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Executive Summary

Current scientific research shows that the global sea level is expected to rise significantly over the next century. The relatively dense development and abundant economic activity along much of the U.S. coastline is vulnerable to risk of coastal flooding, shoreline erosion and storm damages.

In this study we examine the impacts of climate change on North Carolina coastal resources. We consider three important areas of the coastal economy: the impacts of sea-level rise on the coastal real estate market, the impacts of sea-level rise on coastal recreation and tourism and the impacts of tropical storms and hurricanes on business activity. Our baseline year is 2004. All the impacts in this study are measured in 2004 U.S. dollars.

Methods for Coastal Impacts Analysis

Inundation and storm impacts are assessed for four coastal counties ranging from high-development to rural-economies and with shoreline dominated by estuarine to marine environments. We use high-resolution topographic LIDAR (Light Detection and Ranging) data to provide accurate inundation maps in order to identify all property that will be lost under different sea level rise scenarios assuming no adaptation. The sea level rise scenarios are adjusted upward for regional subsidence and range from an 11 centimeters (cm) increase in sea levels by 2030 to an 81 cm increase by 2080. Additional geospatial attributes that described the distance of a property to shoreline and elevation are also generated and entered into a database of corresponding tax values.

To estimate the recreational impacts of sea level rise we calculated current erosion rates for beaches and fishing locations and modeled projected beach widths. Projected increases in erosion are estimated qualitatively for the years 2030 and 2080 by a local expert. These erosion rates are then mapped spatially to describe changes in minimum and maximum beach width assuming no nourishment or barrier island migration.

Storm impacts are assessed by investigating projected climate-related increases in storm intensity along a hurricane track that made landfall in 1996. The percent increase in wind speed due to increased sea surface temperature is estimated using the MAGICC/SCENGEN Global Climate Model. The wind speeds are mapped spatially using a hurricane wind speed model (HURRECON). Maximum wind speeds and wind gusts are averaged by county and used in an economic model to estimate potential business impacts.

Impacts on Real Estate Markets

In the first economic component of this study we estimate the impacts of sea level rise on coastal real estate markets in New Hanover, Dare, Carteret and Bertie County of North Carolina. The study area represents a cross-section of the North Carolina coastline in geographical

distribution and economic development. A simulation approach based on the hedonic property model is developed to estimate the impacts of sea level rise on property values.

Data on property values come from the county tax offices which maintain property parcel records that contain assessed values of property as well as lot size, total square footage, the year the structure was built, and other structural characteristics of the property. Other spatial amenities such as property elevation, ocean and sound/estuarine frontage and distance to shoreline are obtained using Geographic Information System data.

We estimate the loss of property values due to sea level rise using a simulation approach based on hedonic property value models for the four counties. The results indicate that the impacts of sea level rise on coastal property values vary across the North Carolina coastline. Without discounting, the residential property value loss in Dare County ranges from 2% of the total residential property value to 12%. The loss in Carteret County ranges from less than 1% to almost 3%. New Hanover and Bertie counties show relatively small impacts with less than one percent loss in residential property value.

Considering four coastal counties, including the three most populous on the North Carolina coast, the present value of lost residential property value in 2080 is $3.2 billion discounted at a 2% rate. The present value of lost nonresidential property value in 2080 is $3.7 billion at a 2% rate.

Impacts on Recreation and Tourism

In the second economic component of this study we estimate the impacts of sea level rise on coastal recreation and tourism. We estimate the effects of sea-level rise on beach recreation at the southern North Carolina Beaches and recreational fishing that takes place on the entire coast (whereas the property impacts are assessed for only 4 counties).

We use two sets of recreation data and the travel cost method for recreation demand estimation. The first data set includes information on beach trips to southern North Carolina beaches. The second includes information on shore-based fishing trips for the entire North Carolina coast.

We estimate that the lost recreation value of climate change-induced sea level rise to beach goers is $93 million in 2030 and $223 million in 2080 for the southern North Carolina beaches. For those households who only take day trips, 4.3% of recreation value is lost in 2030 and 11% is lost in 2080 relative to 2004 baseline values. For those households who take both day and overnight beach trips, 16% and 34% of recreation value is lost in 2030 and 2080, respectively.

Beach trip spending by non-local North Carolina residents would also change significantly with climate change-induced sea level rise. Spending by those who only take day trips would fall by 2% in 2030 and 23% in 2080 compared to 2004. Those who take both day and overnight trips would spend 16% less in 2030 and 48% less in 2080.

Turning to recreational fishing, the aggregate annual lost recreational value of sea level rise to shore anglers in all of North Carolina would be $14 million in 2030 and $17 million in 2080. This is 3% in 2030 and 3.5% in 2080 of the 2004 baseline values. Angler spending would not change significantly as shore anglers move to other beaches or piers and bridges in response to sea level rise.

The coastal recreation and tourism analysis indicates that there are substantial losses from reduced opportunities of beach trips and fishing trips. The present value of the lost recreation benefits due to sea level rise would be $3.5 billion when discounted at a 2% rate for the southern North Carolina beaches. The present value of the lost recreational fishing benefits due to sea level rise would be $430 million using a 2% discount rate.

Impacts on Business and Industry

In the third component of this study we estimate the impacts of increased storm severity on business and industry, including agriculture, forestry, commercial fisheries and general "business interruption." These are the primary categories of impacts on business and industry for low-intensity hurricane strikes, and changes among low-intensity hurricane categories are identified in this study as the most likely results of climate change. Estimates of business interruption impacts on economic output are presented by county for three climate change scenarios. Although scarce data limit the ability to estimate economic impacts for the vulnerable natural resource sectors, preliminary, order of magnitude assessments are presented.

The impacts of increased storm severity on economic output due to business interruption from 2030-2080 vary across county and climate change scenario, ranging from negligible impacts for Bertie County to $946 million for New Hanover County. These results show the incremental losses due to climate change that could result from a storm strike similar to hurricane Fran, a well-known category 3 storm that struck North Carolina in 1996. County-level estimates vary due to differences in population, industry structure, distance to the coast, and prior hurricane damage history.

The economic impacts of severe storms on the North Carolina agricultural sector are significant. Based on agricultural damage statistics for hurricanes affecting North Carolina between 1996 and 2006, we find that a tropical storm or category 1 hurricane strike causes $30-$50 million in total statewide agricultural damage, a category 2 storm in the ballpark of $200 million, and a category 3 storm on the order of $800 million. Increases in hurricane intensity due to climate change could have substantial impacts on agriculture in North Carolina.

Based on the limited data from hurricane Fran (category 3) and hurricane Isabel (category 2), the incremental forest damage associated with an increase in hurricane severity from category 2 to category 3 is substantial, on the order of 150% per storm event, or about $900 million.

Consistent time series data on the damages to commercial fishing operations caused by tropical storms and hurricanes do not currently exist for North Carolina. However, two recent case studies indicate that commercial fisheries suffer economic losses primarily in the form of damaged fishing gear and reductions in the number of safe fishing days. In addition, there is some evidence that the populations of some target species may fall following hurricanes, further reducing the profitability of fishing.

Acronyms

AAA – American Automobile Association

Cat 1 - Category 1 hurricane on the Saffir-Simpson hurricane severity scale

Cat 2 - Category 2 hurricane on the Saffir-Simpson hurricane severity scale

Cat 3 - Category 3 hurricane on the Saffir-Simpson hurricane severity scale

FDEL - Full day equivalents lost, the number of days of lost business output due to a storm strike

FEMA - Federal Emergency Management Agency

GDP - Gross Domestic Product

GIS - Geographic Information Systems

HURRECON – Model used to estimate wind speeds from point locations along a storm track

IMPLAN - Name of economic input-output computer model developed by MIG, Inc.

IPCC – Intergovernmental Panel on Climate Change

LIDAR - Light Detection and Ranging

MAGICC/SCENGEN (Hulme et al. 1995) – Global Climate Model used to estimate sea surface temperatures for calculating changes in hurricane intensity

MRFSS – Marine Recreational Fishery Statistical Survey

NC – North Carolina

NCASS - North Carolina Agricultural Statistics Service

NCDMF - North Carolina Division of Marine Fisheries

NLOGIT – Nested Logit version of LIMDEP (Limited Dependent Variable) econometric software

NMFS – National Marine Fisheries Service

NRUM – Nested random utility model

NSRE – National Survey of Recreation and the Environment

SAS – Statistical Analysis Software

TS - Tropical storm

USACE – U.S. Army Corps of Engineers

WTP - Willingness to pay

ZIPFIP – Zip code - Federal Information Processing Standard computer software

1. Introduction

Rapid economic growth in the coastal zone in the last few decades has resulted in larger populations and more valuable coastal property. However, coastal development is exposed to considerable risk as sea level is projected to rise 0.18 to 0.59 meters over the next century (Intergovernmental Panel on Climate Change 2007) creating potential problems for the coastal economy. In this study we estimate the impacts of sea level rise on property values, beach recreation and tourism and storm damages in coastal North Carolina. This research offers a unique integration of geospatial data and economic models of the coastal economy. Our baseline year is 2004. All the impacts in this study are measured in 2004 U.S. dollars. We estimate impacts for 2030 and 2080. When appropriate, we estimate the present value of impacts from 2004 to 2080 using discount rates of 0%, 2% and 7%.

North Carolina was chosen as the case study primarily due to its economic vulnerability to climate change. One problem is climate-change induced sea level rise. Coastal North Carolina is located within the relatively low-income eastern region of the state. The coastal real estate market and coastal tourism are important economic sectors in this region. Given the barrier island roads and highways that act as barricades, sea-level rise is expected to result in significant changes in beach width impacting the land that currently hosts beach cottages and beach recreation. Further, to the extent that climate change leads to more severe hurricanes, business activity will be negatively affected.

Methods for Coastal Impacts Analysis

In Section 2 of this report we describe the geospatial data developed to integrate climate change impacts into the economic models.

This research considers Bertie, Carteret, Dare and New Hanover counties, which represent a cross-section of the North Carolina coastline in geographical distribution and economic development. For coastal counties selected for analysis, we use coastal property parcel data and develop additional climate change related attributes for each property parcel and estimates for each coastal county using several different modeling approaches. The climate change related attributes chosen for this study include:

1. Average parcel elevation (from LIDAR elevation data ±25 cm accuracy)
2. Indicator for whether the parcel (i.e. >50%) is inundated by sea level rise for the years 2030 and 2080 for mid, low, and high scenarios
3. Frequency of wind speeds over a threshold projected for the next 100 years for each parcel based on increasing wind intensity for a hurricane track which made landfall in coastal North Carolina in 1996
4. Federal Emergency Management Agency (FEMA) floodzone that parcel is currently inside

5. Sensitivity of parcels to changes in projected FEMA floodzone change that parcel will be inside due to increase in storm-surge event
6. Estimated erosion and loss of shore-fishing areas based off measured erosion rates and qualitative projections for future erosion taking into consideration sea-level rise and increased storminess
7. Estimated erosion and loss of recreational (swimming) beaches

Impacts on Real Estate Markets

In section 3 of this report we present estimates of the impacts of climate change in real estate markets. Data on property values come from the county tax offices. Each county tax office maintains property parcel records that include sales transactions, lot perimeter, total square footage of the property, the year the structure was built, and other characteristics of the property. High-resolution LIDAR (Light Detection and Ranging) elevation data are utilized to identify the inundation areas for different sea level rise scenarios. Other spatial amenities (e.g., ocean/sound frontage and distance to the shore) that may affect property values are measured using Geographic Information Systems (GIS).

