulf		3,477,685		1,417,479		$196,291.28	
Central Gulf	Louisiana	2,747,135	79.0%	1,124,270	79.3%	$160,269.42	81.6%
Central Gulf	Mississippi	391,293	11.3%	147,529	10.4%	$15,335.37	7.8%
Central Gulf	Texas	339,257	9.8%	145,680	4.2%	$20,686.49	0.6%
Western Gulf		6,424,298		2,957,536		$483,752.77	
Western Gulf	Texas	6,424,298	100%	2,957,536	100%	$483,752.77	100%
Southern California		17,856,917		8,063,690		$1,202,792.42	
Southern California	California	17,856,917	100%	8,063,690	100%	$1,202,792.42	100%
Central Northern CA		11,372,056		5,476,059		$1,149,763.80	
Central Northern CA	California	11,372,056	100%	5,476,059	100%	$1,149,763.80	100%
Oregon Washington		2,418,545		1,102,548		$125,912.29	
Oregon Washington	Oregon	1,633,649	67.5%	837,696	76.0%	$95,594.01	75.9%
Oregon Washington	Washington	784,896	32.5%	264,852	24.0%	$30,318.29	24.1%
Puget Sound		4,848,331		2,378,892		$406,854.80	
Puget Sound	Washington	4,848,331	100%	2,378,892	100%	$406,854.80	100%
Lake Superior		484,491		199,462		$19,142.83	
Lake Superior	Michigan	188,710	39.0%	64,342	32.3%	$6,234.45	32.6%
Lake Superior	Minnesota	215,960	44.6%	105,412	52.8%	$10,070.20	52.6%
Lake Superior	Wisconsin	79,821	16.5%	29,708	14.9%	$2,838.18	14.8%
Lake Michigan		9,853,124		4,656,404		$705,336.31	
Lake Michigan	Illinois	5,927,338	60.2%	2,931,748	63.0%	$500,396.52	70.9%
Lake Michigan	Indiana	765,442	7.8%	288,891	6.2%	$35,075.44	5.0%
Lake Michigan	Michigan	1,173,833	11.9%	459,493	9.9%	$48,634.37	6.9%

Lake Michigan	Wisconsin	1,986,511	20.2%	976,272	21.0%	$121,229.98	17.2%
Lake Huron		700,942		229,579		$23,145.59	
Lake Huron	Michigan	700,942	100%	229,579	100%	$23,145.59	100%
Lake Erie		7,922,966		3,752,098		$481,607.55	
Lake Erie	Michigan	4,030,628	51%	1,832,400	49%	$261,872.44	54%
Lake Erie	New York	1,049,522	13%	518,862	14%	$54,715.97	11%
Lake Erie	Ohio	2,566,844	32%	1,278,808	34%	$153,212.10	32%
Lake Erie	Pennsylvania	275,972	3%	122,028	3%	$11,807.04	2%
Lake Ontario		1,508,961		637,909		$66,074.89	
Lake Ontario	New York	1,508,961	100%	637,909	100%	$66,074.89	100%

Table XII-3. Counties Included in Analysis by Region and State

Region	State	County Name
		Cumberland
		Hancock
		Kennebec
		Knox
	Maine	Lincoln
		Penobscot
		Sagadahoc
		Waldo
		Washington
		York
	New Hampshire	Rockingham
Gulf of Maine		Strafford
		Barnstable
		Essex
		Middlesex
	Massachusetts	Norfolk
		Plymouth
		Suffolk
		Bristol
		Dukes
		Nantucket
		Bristol
		Kent
	Rhode Island	Newport
		Providence
		Washington
		Fairfield
New York Bight	Connecticut	Middlesex
		New Haven
		New London
		Albany
		Bronx
	New York	Columbia
		Duchess
		Greene
		Kings
		Nassau
		New York
		Orange
	New York	Putnam
		Queens
New York Bight		Richmond
		Rockland
		Suffolk
		Ulster
		Westchester
		Atlantic
		Bergen
		Essex
	New Jersey	Middlesex
		Monmouth
		Ocean
		Passaic
		Union
		Burlington
		Camden
	New Jersey	Cape May
		Cumberland
		Gloucester
		Salem
Delaware River		Kent
	Delaware	New Castle
		Sussex
		Bucks
	Pennsylvania	Delaware
		Montgomery
		Philadelphia
		Anne Arundel
		Baltimore
		Calvert
		Caroline
Chesapeake Bay	Maryland	Cecil
		Charles
		Dorchester