The hedonic property price functions are estimated using structural, location, and environmental attributes. Separate hedonic price schedules are estimated for residential and nonresidential properties. Based on the hedonic regression results, a simulation method is developed to estimate the value of each lost property in the inventory of coastal property. The simulation method maintains the assumption that the value of amenities and risks of the lost properties are transferred to other properties. It implies that the coastal property at the time of loss would not have the peak value that stems from waterfront location.

The following general categories of the impacts are identified:

- The value of land loss
- The value of capital (structure) loss
- The cost of relocating structures further inland
- The value of public infrastructure loss

This study focuses on the first two categories which represent more direct and immediate measures of the impacts. The other categories relate more to adjustments induced by sea level rise, and the impacts are relatively small compared to the first two categories. The estimated impacts of sea level rise on property values are provided for various sea level rise scenarios.

Impacts on Recreation and Tourism

In section 4 of this report we consider the impacts of sea-level rise on recreational fishing and non-fishing beach recreation. All of coastal North Carolina is included in the recreational fishing analysis. Due to data limitations the beach counties considered for the recreational swimming analysis are the southern counties of Brunswick, New Hanover, Pender, Onslow and Carteret.

In the beach recreation analysis we estimate the economic costs and impacts to the beach tourism industry at the county level arising from sea-level rise. The beach recreation economic effects are estimated using a recreation demand methodology and data gathered for the U.S. Army Corps of Engineers.

Using the 2005 USACE data, a nested logit random utility model (NRUM) is estimated. Information from the geospatial analysis is used to identify beach recreation sites that will potentially become unavailable with sea-level rise (e.g., changes in beach width). The recreation demand model is used to simulate site closure at these locations and the resulting reallocation of beach recreation trips. These estimates are combined with trip expenditures data to estimate the economic effects on North Carolina coastal counties.

The recreational fishing economic costs and impacts are estimated using a similar recreation demand methodology and data gathered by the National Marine Fisheries Service (NMFS) through their Marine Recreational Fishery Statistics Survey Program (MRFSS). The MRFSS is collected annually. Using the 2005 MRFSS data, a nested logit site selection model is estimated. Information from the geospatial analysis is used to identify shore fishing sites that will potentially become unavailable with sea-level rise. The recreation demand model is used to simulate site closure at these locations and the resulting reallocation of shore-based fishing trips.

Impacts on Business and Industry

In section 5 of this report we estimate the impacts of changes in the severity of tropical storms and hurricanes due to climate change on regional business and industry, including agriculture, forestry, commercial fisheries, and general "business interruption." These are the primary business/industry impact categories for low-intensity hurricane strikes. Changes among low-intensity hurricane categories were identified as the most likely impacts of climate change on storm intensity. Although low-intensity storms cause less physical damage to infrastructure than do high-intensity storms, low-intensity storms occur with much greater frequency, especially in North Carolina. The cumulative economic impacts of frequent low-intensity storm strikes can rival the impacts of infrequent high-intensity storm strikes.

Unfortunately, differences in storm frequency due to climate change are not considered in this analysis. Hence, storm impact estimates are presented holding storm strike frequency constant at the 2006 historical average. The study considers three relatively urban counties, Dare, Carteret, and New Hanover, and one relatively rural county, Bertie. For each county, three scenarios are compared, a baseline scenario of tropical storm and hurricane severity, and two alternative scenarios reflecting increased storm and hurricane severity due to climate change in 2030 and 2080.

Business interruption impacts are temporary reductions in business activity/output due to hurricane strikes. Reductions in business activity are caused by temporary loss of power, inability of employees to reach jobs due to fallen trees and local flooding, inability of customers to reach businesses, and inability of businesses to obtain supplies. In many coastal areas, significant reductions in business activity are due to reductions in tourism caused by storm threat and strike. The impacts of reductions in tourism due to increased storm severity are captured by our measure of business interruption impacts.

Estimates of business interruption impacts on economic output by county are developed for three climate change scenarios. For each scenario, business interruption impacts are based on results for the Wilmington, NC, region. We use an existing study that estimated business interruption impacts by industry sector at the county level for several low-intensity hurricanes striking Wilmington, NC, in the 1990's. The impacts are adjusted for inflation and projected increases in regional population and per capita economic output and applied to each scenario for New Hanover County. For other counties, the impacts are adjusted according to differences in industry mix across counties. The industry mix for each county is obtained from the IMPLAN economic impact software database (MIG 2005). The business interruption impacts of climate change for each county are measured by the differences in economic output impacts across climate change scenarios.

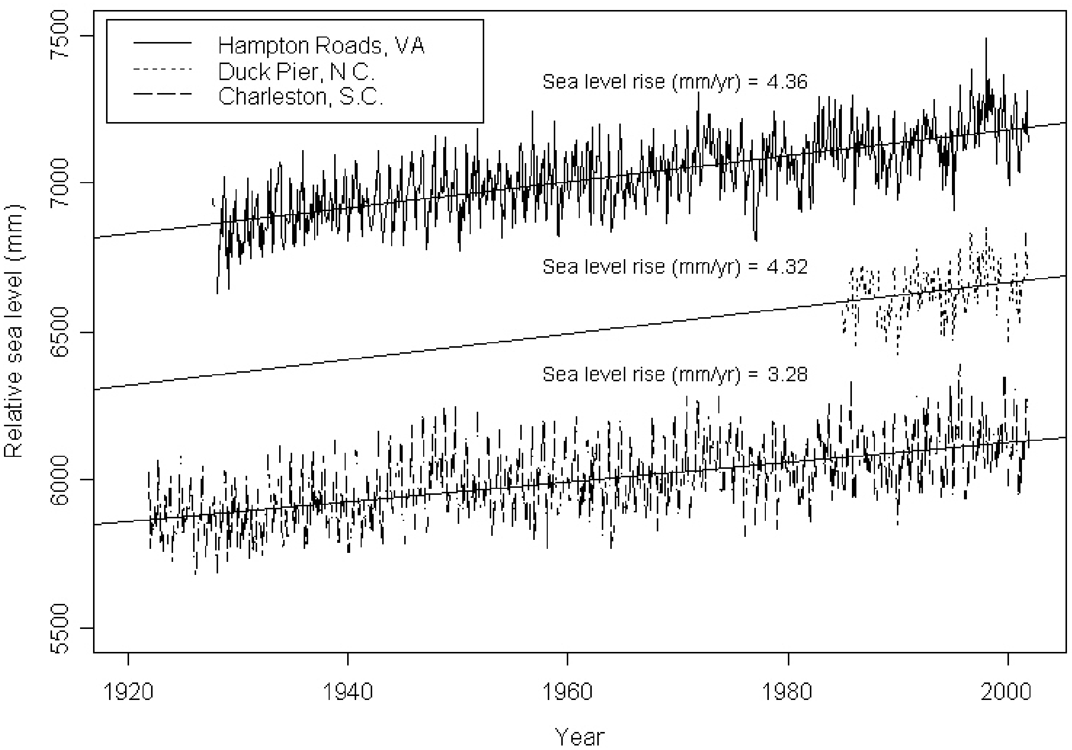
In addition to business interruption impacts, incremental storm damages to natural resource industries (agriculture, forestry and commercial fisheries) due to climate change are also assessed by comparing historical storm damages across storm categories for storm categories that are relevant to this study. Although data scarcity limits the ability to estimate economic impacts for the natural resource sectors, preliminary assessments are presented.

2. Methods for Coastal Impacts Analysis

Site Description

North Carolina's coastal plain is one of several large coastal systems around the world threatened by rising sea level (Moorhead and Brinson 1995, Titus and Richman 2001). Over 5000 km^2 of land are below 1-m elevation (relative to NAVD 88) and rates of sea level rise in this region are approximately double the global average due to local isostatic subsidence (Douglas and Peltier 2002, Poulter and Halpin, forthcoming). In the northern region of the state, rates of sea level rise are up to 0.4 meters per century, decreasing somewhat to 0.32 meters per century in the southern coastal region (Figure 1). Continued and projected sea level rise is expected to significantly impact natural and economic systems with estimates anywhere between 0.3 to 1.1 meters likely (Church et al. 2001).

Figure 1: Observed rates of sea level rise along the North Carolina coast (data from the Permanent Service for Mean Sea Level). From north to south, the gages are Hampton Roads, Duck Pier, and Charleston,.



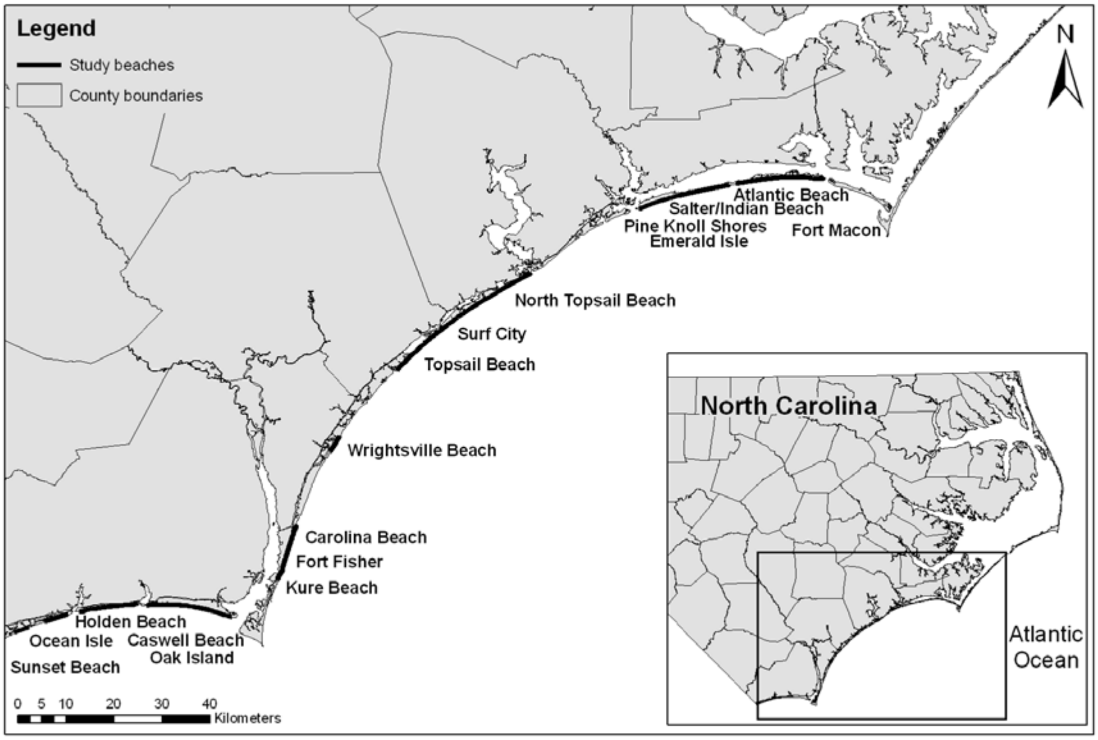
The study area considered in this analysis ranged from approximately 75-78º W and 34-35º N latitude. The climate is humid, sub-tropical (Christensen 2000) with an annual temperature of around 16º C and annual precipitation of around 1100 mm yr^{-1}. The natural landscape is well-known for its high biodiversity (Schafale and Weakley 1990) and includes habitat for American alligator, red-cockaded woodpecker, and black bear as well as numerous plant species. In addition, there are significant sources of carbon stored in extensive coastal peatlands that are vulnerable to erosion and decomposition from increasing sulphates concentrations introduced by rising sea level (Poulter et al. 2006, Henman and Poulter In Review).

Shoreline Impacts (Recreation and Fishing)

Recreation

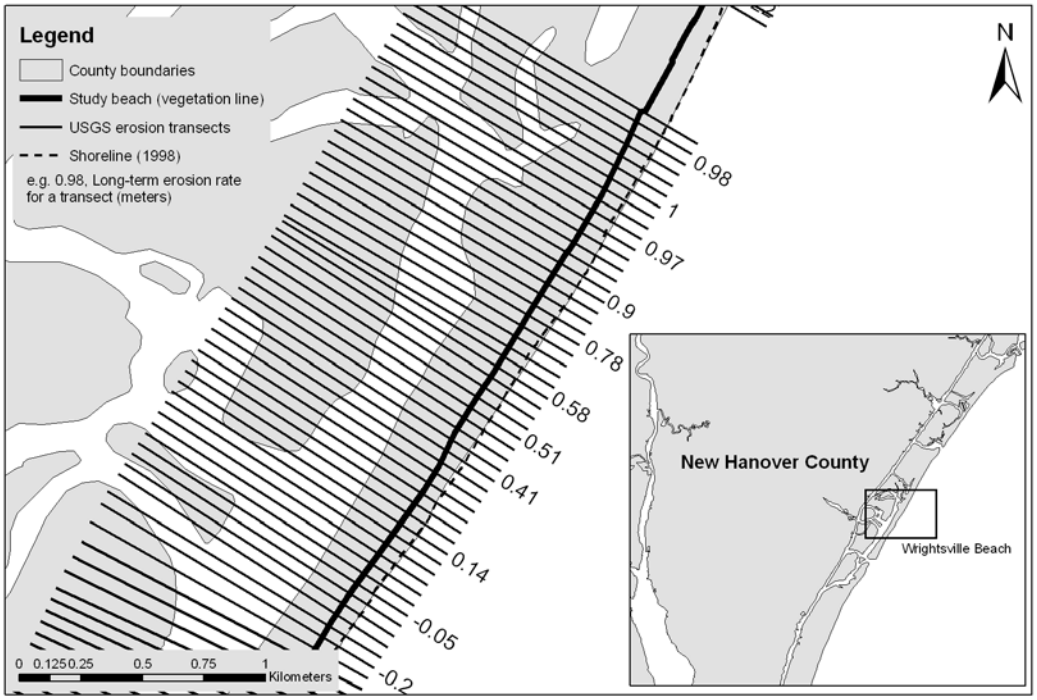
Seventeen beaches along the southern North Carolina coast were identified as major tourism destinations and selected for analysis of changing erosion rates with sea level rise (Figure 2). Data on beach width, length and usage were obtained from the U.S. Army Corps of Engineers. For each beach, the ocean-side vegetation line (where dune vegetation ends and unvegetated beach begins) was digitized into a Geographic Information System from USDA National Air Inventory Program's photographs. When possible, digitized vegetation line data were used from the North Carolina Division of Coastal Management datasets.

Figure 2: Location of the 17 recreational swimming beaches analyzed in this study



To calculate the erosion rate for each beach we used erosion rate transect data provided by the USGS (Figure 3). These data consist of long and short-term erosion data measured directly from aerial photograph time sequences. Each transect extends from the ocean toward the estuary and with attributes describing erosion. A series of these transects run north to south and capture any spatial variation in the rates of erosion that exist along the shoreline. Transects (separated by approximately 100 meters) were intersected with the vegetation line for a beach to obtain erosion rates. The erosion attributes for each transect were then partitioned according to each beach providing a range of erosion estimates that were then summarized to mean, minimum, maximum, and standard deviation (Table 2-1).

Figure 3: Erosion rates calculated for Wrightsville Beach from USGS erosion transects that intersect the Wrightsville Beach vegetation line.



Nourishment of beaches has been significant in coastal North Carolina which resulted in positive erosion rates (or accreting beaches). We identified beaches that had been nourished anytime prior to 1997 using data from the Program for Developed Shorelines at Duke University (Table 2-1). The erosion rate for these beaches was removed from our analysis. To estimate erosion rates for nourished beaches we used the overall mean erosion rate from all the erosion estimates from non-nourished beaches. This overall mean was used to project changes in erosion from climate change (Table 2-2).

To project changes in erosion from rising sea level and increased storminess we met with Dr. Orrin Pilkey from the Earth and Ocean Sciences Department at Duke University. Due to significant uncertainty in modeling shoreline response to global change (Cooper and Pilkey 2005, Slott et al. In press), Dr. Pilkey provided us with a range of percent increases in historic erosion rates that are most likely in the future based on his extensive experience in coastal NC. The historic erosion rates were adjusted by these percentages and then used for projecting future shoreline change. Two endpoints were used to project changes in beach width, the year 2030 and 2080 (with a low, mid, and high scenario for each year (Table 2-3)). The annual erosion rate was multiplied by the number of years to determine beach width lost, and this figure was subtracted from the beach widths provided by the U.S. Army Corps of Engineers.

Table 2-1: Summary of beach dimensions, nourishment, and erosion statistics for recreational beaches

Beach Name	Vegetation line from DCM	Nourished prior to 1997	Beach width (m)	Erosion Summary (m yr^{-1})				
				Mean	Standard Deviation	Minimum	Maximum	Number of transects (n)
Fort Macon	Yes	Y	27.43	0.70	0.25	0.12	1.09	43
Atlantic Beach	Yes	Y	41.15	0.25	0.24	-0.27	0.71	147
Pine Knoll Shores	Yes	N	33.53	-0.22	0.05	-0.33	-0.08	155
Salter Path/Indian Beach	Yes	N	27.43	-0.22	0.02	-0.24	-0.20	16
Emerald Isle		Y	39.62	0.30	0.22	-0.13	0.92	389
North Topsail Beach		Y	24.99	-0.11	0.22	-0.62	0.60	354
Surf City		Y	27.43	0.06	0.27	-0.53	0.61	191
Topsail Beach	Yes	Y	33.53	0.27	0.46	-0.35	1.20	115
Wrightsville Beach	Yes	Y	48.77	0.41	0.46	-0.47	1.00	65
Carolina Beach	Yes	Y	56.39	-0.31	0.23	-0.94	0.00	137
Kure Beach		N	39.62	-0.79	0.50	-2.03	-0.45	70
Fort Fisher		N	121.92	0.38	1.36	-1.48	5.09	24
Caswell Beach	Yes	N	24.38	-0.68	0.63	-1.43	0.31	91
Oak Island		N	36.58	-0.66	0.37	-1.35	-0.10	242
Holden Beach	Yes	Y	27.43	-0.56	0.46	-2.71	0.82	231
Ocean Isle Beach		Y	25.91	-0.50	0.53	-0.91	1.19	103
Sunset Beach		Naturally accreting	35.05	0.48	0.25	-0.09	0.83	58

This study makes a number of assumptions that affect the accuracy of this analysis. However, we provide a wide range of estimates to reflect this uncertainty. These assumptions include using a constant rate of erosion for the entire coastline of North Carolina, assuming that barrier island migration will not occur, that nourishment will not occur, and that the baseline erosion rate is accurate. The resulting economic analysis is not sensitive to these assumptions so we focus on the midrange erosion scenario.

Table 2-2: Summary of sea level rise, percent erosion increases, wind speed adjustments, and storm surge buffers for the low, mid, and high climate scenarios.

Year	Scenario	Projected sea level, including both eustatic and isostatic components (m)	Increase in erosion (%)	Wind Speed (%)	Storm surge buffer (m)
2030	Low	0.11	10	2	250
	Mid	0.16	20	2	500
	High	0.21	30	3	750
2080	Low	0.26	20	5	1000
	Mid	0.46	40	8	1500
	High	0.81	60	10	2000

In addition, it should be recognized that near-term human modification of beaches (i.e. shoreline hardening and bulkheading) will have a significantly greater effect on sediment supply and erosion dynamics than climate change (personal communication, Orrin Pilkey). However, shoreline hardening is not currently a policy option in North Carolina.