		Harford
		Kent
		Prince George's
		Queen Anne's
	Maryland	Somerset
		St. Mary's
		Talbot
		Wicomico
		Worcester
	District of Columbia	District of Columbia
	Virginia	Accomack
		Alexandria
		Caroline
Chesapeake Bay		Charles City
		Chesapeake
		Chesterfield
		Essex
		Fairfax
		Gloucester
		Hampton
		Hanover
		Henrico
		Hopewell
		Isle of Wight
		James City
	Virginia	King George
		King William
		King and Queen
		Lancaster
		Mathews
		Middlesex
		New Kent
		Newport News
		Norfolk
		Northampton
		Northumberland
		Poquoson
		Portsmouth
		Prince George
		Prince William
		Richmond
		Spotsylvania
		Stafford
		Suffolk
Chesapeake Bay	Virginia	Surry
		Virginia Beach
		Westmoreland
		York
		Beaufort
		Bertie
		Brunswick
		Camden
		Carteret
		Chowan
		Craven
		Currituck
		Dare
		Gates
North Carolina	North Carolina	Hertford
		Hyde
		Jones
		Martin
		New Hanover
		Onslow
		Pamlico
		Pasquotank
		Pender
		Perquimans
		Tyrrell
		Washington
		Beaufort
		Berkeley
South Carolina	South Carolina	Charleston
		Colleton
		Georgetown
		Horry
		Jasper
		Bryan
		Camden
		Chatham
Georgia	Georgia	Glynn

		Liberty
		Long
		McIntosh
		Wayne
		Brevard
		Broward
		Clay
		Duval
		Flagler
		Indian River
Florida Atlantic	Florida	Martin
		Miami-Dade
		Nassau
		Palm Beach
		Putnam
		St. Johns
		St. Lucie
		Volusia
		Charlotte
		Collier
		Hillsborough
Southern Gulf	Florida	Lee
		Manatee
		Monroe
		Pinellas
		Sarasota
		Bay
		Citrus
		Dixie
		Escambia
		Franklin
Eastern Gulf	Florida	Gulf
		Hernando
		Levy
		Okaloosa
		Pasco
		Santa Rosa
		Taylor
Eastern Gulf	Florida	Wakulla
		Walton
	Alabama	Baldwin
		Mobile
		Hancock
	Mississippi	Harrison
		Jackson
		Acadia
		Ascension
		Assumption
		Calcasieu
		Cameron
		Iberia
		Iberville
		Jefferson
		Jefferson Davis
		Lafayette
		Lafourche
		Livingston
		Orleans
Central Gulf	Louisiana	Plaquemines
		Pointe Coupee
		St. Bernard
		St. Charles
		St. James
		St. John the Baptist
		St. Martin
		St. Mary
		St. Tammany
		Tangipahoa
		Terrebonne
		Vermilion
		West Baton Rouge
	Texas	Jefferson
		Orange
		Aransas
		Brazoria
		Calhoun
Western Gulf	Texas	Cameron
		Chambers
		Galveston
		Harris
		Jackson
		Kenedy

Western Gulf		Kleberg
		Matagorda
		Nueces
		Refugio
		San Patricio
		Victoria
		Willacy
		Los Angeles
		Orange
Southern California	California	San Diego
		Santa Barbara
		Ventura
		Alameda
		Contra Costa
		Del Norte
		Humboldt
		Marin
		Mendocino
		Monterey
		Napa
Central Northern CA	California	Sacramento
		San Francisco
		San Joaquin
		San Luis Obispo
		San Mateo
		Santa Clara
		Santa Cruz
		Solano
		Sonoma
		Yolo
		Clatsop
		Columbia
		Coos
		Curry
Oregon Washington	Oregon	Douglas
		Hood River
		Josephine
		Lane
	Oregon	Lincoln
		Multnomah
Oregon Washington		Tillamook
		Clallam
		Clark
		Cowlitz
	Washington	Grays Harbor
		Jefferson
		Pacific
		Skamania
		Wahkiakum
		Island
		King
		Kitsap
		Mason
Puget Sound	Washington	Pierce
		San Juan
		Skagit
		Snohomish
		Thurston
		Whatcom
		Cook
	Minnesota	Lake
		St. Louis
		Ashland
	Wisconsin	Bayfield
		Douglas
		Iron
Lake Superior		Alger
		Baraga
		Chippewa
	Michigan	Gogebic
		Houghton
		Keweenaw
		Luce
		Marquette
		Ontonagon
		Brown
Lake Michigan	Wisconsin	Door
		Kenosha
		Kewaunee
		Manitowoc

		Marinette
	Wisconsin	Milwaukee
		Oconto
		Ozaukee
		Racine
		Sheboygan
	Illinois	Cook
		Lake
		LaPorte
Lake Michigan	Indiana	Lake
		Porter
		Allegan
		Antrim
		Benzie
		Berrien
		Charlevoix
		Delta
		Emmet
	Michigan	Grand Traverse
		Leelanau
		Mackinac
		Manistee
		Mason
		Menominee
		Muskegon
		Oceana
		Ottawa
		Schoolcraft
		Van Buren
		Alcona
		Alpena
		Arenac
		Bay
		Cheboygan
		Huron
		Iosco
Lake Huron	Michigan	Presque Isle
		Saginaw
		Sanilac
Lake Huron	Michigan	St. Clair
		Tuscola
		Macomb

	Michigan	Monroe
		Oakland
		Wayne
		Ashtabula
		Cuyahoga
		Erie
Lake Erie	Ohio	Lake
		Lorain
		Lucas
		Ottawa
		Wood
	Pennsylvania	Erie
	New York	Chautauqua
		Erie
		Cayuga
		Jefferson
		Monroe
Lake Ontario	New York	Niagara
		Orleans
		Oswego
		St. Lawrence
		Wayne