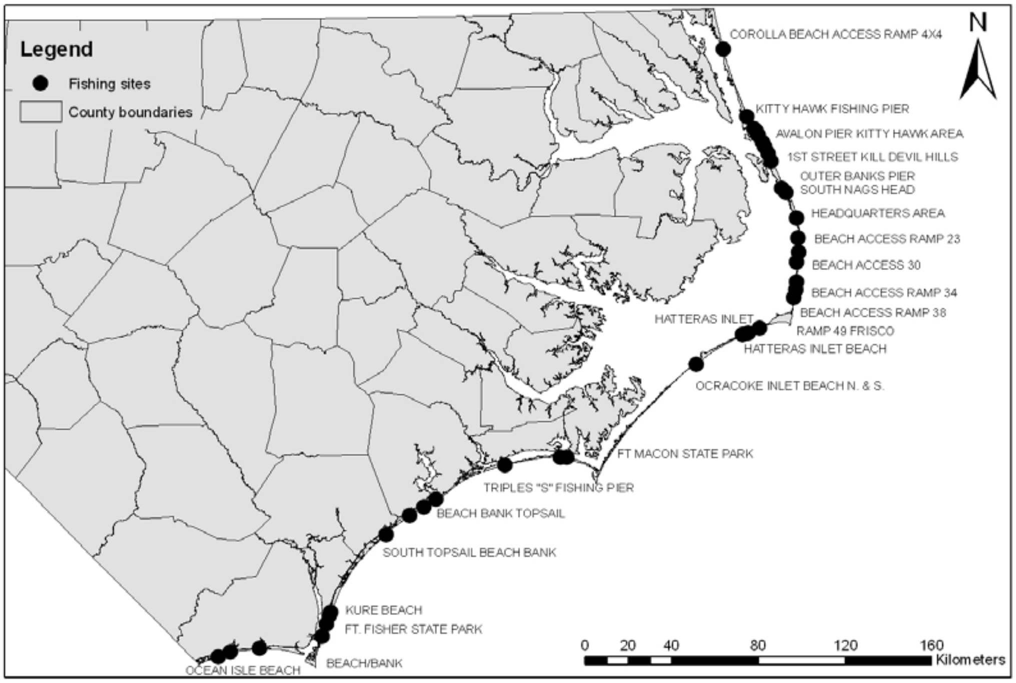
Table 2-3: Summary of projected erosion rates and width of beach losses for 2030 and 2080

	Projection Year					
	30-Years			80-Years		
Percent increase in erosion (%)	10	20	30	20	40	60
Average erosion rate from 20th century long-term rate of 0.4 m yr^{-1}	0.4	0.5	0.6	0.5	0.6	0.7
Long-term beach loss from erosion (m)	14.1	15.4	16.7	41.0	47.9	54.7

Fishing

Thirty-seven fishing locations were identified in this study as important open-ocean fishing locations (Figure 4). The vegetation line for each location was digitized for 1-3 km in either direction of the fishing location (initially identified as a lat/long point). The vegetation line was digitized using 2005 USDA National Air Inventory Program photographs using the same methods for the recreational beaches. The beach width for the fishing locations was not provided and was calculated by measuring the distance between the vegetation line and a vectorized 1998 shoreline provided by the North Carolina Division of Coastal Management.

Figure 4: Location of fishing beaches used in this study

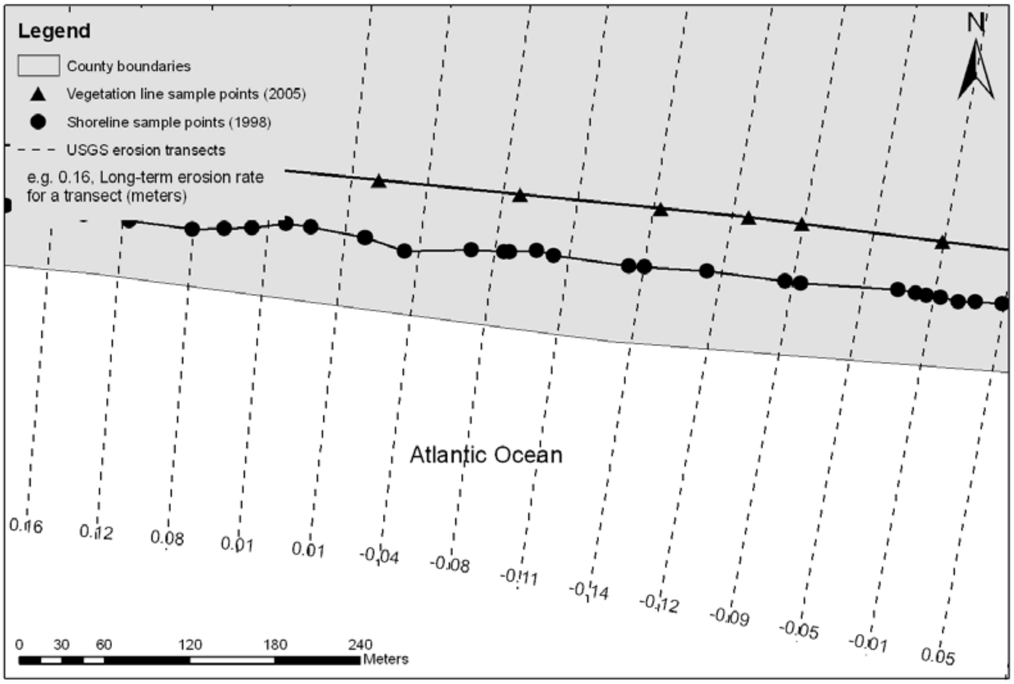


The erosion rates were calculated using the same methods as described for the recreational beaches. The same USGS dataset consisting of transects with erosion attributes was intersect with the fishing location data (Figure 5). The mean erosion rate for all non-nourished (and non-inlet) fishing locations was calculated. We did not use erosion rates from inlets to calculate the mean erosion rate because these locations are exceptionally dynamic and not representative of the entire coastline. Projected changes in beach width were then calculated for low, mid, and high scenarios for the years 2030 and 2080 using the percent increase factors recommended by Dr. Orrin Pilkey (Table 2-4). The resulting economic analysis focuses on the midrange erosion scenario.

Table 2-4: Summary statistics for fishing beaches and their erosion rates.

Beach Name	Beach width (m)	Erosion Summary (m yr^{-1})				
		Mean	Standard Deviation	Minimum	Maximum	Number of transects (n)
HOLDEN BEACH	27.17	-0.74	0.39	-2.71	-0.43	118
BEACH/BANK	43.14	-0.37	0.45	-0.81	0.82	113
OCEAN ISLE BEACH	36.66	-0.50	0.53	-0.91	1.19	103
TRIPLES "S" FISHING PIER	42.76	0.25	0.24	-0.27	0.71	147
FT MACON STATE PARK	46.88	0.70	0.25	0.12	1.09	43
EMERALD ISLE PUBLIC ACCESS AREA	39.11	0.30	0.22	-0.13	0.92	389
COROLLA BEACH ACCESS RAMP 4X4	66.27	-0.63	0.20	-0.9	-0.29	52
OREGON INLET SOUTH	211.47	-3.68	0.11	-3.93	-3.51	21
HATTERAS INLET	225.65	-5.42	0.06	-5.5	-5.32	13
HEADQUARTERS AREA	65.47	0.46	0.20	-0.1	0.7	47
AVALON PIER KITTY HAWK AREA	36.51	-0.83	0.14	-1.11	-0.61	96
JEANETTE'S OCEAN FISHING PIER	58.70	-0.83	0.11	-1.02	-0.66	32
KITTY HAWK FISHING PIER	36.22	-0.76	0.14	-0.96	-0.37	100
OUTER BANKS PIER SOUTH NAGS HEAD	310.36	-4.41	0.61	-5.81	-3.91	21
BEACH ACCESS RAMP 20	81.31	0.16	0.19	-0.28	0.4	40
BEACH ACCESS RAMP 23	84.87	1.02	0.42	0.3	1.6	80
BEACH ACCESS 27	59.53	0.12	0.16	-0.25	0.45	64
BEACH ACCESS 30	83.26	1.25	0.44	0.29	2.01	57
BEACH ACCESS RAMP 34	94.83	-0.42	0.40	-0.88	0.74	69
BEACH ACCESS RAMP 38	82.32	-1.81	1.12	-4.13	-0.45	135
CALVIN STREET KILL DEVIL HILLS	49.87	-0.56	0.15	-0.76	-0.23	26
1ST STREET KILL DEVIL HILLS	60.12	-0.35	0.06	-0.45	-0.22	33
PUBLIC ACCESS E.GULFSTREAM S.NAGSHD	45.02	-0.92	0.10	-1.05	-0.69	26
PUBLIC ACESS E. BONNETT ST NAGSHEAD	50.37	-1.24	0.16	-1.49	-0.95	33
PUBLIC ACCESS E.FOREST ST NAGSHEAD	47.73	-0.72	0.04	-0.79	-0.64	30
RAMP 49 FRISCO	55.03	-5.87	0.09	-6.01	-5.7	49
OCRACOKE INLET BEACH N. & S.	122.39	-5.42	0.06	-5.5	-5.32	13
HATTERAS INLET BEACH	276.45	-5.42	0.06	-5.5	-5.32	13
KURE BEACH	77.36	-0.20	0.13	-0.59	0	78
FT. FISHER STATE PARK	37.45	0.38	1.36	-1.48	5.09	24
CAROLINA BEACH NW EXTENSION	144.28	-1.36	0.17	-1.57	-1.02	35
CAROLINA BEACH PIER	79.40	-0.45	0.24	-0.94	-0.07	59
BEACH BANK TOPSAIL	51.34	0.00	0.07	-0.18	0.13	170
ACCESS AT NEW RIVER INLET DRIVE	50.97	-0.28	0.18	-0.62	0.11	152
NEW RIVER INLET, TOPSAIL ISLAND	60.87	0.07	0.34	-0.42	0.6	32
SOUTH TOPSAIL BEACH BANK	30.41	0.03	0.04	-0.04	0.1	58

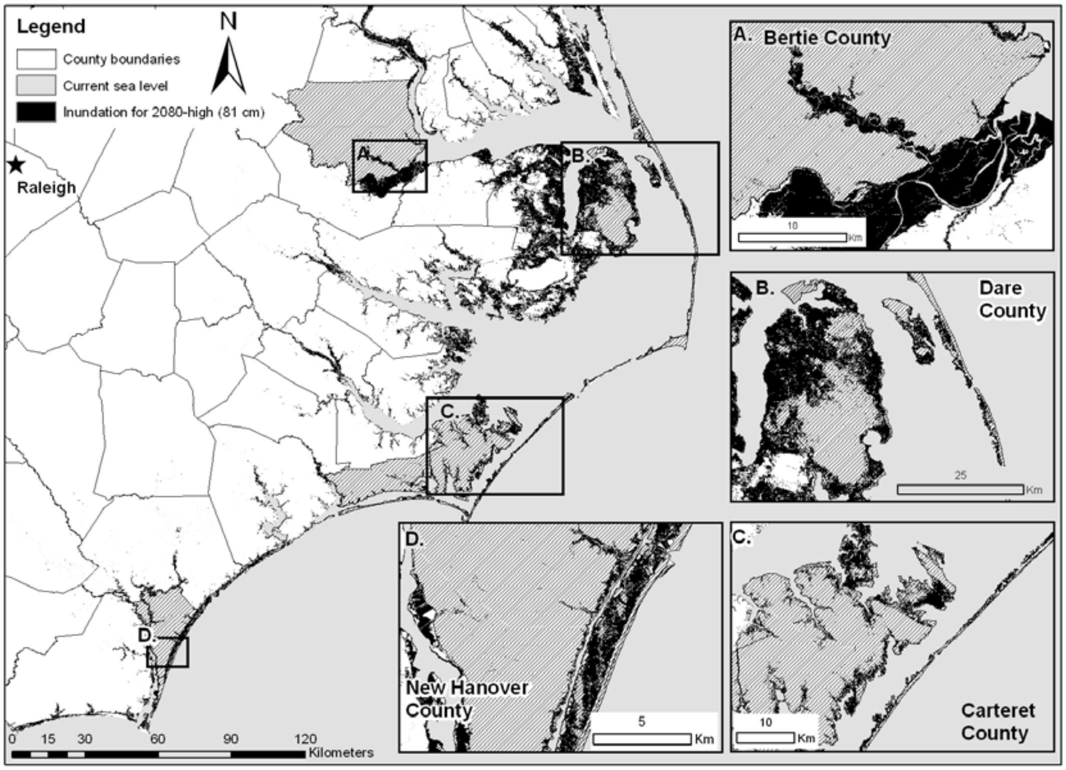
Figure 5: Erosion rates for fishing beaches calculated by intersecting USGS erosion transects with vegetation line. Beach width was computed as the distance between shoreline (determined by the NC Division of Coastal Management) and the vegetation line



Inundation Impacts

Six scenarios for future sea level rise were provided from recent GCM output representing low, mid, and high scenarios for 2030 and 2080 (Table 2-2). Estimates for sea level rise from the recent IPCC report (In Prep) are somewhat lower than the previous (2001) report, and considerable uncertainty continues to exist (Rahmstorf 2006). These scenarios were adjusted for regional subsidence that is geologically important in North Carolina (Tushingham and Peltier 1991). A LIDAR derived digital elevation model with +/- 25 cm vertical accuracy was assembled using data from the North Carolina Floodplain Mapping Program (NCFMP 2004). The horizontal resolution of the digital elevation model (DEM) was 15 meters. To model inundation from sea level rise we used an 8-side rule to maintain hydrologic contagion between the ocean and flooded grid cells (to prevent ponding in interior regions). The inundation results by county are shown in Figure 6.

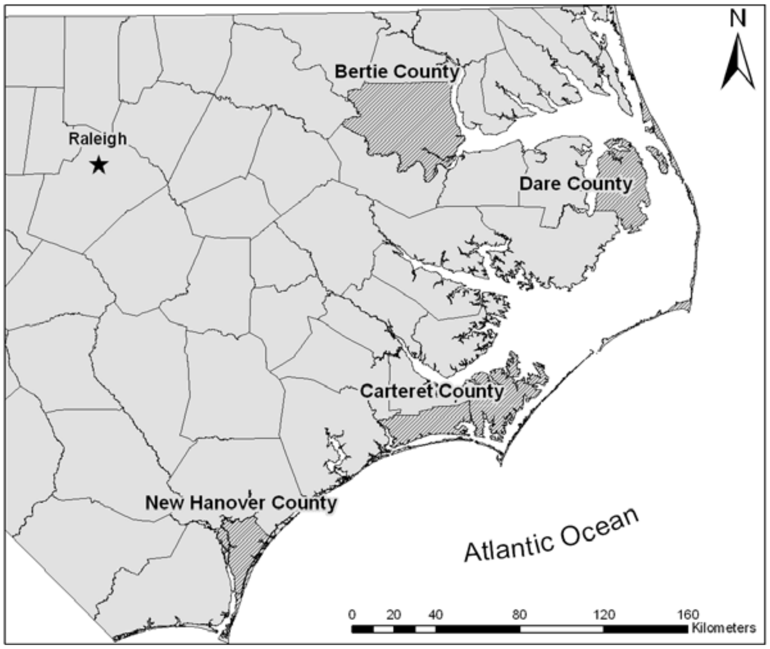
Figure 6: Inundation of coastal North Carolina with detailed examples for each of the counties investigated in this study. This particular example uses the high scenario for the year 2080 which includes both eustatic and isostatic sea level rise.



Tax Parcel Data

<u>Centroids</u>. Tax parcel spatial and tabular attributes were acquired for four counties representing a variety of geomorphic and economic resources. These counties were Bertie, Dare, Carteret, and New Hanover (Figure 7). The centroid for each tax parcel was calculated (restricting its location to within the tax parcel boundary) assuming that it represented average conditions within the tax parcel (Figure 8).

Figure 7: Location of counties analyzed for property impacts



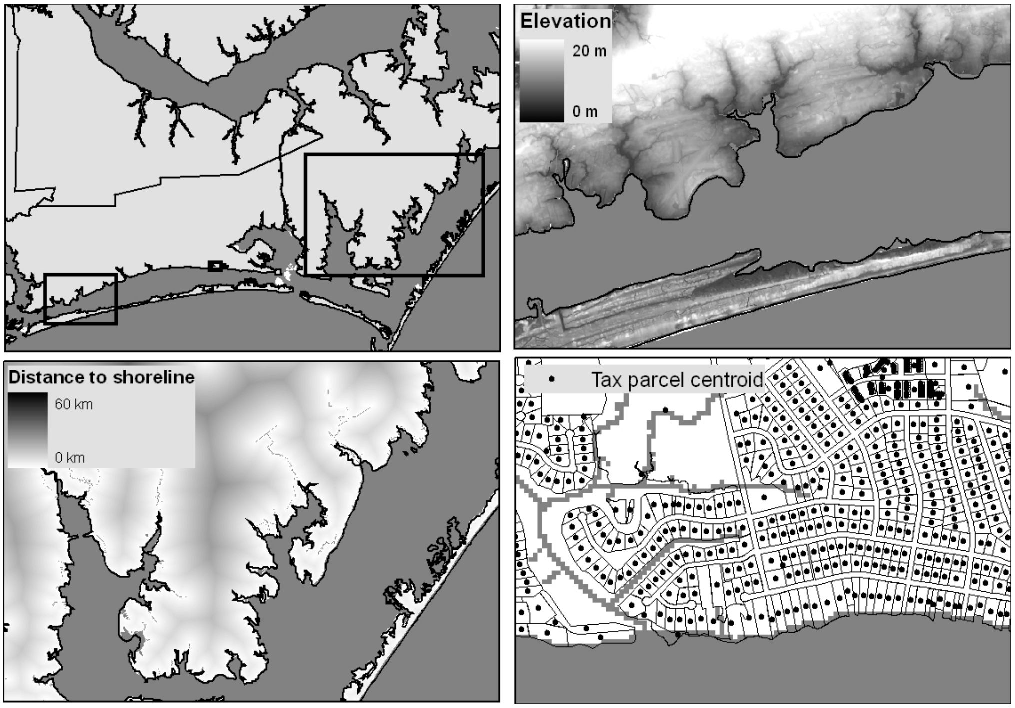
Shoreline location. Oceanfront and estuarine-front properties were identified for all four counties for current sea level. Attributes were added to these tax parcels indicating what type of shoreline position they currently occupy.

Shoreline distance. Distance to shoreline was created for each inundation scenario. We used Euclidean distance to describe the proximity of a tax parcel to the shoreline. Tax parcel centroids were then used to sample the seven distance surfaces (current and 6-scenarios).

Elevation. Elevation was sampled and assigned as an attribute to each tax parcel using the centroid. The LIDAR derived DEM was used as the source of elevation data. This DEM has had buildings systematically removed although there may still be errors that are greater than the average +/- 0.25 m. Therefore, it is most likely that the elevation values reported for tax parcels in dense urban areas represent an over-estimate for elevation.

Inundation. The six inundation grids representing the new shoreline-ocean interface following sea level rise was sampled by the tax parcel centroids. Attributes reflecting whether a tax parcel was inundated were added to each centroid.

Figure 8: Example of data sampling for property values for Carteret County (a), lidar elevation surface (b), distance to shoreline example (c), and tax parcel centriods (d).



Impacts on Hurricane Flooding

To evaluate changes in flood frequency we acquired a storm surge map from the North Carolina Center for Geographic Information and Analysis. This map indicates zones of potential flooding from storm surge for a Category 1, 2, 3, 4 or 5 hurricane using output generated from the SLOSH hydrodynamic model. We conducted a sensitivity analysis to determine the impact of these storm surge boundaries extending further inland as sea level rise and more intense hurricanes alter flooding. Six scenarios were developed where we buffered the storm surge boundaries by various distances so that the Category 4-5 zone expanded further inland (Table 2-2). The centroids for individual tax parcels were then intersected with the storm surge zone maps to determine whether inundation occurred.

Impacts on Hurricane Wind Speeds

Perhaps the best way to characterize the general effects of climate change on storm wind speed at a particular location (for example, a particular county in coastal North Carolina) is to describe changes in the wind speed frequency distribution (often modeled as a Weibull distribution) at the location. However, the climate models used in this study did not provide the types of output needed to fully specify changes in wind speed frequency distributions. Instead, the climate models provided information sufficient to characterize wind speeds for one storm under three scenarios. The climate models provided maximum sustained wind speed data for each of the four case study counties for three scenarios: a baseline scenario defined as the 1996 hurricane Fran strike, and two climate change scenarios defined as the hurricane Fran strike adjusted for the effects of climate change in 2030 and 2080. Analysis of these three scenarios allows results to be presented in terms that will be relatively familiar and interpretable by a lay audience—a comparison of a recent, familiar, "known" storm with storms affected by climate change. The baseline storm (hurricane Fran) is a category 3 hurricane on the Saffir-Simpson hurricane intensity scale. Hence, our analysis provides estimates of the effects of climate change for a storm that *would be* a category 3 hurricane under conditions of no climate change and that strikes North Carolina with a track similar to the one taken by hurricane Fran.

We used the Hurrecon model (Boose et al. 1994, Foster et al. 1999) to estimate wind speeds for coastal North Carolina based on the Hurricane Fran track of 1996 (a Category 3 hurricane that made landfall in New Hanover County) (see Table 2-5). Hurricane Fran's track was interpolated from 3-hourly measurements provided by NOAA to 1-hourly data. For each time point, maximum wind gusts and maximum sustained wind velocity surfaces were calculated using Hurrecon. This model takes the observed maximum wind speed along the hurricane track and predicts wind speeds based on distance from the eye of the hurricane making relatively simple assumptions about surface roughness.

For the climate change scenario, we estimated wind speeds for a hypothetical hurricane following hurricane Fran's track that would have been a category 3 hurricane in the absence of climate change. The spatial distribution of wind speeds generated for the climate change scenarios are similar to the baseline hurricane Fran wind fields due to the spatial resolution used in the inputs to the Hurrecon model and the sensitivity (or lack thereof) of the function describing the rate of decreasing wind speeds as the distance from the eye increases. Baseline (hurricane Fran) wind speed intensity was modified based on an analysis of model runs provided by MAGIC/SCENGEN that relates storm intensity (wind speed) to sea surface temperature (Knutson and Tuleya 2004) provided by Joel Smith (Stratus Consulting). The resulting percentage increases in wind speeds for the climate change scenarios are presented in Table 2-2. Wind speeds for the climate change scenarios were calcuated by simply multiplying baseline (hurricane Fran) wind speeds by the percentage increases in wind speeds.

As with the previous methods, the centroids for the tax parcels were intersected with the maximum wind speed maps (for gusts and maximum sustained wind speed). For each county considered in the analysis, average (within the county) maximum sustained wind speed was calculated for the baseline 1996 category 3 hurricane (Fran) scenario and for each climate change scenario, assuming that the storms in the climate change scenarios follow hurricane Fran's spatial track (Table 2-5). Wind speeds vary across counties for a given scenario due to differences across counties in latitude, distance from the ocean, topography, etc.

Table 2-5: Maximum sustained wind speed (m/s) data for a category 3 hurricane (hurricane Fran) under baseline (no climate change) conditions and two climate change scenarios.

	Category 3 Hurricane (Hurricane Fran) Baseline			Climate Change Scenarios					
	1996	1996	1996	2030	2030	2030	2080	2080	2080
County	MIN	MID	MAX	MIN	MID	MAX	MIN	MID	MAX
Bertie	23	24	31	23	25	32	25	26	33
Carteret	28	34	43	29	35	44	30	37	46
Dare	22	28	32	22	28	33	24	30	35
New Hanover	36	38	47	37	39	48	39	41	51

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3. Impacts on Real Estate Markets

Introduction

Coastal areas in the U.S. have seen growing populations and increased economic activity in recent years. Population in the coastal zone grew 37% between 1970 and 2000. The coastal zone contains only 4% of the U.S. land area, but the economic activity measured by employment and value added in the coastal zone contributed 11% to the U.S. economy in 2000 (Colgan 2004). Population growth has been accompanied by unparalleled growth in property values. The Heinz Center Report (2000) estimated that a typical coastal property is worth from 8% to 45% more than a comparable inland property. The relatively dense populations and valuable coastal properties are vulnerable to substantial risks including coastal flooding, shoreline erosion, and storm damages.

The purpose of this section of the study is to estimate the impacts of sea level rise on property values in coastal North Carolina. The sea level rise scenarios considered are an 11 centimeters (cm) increase in sea level by 2030 (2030-Low), a 16 cm increase by 2030 (2030-Mid), a 21 cm increase by 2030 (2030-High), a 26 cm increase by 2080 (2080-Low), a 46 cm increase by 2080 (2080-Mid), and an 81 cm increase by 2080 (2080-High). Data on property values come from the county tax offices which maintain property parcel records that include assessed value of property as well as lot size, total square footage, the year the structure was built, and other structural characteristics of the property. Spatial amenities such as ocean and sound/estuarine frontage, distance to nearest shoreline and elevation are also obtained using the Geographic Information Systems (GIS). All impacts are measured in 2004 U.S. dollars.

This study estimates the loss of property values due to sea level rise using a simulation approach within a hedonic property model framework. In this approach, the property values are regressed on structural, location, and environmental attributes. Separate hedonic schedules are estimated for residential and non-residential properties. The estimated regression provides the relative importance of each property attribute in determining the property values. Numerous studies have applied hedonic property value models to estimate the impact on property values from hazard risks such as flood hazards (MacDonald, Murdoch, and White 1987; MacDonald, et al. 1990; Bin and Polasky 2004), earthquake/volcanic hazards (Bernknopf, Brookshire, and Thayer 1990; Beron et al. 1997), hazardous waste and Superfund sites (Clark and Allison 1999; Gayer, Hamilton, and Viscusi 2000; McClusky and Rausser 2001), erosion hazards (Kriesel, Randall, and Lichtkoppler 1993; Landry, Keeler, and Kriesel 2003), and wind hazards (Simmons, Kruse, and Smith 2000).

The results indicate that the impacts of sea level rise vary among different portions of North Carolina coastline. Without discounting, the residential property value loss in Dare County ranges from $406 million (2.18%) to $4.5 billion (11.59%), and the loss in Carteret County ranges from $43 million (0.48%) to $488 million (2.58%). New Hanover and Bertie counties show relatively smaller impacts. New Hanover County has the estimated residential property value loss between $62 million (0.35%) and $354 million (0.96%), and Bertie County has the loss between $3 million (0.29%) and $12 million (0.51%).

Using a 2% discount rate, the residential property value loss in Dare County ranges from $242 million (1.30%) to $2.7 billion (6.93%), and the loss in Carteret County ranges from $26 million (0.29%) to $291 million (1.54%). New Hanover County has the estimated residential property value loss between $37 million (0.21%) and $212 million (0.57%), and Bertie County has the loss between $2 million (0.17%) and $7 million (0.30%).

Using a 7% discount rate, the residential property value loss in Dare County ranges from $70 million (0.38%) to $776 million (2.00%), and the loss in Carteret County ranges from $7 million (0.08%) to $84 million (0.44%). New Hanover County has the estimated residential property value loss between $11 million (0.06%) and $61 million (0.16%), and Bertie County has the loss between $1 million (0.05%) and $2 million (0.09%).

Overall, the northern part of the North Carolina coastline is comparatively more vulnerable to the effect of sea level rise than the southern part. Low-lying and heavily developed areas in the northern coastline of North Carolina are especially at high risk from sea level rise.

Methods

Since the pioneering work by Rosen (1974), hedonic property models have been extensively used to infer the preferences of real estate and other market participants. The models assume that values of heterogeneous bundles of property attributes are reflected in differential property prices. Given that residential property can be distinguished based upon structural, neighborhood, and environmental characteristics, one can assume that utility (i.e., happiness) derives directly from these attributes rather than consumption of the property itself. The market price of property, which is observable, thus represents the value of the collection of attributes. Residential homes are composite goods that contain different amounts of a variety of attributes, and observing how property values change as the level of various attributes change provides a way of estimating the marginal value of these attributes to property owners. Palmquist (2004) provides a useful summary of the hedonic property models.

Suppose that $\boldsymbol{S}$ represent a matrix of structural characteristics such as lot size, age, and number of bathrooms. Let $\boldsymbol{N}$ represent neighborhood characteristics such as township and distance to nearest shoreline. Also, let $\boldsymbol{E}$ represent environmental characteristics such as ocean/sound frontage and property elevation. Given a vector of observed property values, $\boldsymbol{R}$, the hedonic price function can be written as:

$$\boldsymbol{R} = \boldsymbol{R}(\boldsymbol{S}, \boldsymbol{N}, \boldsymbol{E}). \qquad [1]$$

The housing market is assumed to be in equilibrium, which requires that households optimize their residential choice (determining $\boldsymbol{S}$, $\boldsymbol{N}$, and $\boldsymbol{E}$) based on the exogenous price schedule for available housing in a market. Estimation and partial differentiation of the hedonic price function with respect to an attribute reveals the average household's marginal willingness to pay (WTP) for that attribute. The analysis is only useful for estimating WTP for marginal (i.e., small) changes in environmental quality (e.g., long term shoreline erosion). Additional data on demand-shifting parameters (i.e. income and other socioeconomic variables) are necessary to estimate the welfare impacts from non-marginal environmental changes.

This study estimates the following hedonic price function:

$$\ln \boldsymbol{R} = \alpha + \sum_i \beta_i \boldsymbol{S}_i + \sum_j \gamma_j \boldsymbol{N}_j + \sum_k \phi_k \boldsymbol{E}_k + \boldsymbol{\varepsilon}, \qquad [2]$$

where ln ***R*** is the log of assessed property value, α, β, γ, and ϕ are the unknown parameters to be estimated, and $\boldsymbol{\varepsilon}$ is an independent random error term. Both reported sales prices and market assessed values have been used in the hedonic literature as proxies for the true sales prices.

Reported sales prices may not reflect the true sales prices because they may not incorporate the price adjustments in the sales negotiation process or they may be intentionally misreported (Mooney and Eisgruber 2001). Many state statutes require that all property be valued at 100 percent of current market value for their property tax purpose. In fact, Dare County recently implemented countywide re-evaluation of property values to reflect the real market prices. This study uses the market assessed values as the dependent variable in the hedonic regression because these values are highly correlated with the reported sales prices (for a limited number of the records with recent sales transactions) and result in a larger sample size for econometric analysis.

We use quadratic specifications for non-dichotomous property attributes such as age of the property and total structural square footage in order to capture the diminishing marginal effect. The effect of these attributes on property values is assumed to decline as the level of these attributes increase. The primary results are robust across several alternative specifications, and the current specification provided the best overall model fit. We report the standard errors and p-values based upon the consistent estimator of the covariance matrix corrected for potential heteroskedasticity.

Equation [2] is estimated using all observations that locate within a mile from the coastline.[1] Separate hedonic price schedules are estimated for residential and non-residential properties. The estimated hedonic price functions are then used to simulate the property value loss for various sea level rise scenarios. We use a method similar to Parsons and Powell (2001). The net loss in property values from sea level rise in year *t* can be represented by

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[1] With an exception of Bertie County, almost all observations in Dare, Carteret, and New Hanover counties locate within a mile from the shoreline. In Bertie County, coastal property owners may not consider the adjacent inland properties as potential substitutes. All properties at risk are within a mile from the coastline.

$$Net\ \mathrm{Loss}_t = \delta \cdot \left\{ \boldsymbol{R}_{LOST,t} - A_{LOST,t} + \Delta \boldsymbol{R}_{INV,t} \right\}. \qquad [3]$$

The first term $\boldsymbol{R}_{LOST,t}$ is the value of lost properties in year *t*. The second term $A_{LOST,t}$ is the amenity value of the lost properties in year *t*, which is purged from the total value. The property at the time of loss would not have the peak value which stems from the amenities associated with its current waterfront location. The third term $\Delta\mathbf{R}_{INV,t}$ is the change in the value of other properties in the inventory due to a permanent change in location and the market condition of the developed area, and δ is the discount factor.

We focus on the first two terms because estimating the third term requires additional data as it depends on the perception and behaviors of coastal property owners (i.e. discounting and risk preference), communities, and regulatory agencies. The third term relates to adjustments induced by sea level rise, and the impacts are relatively small compared to the first two categories. The net loss in [3] is measured by the following steps. First, the hedonic price models are estimated to predict the contribution of each attribute to the value of the property. Second, the value of risks and amenities of the lost properties are purged from the total value of the lost properties. It is assumed that each lost property has the same structural characteristics but no water frontage and that it has the distance from the shoreline and the elevation evaluated at the sample mean. Third, the predicted value of each lost property is inflated to 2030 or 2080.[2] The value is then discounted to present using various discount rates (no discounting, 2%, 5%, and 7%) for sensitivity analysis.

Results

Table 3-1 shows the distribution of current property values at risk from sea level rise. Displayed are the current property values that will be lost under the inundation scenarios. The most significant loss is occurring in Dare County, followed by Carteret, New Hanover, and Bertie counties. For Dare County, the percentage of the loss to the total property value ranges from 6% to 19%. Dense development along the Outer Banks in Dare County is subject to the most dynamic geological process in North Carolina. Carteret County has the loss ranging from 2% to 5% while New Hanover County has a relative small impact between less than one percent and 1.5%. The impact on Bertie County is also similar to that of New Hanover County. The hedonic regression and simulation results for each county are reported below.

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[2] The adjustment is based on a Special Report on Emissions Scenarios (SRES) by the IPCC. Per capita personal income level in 2004 is compared to the 2030 and 2080 income levels, which provides 1.517 for inflating the 2004 lost values to 2030 dollars and 3.172 for the inflating 2004 lost values to 2080 dollars.

Table 3-1: Current Property Values at Risk in North Carolina

	Total Values	Sea Level Rise Scenarios					
		2030-Low	2030-Mid	2030-High	2080-Low	2080-Mid	2080-High
New Hanover							
Total	$16,154,421,910	$80,363,644	$84,415,484	$88,871,520	$95,187,467	$123,010,639	$227,704,809
*(n)	85,786	495	516	544	574	680	1,063
**(%)		0.50%	0.52%	0.55%	0.59%	0.76%	1.41%
Residential	$11,688,362,599	$62,149,975	$66,201,267	$70,590,850	$72,850,081	$90,724,269	$167,398,608
(n)	74,984	345	360	385	403	476	773
(%)		0.53%	0.57%	0.60%	0.62%	0.78%	1.43%
Nonresidential	$4,466,059,311	$18,213,669	$18,214,217	$18,280,670	$22,337,386	$32,286,370	$60,306,201
(n)	10,802	150	156	159	171	204	290
(%)		0.41%	0.41%	0.41%	0.50%	0.72%	1.35%
Dare							
Total	$18,800,008,900	$1,142,866,500	$1,241,804,000	$1,332,870,500	$1,622,998,600	$2,224,747,700	$3,544,751,100
(n)	38,780	1,506	1,725	1,965	2,331	4,004	7,716
(%)		6.08%	6.61%	7.09%	8.63%	11.83%	18.86%
Residential	$12,262,755,500	$365,991,100	$410,835,300	$461,919,900	$521,547,700	$906,674,500	$1,801,992,600
(n)	27,006	825	927	1,051	1,225	2,143	4,371
(%)		2.98%	3.35%	3.77%	4.25%	7.39%	14.69%
Nonresidential	$6,537,253,400	$776,875,400	$830,968,700	$870,950,600	$1,101,450,900	$1,318,073,200	$1,742,758,500
(n)	11,774	681	798	914	1,106	1,861	3,345
(%)		11.88%	12.71%	13.32%	16.85%	20.16%	26.66%
Carteret							
Total	$8,217,336,284	$172,082,588	$176,378,147	$185,818,633	$202,376,889	$260,333,900	$433,401,826
(n)	55,509	1,077	1,140	1,225	1,322	1,977	3,890
(%)		2.09%	2.15%	2.26%	2.46%	3.17%	5.27%
Residential	$5,960,237,380	$42,828,093	$45,528,169	$49,406,827	$56,115,882	$92,285,041	$208,047,285
(n)	34,073	192	207	228	261	468	1,204
(%)		0.72%	0.76%	0.83%	0.94%	1.55%	3.49%
Nonresidential	$2,257,098,904	$129,254,495	$130,849,978	$136,411,806	$146,261,007	$168,048,859	$225,354,541
(n)	21,436	885	933	997	1,061	1,509	2,686
(%)		5.73%	5.80%	6.04%	6.48%	7.45%	9.98%
Bertie							
Total	$1,001,181,659	$5,248,975	$6,057,921	$6,631,122	$6,748,592	$8,450,076	$12,571,118
(n)	17,502	72	81	93	99	126	174
(%)		0.52%	0.61%	0.66%	0.67%	0.84%	1.26%
Residential	$727,088,075	$3,215,894	$3,731,251	$3,919,220	$4,035,716	$4,988,806	$7,660,841
(n)	15,777	55	61	68	73	91	126
(%)		0.44%	0.51%	0.54%	0.56%	0.69%	1.05%
Nonresidential	$274,093,584	$2,033,081	$2,326,670	$2,711,902	$2,712,876	$3,461,270	$4,910,277
(n)	1,725	17	20	25	26	35	48
(%)		0.74%	0.85%	0.99%	0.99%	1.26%	1.79%

* The number of property at risk

** The percentage to the total property value

New Hanover County

New Hanover County is located in the southern part of the NC coastline and is highly developed relative to other coastal counties. The variable definitions and summary statistics for a total of 39,546 residential properties are given in Table 3-2. The average residential property value is \$176,554. The data contain a series of structural attributes that are common in hedonic analysis. The properties are on average 25 years old and have about 1786 total structure square feet. About 90 percent of the observations have central air conditioning, and about one third of the houses are multistory units. Geocoded data provide an indicator for coastal water frontage and other important spatial measures. About one percent of the properties have ocean frontage and two percent have a sound/estuarine frontage. The mean distance to the nearest shoreline is about 1812 feet and the elevation of the properties is on average 26 feet above see level. The distance to the nearest shoreline is measured as the Euclidean distance in feet from the edge of each property to the nearest coastline.

Table 3-2: Definitions and Summary Statistics for the New Hanover Residential Property Data

Variable	Description	Mean	Standard Deviation
AV	Real assessed property value as of May 2006	176,554.01	152,684.14
WRIGHTS	Wrightsville Beach township (= 1)	0.02	0.13
CAROLINA	Carolina Beach township (= 1)	0.04	0.20
KURE	Kure Beach township (= 1)	0.03	0.16
FIGEIGHT	Castle Hayne township (=1)	0.02	0.15
LOTSIZE	Total lot size measured in square feet	16,375.63	23,106.41
SQFT	Total structure square footage	1,786.05	798.79
AGE	Age of house	25.46	23.12
BATHRM	Number of bathrooms	2.23	0.85
AIRCOND	Central air conditioning (= 1)	0.90	0.30
FIREPLCE	Fireplace (= 1)	0.64	0.48
MULTISTR	Multistory house (= 1)	0.30	0.46
DETGAR	Detached garage (= 1)	0.07	0.26
OCEAN	On ocean front (= 1)	0.01	0.08
SOUND	On sound front (= 1)	0.02	0.12
DIST	Distance to nearest shoreline measured in feet	1,811.87	1,273.46
ELEV	Elevation of property measured in feet	26.21	12.14

Note: The number of observations is 39,546.

The baseline hedonic property model is estimated using the 39,546 residential property records. The natural log of assessed property values are used as the dependent variable, giving the hedonic regression the common semilog functional form. The regression model controls for heterogeneity across townships using a set of dummy variables representing four townships in New Hanover County. The coefficient estimates are reported in Table 3-3. Adjusted R^2 is 0.86, indicating overall a good fit. Most structural and neighborhood variables are statistically significant at any conventional level of significance (p-value < 0.0001), with an exception of the multistory indicator. Most coefficient signs are consistent with common findings in the hedonic literature.

Table 3-3: Estimation Results for the New Hanover Residential Hedonic Model

Variable	Coefficient	Standard Error	P-value
Constant	10.612	0.012	<.0001
WRIGHTS	0.837	0.010	<.0001
CAROLINA	0.128	0.007	<.0001
KURE	0.272	0.007	<.0001
FIGEIGHT	-0.168	0.008	<.0001
LOTSIZE	2.44E-06	8.44E-08	<.0001
LOTSIZE^2	-1.40E-12	1.26E-13	<.0001
SQFT	0.001	3.74E-06	<.0001
SQFT^2	-2.39E-08	4.04E-10	<.0001
AGE	-0.005	1.68E-04	<.0001
AGE^2	1.97E-05	1.82E-06	<.0001
BATHRM	0.200	0.006	<.0001
BATHRM^2	-0.016	0.001	<.0001
AIRCOND	0.155	0.005	<.0001
FIREPLCE	0.144	0.003	<.0001
MULTISTR	-4.66E-04	0.003	0.8817
DETGAR	0.058	0.004	<.0001
OCEAN	0.545	0.014	<.0001
SOUND	0.345	0.010	<.0001
DIST	-2.97E-05	3.42E-06	<.0001
DIST^2	5.04E-09	6.78E-10	<.0001
ELEV	-0.009	4.47E-04	<.0001
ELEV^2	8.92E-05	7.26E-06	<.0001

Notes: Number of observations is 39,546. Dependent variable is the log of assessed property values. Omitted category for township is Wilmington. Adjusted R^2 is 0.8641.

Proximity to shoreline has a strong positive effect on property values. Water frontage also commands a substantial premium and raises the property values by about 55% for ocean frontage and 35% for sound frontage. Milon, Gressel, and Mulkey (1984) estimated a large positive value from being close to the shore. They found that property values declined 36% in moving 500 feet from the Gulf of Mexico. Other studies have also found positive values for water proximity (Shabman and Bertelson 1979; Earnhart 2001).

The specification used to generate the results for nonresidential properties is identical to the one used to generate Table 3-3. However, the parcel records for nonresidential properties such as governmental properties normally do not contain structural information (e.g. number of room, fireplace, etc). Thus, the hedonic regression is estimated with fewer independent variables.[3]

The simulation results under different sea level rise scenarios are reported in Table 3-4 for both residential and non-residential observations. The discount rates of 2%, 5%, and 7% as well as a zero discount rate are used to provide the present value of the loss. Without discounting,

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[3] The results are available upon request.

the residential property value loss in New Hanover County ranges from $62 million (0.35%) to $354 million (0.96%), and the non-residential property value loss ranges from $33 million (0.49%) to $155 million (1.09%).

Table 3-4: Present Value of Property Value Losses for New Hanover County

Residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$61.82	0.35%	$36.94	0.21%	$17.39	0.10%	$10.64	0.06%
2030-Mid	$65.49	0.37%	$39.14	0.22%	$18.42	0.10%	$11.28	0.06%
2030-High	$69.72	0.39%	$41.66	0.23%	$19.61	0.11%	$12.00	0.07%
2080-Low	$151.56	0.41%	$90.57	0.24%	$42.62	0.11%	$26.10	0.07%
2080-Mid	$194.37	0.52%	$116.15	0.31%	$54.66	0.15%	$33.47	0.09%
2080-High	$354.14	0.96%	$211.63	0.57%	$99.60	0.27%	$60.98	0.16%
Non-residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$33.01	0.49%	$19.73	0.29%	$9.28	0.14%	$5.68	0.08%
2030-Mid	$33.01	0.49%	$19.73	0.29%	$9.28	0.14%	$5.68	0.08%
2030-High	$33.28	0.49%	$19.89	0.29%	$9.36	0.14%	$5.73	0.08%
2080-Low	$78.81	0.56%	$47.09	0.33%	$22.16	0.16%	$13.57	0.10%
2080-Mid	$103.96	0.73%	$62.13	0.44%	$29.24	0.21%	$17.90	0.13%
2080-High	$154.62	1.09%	$92.40	0.65%	$43.49	0.31%	$26.63	0.19%

Notes: 2030-Low, 2030-Mid, and 2030-High represent an 11 cm, a 16 cm, and a 21 cm increase in sea level by 2030, respectively. Similarly, 2080-Low, 2080-Mid, and 2080-High represent a 26 cm, a 46 cm, and an 81 cm increase in sea level by 2080, respectively. Dollars are measured in million. Reported are the percent to the total property values.

Based on a 2% discount rate, the residential property value loss ranges from $37 million (0.21%) to $212 million (0.57%), and the non-residential property value loss ranges from $20 million (0.29%) to $92 million (0.65%). Based on a 7% discount rate, the residential property value loss ranges from $11 million (0.06%) to $61 million (0.16%), and the non-residential property value loss ranges from $6 million (0.08%) to $27 million (0.19%). The non-residential properties display a smaller impact, although the percent terms are quite comparable to those of the residential properties.

Dare County

Dare County is located in the northern part of the NC coastline and represents one of the most developed areas on the NC coastline. The northern section of the NC coastline experiences very active geological process compared to other parts of the coastline. The area is low-lying and vulnerable to various coastal natural hazards.

The variable definitions and summary statistics for a total of 25,870 residential properties are given in Table 3-5. The average property value is about $456,058.[4] The properties are on average 21 years old and have the total lot size of about 21,548 square feet. More than 90 percent of the houses have central air conditioning and about one half of them are multistory homes. Given the location of the county and substantial development on the Outer Banks, Dare County has about eight percent of the properties on the ocean front and about twelve percent on the sound/estuarine front. The mean distance to nearest shoreline is about 1360 feet and the elevation of the properties is on average 7.9 feet above sea level. Most homes are located close to shorelines and have lower elevations.

Table 3-5: Definitions and Summary Statistics for the Dare Residential Property Data

Variable	Description	Mean	Standard Deviation
AV	Real assessed property value as of May 2006	456,058.27	358,961.55
AVON	Avon township (= 1)	0.06	0.23
BUXTON	Buxton township (= 1)	0.02	0.15
DUCK	Duck township (= 1)	0.08	0.28
FRISCO	Frisco township (=1)	0.04	0.19
HATTERAS	Hatteras township (=1)	0.03	0.16
KDH	Kill Devil Hills township (=1)	0.20	0.40
KITTY	Kitty Hawk township (=1)	0.08	0.27
NAGS	Nags Head township (=1)	0.15	0.36
RODANT	Rodant township (=1)	0.02	0.12
SALVO	Salvo township (=1)	0.02	0.15
SOUTHERN	Southern Shores township (=1)	0.09	0.28
WAVES	Waves township (=1)	0.01	0.11
LOTSIZE	Total lot size measured in square feet	21,547.65	135,918.19
AGE	Age of house	21.35	17.17
BEDRM	Number of bedrooms	3.54	1.12
AIRCOND	Central air conditioning (= 1)	0.91	0.29
MULTISTR	Multistory house (= 1)	0.51	0.50
HDWDFL	Hardwood floor (= 1)	0.07	0.25
OCEAN	On ocean front (= 1)	0.08	0.27
SOUND	On sound front (= 1)	0.12	0.32
DIST	Distance to nearest shoreline measured in feet	1,361.90	969.58
ELEV	Elevation of property measured in feet	7.86	7.10

Note: The number of observations is 25,870.

The baseline hedonic regression results are reported in Table 3-6. The natural log of assessed property values is used as the dependent variable, and the quadratic specification is used for non-dichotomous independent variables to capture diminishing marginal returns. The regression model controls for heterogeneity across townships using a set of dummy variables representing 12 townships on the Outer Banks. Omitted category is the townships located on the mainland. Table 3-6 shows that most structural and neighborhood variables are statistically significant at any conventional level of significance with the exception of the squared age and elevation. Lower elevation of property is likely to provide easy access to coastal water, yet at the

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[4] Note that there was a county wide reevaluation of property values in 2004 which resulted in the higher property values in Dare County.

same time higher vulnerability to storm surge flooding or shoreline erosion. Again, increasing distance from the shoreline has a strong negative impact on property values. Water frontage also commands a substantial premium and raises the property values substantially.

Table 3-6: Estimation Results for the Dare Residential Hedonic Model

Variable	Coefficient	Standard Error	P-value
Constant	11.750	0.020	<.0001
AVON	0.171	0.010	<.0001
BUXTON	0.073	0.014	<.0001
DUCK	0.588	0.009	<.0001
FRISCO	0.097	0.012	<.0001
HATTERAS	0.232	0.014	<.0001
KDH	0.157	0.007	<.0001
KITTY	0.223	0.009	<.0001
NAGS	0.257	0.007	<.0001
RODANT	0.331	0.017	<.0001
SALVO	0.314	0.015	<.0001
SOUTHERN	0.572	0.009	<.0001
WAVES	0.284	0.020	<.0001
LOTSIZE	3.69E-07	3.28E-08	<.0001
LOTSIZE2	-3.17E-14	3.19E-15	<.0001
AGE	-0.004	3.43E-04	<.0001
AGE2	3.87E-06	3.91E-06	0.3226
BEDRM	0.220	0.008	<.0001
BEDRM2	-0.004	0.001	<.0001
AIRCOND	0.141	0.008	<.0001
MULTISTR	0.163	0.005	<.0001
HDWDFL	0.162	0.008	<.0001
OCEAN	0.730	0.008	<.0001
SOUND	0.321	0.007	<.0001
DIST	-9.52E-05	7.37E-06	<.0001
DIST2	9.54E-09	1.82E-09	<.0001
ELEV	0.001	0.001	0.4799
ELEV2	-9.37E-05	2.34E-05	<.0001

Notes: Number of observations is 25,870. Dependent variable is the log of assessed property values. Mainland townships are omitted. Adjusted R^2 is 0.7082.

The simulation results for the impact on property values are shown in Table 3-7. Without discounting, the residential property value loss in Dare County ranges from $406 million (2.18%) to $4.5 billion (11.59%), and the non-residential property value loss ranges from $248 million (2.50%) to $5.7 billion (27.84%). Based on a 2% discount rate, the residential property value loss ranges from $242 million (1.30%) to $2.7 billion (6.93%), and the non-residential property value loss ranges from $148 million (1.50%) to $3.4 billion (16.42%). Based on a 7% discount rate, the residential property value loss ranges from $70 million (0.38%) to $776 million (2.00%), and the non-residential property value loss ranges from $43 million (0.43%) to $981 million (4.73%). The results indicate that Dare County has the most significant impact from sea level rise among the North Carolina coastal counties.

Table 3-7: Present Value of Property Value Losses for Dare County

Residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$405.77	2.18%	$242.48	1.30%	$114.12	0.61%	$69.87	0.38%
2030-Mid	$454.85	2.45%	$271.81	1.46%	$127.92	0.69%	$78.32	0.42%
2030-High	$514.30	2.76%	$307.33	1.65%	$144.64	0.78%	$88.56	0.48%
2080-Low	$1,231.93	3.17%	$736.17	1.89%	$346.47	0.89%	$212.13	0.55%
2080-Mid	$2,200.69	5.66%	$1,315.09	3.38%	$618.92	1.59%	$378.95	0.97%
2080-High	$4,507.78	11.59%	$2,693.75	6.93%	$1,267.77	3.26%	$776.22	2.00%
Non-residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$248.16	2.50%	$148.29	1.50%	$69.79	0.70%	$42.73	0.43%
2030-Mid	$277.69	2.80%	$165.94	1.67%	$78.10	0.79%	$47.82	0.48%
2030-High	$304.11	3.07%	$181.73	1.83%	$85.53	0.86%	$52.37	0.53%
2080-Low	$718.21	3.46%	$429.19	2.07%	$201.99	0.97%	$123.67	0.60%
2080-Mid	$1,099.95	5.30%	$657.31	3.17%	$309.35	1.49%	$189.41	0.91%
2080-High	$5,698.54	27.48%	$3,405.33	16.42%	$1,602.66	7.73%	$981.26	4.73%

Notes: 2030-Low, 2030-Mid, and 2030-High represent an 11 cm, a 16 cm, and a 21 cm increase in sea level by 2030, respectively. Similarly, 2080-Low, 2080-Mid, and 2080-High represent a 26 cm, a 46 cm, and an 81 cm increase in sea level by 2080, respectively. Dollars are measured in million. Reported are the percent to the total property values.

Carteret County

Carteret County is located in the central part of the NC coastline. The total property value in the county is about half of those of New Hanover County and Dare County. The variable definitions and summary statistics for a total of 27,789 residential properties are given in Table 3-8. The average property value is about $171,934. The properties are on average 28 years old and about 1718 total structure square feet. Most homes have two bathrooms and about 28,578 total lot size measured in square feet. About three percent of the properties have an ocean-frontage and thirteen percent have the sound/estuarine frontage. The mean distance to nearest shoreline is about 1123 feet and the elevation of the properties is on average 13 feet above see level.

Table 3-8: Definitions and Summary Statistics for the Carteret Residential Property Data

Variable	Description	Mean	Standard Deviation
AV	Real assessed property value as of May 2006	171934.93	146659.57
ATLANTIC	Atlantic township (= 1)	0.01	0.11
CEDAR	Cedar Island township (= 1)	0.01	0.07
DAVIS	Davis township (=1)	0.01	0.08
HARKERS	Harkers Island township (=1)	0.03	0.17
HARLOWE	Harlowe township (=1)	0.02	0.13
MARSHALL	Marshall township (=1)	0.01	0.10
MERRIMON	Merrimon township (=1)	0.01	0.10
MOREHEAD	Morehead township (=1)	0.38	0.48
NEWPORT	Newport township (=1)	0.08	0.28
SEALEVEL	Sea Level township (=1)	0.01	0.07
SMYRNA	Smyrna township (=1)	0.01	0.10
STACY	Stacy township (=1)	0.00	0.06
STRAITS	Straits township (=1)	0.04	0.19
WHITE OAK	White Oak township (=1)	0.27	0.45
LOTSIZE	Total lot size measured in square feet	28578.31	45745.65
SQFT	Total structure square footage	1718.76	736.87
AGE	Age of house	28.34	22.92
BATHRM	Number of bathrooms	2.03	0.80
OCEAN	On ocean front (= 1)	0.03	0.16
SOUND	On sound front (= 1)	0.13	0.34
DIST	Distance to nearest shoreline measured in feet	1122.99	946.93
ELEV	Elevation of property measured in feet	12.76	7.99

Note: The number of observations is 27,789.

The baseline hedonic regression results are reported in Table 3-9. The regression model controls for heterogeneity across townships using a set of dummy variables representing 14 townships in Carteret County. The omitted category is Beaufort. Most structural and neighborhood variables are statistically significant at any conventional level of significance with the exception of lot size and elevation, and the coefficient signs are consistent with common findings in the hedonic literature. Adjusted R^2 from the regression is 0.69.

Table 3-9: Estimation Results for the Carteret Residential Hedonic Model

Variable	Coefficient	Standard Error	P-value
Constant	10.215	0.021	<.0001
ATLANTIC	-0.347	0.022	<.0001
CEDAR	-0.447	0.033	<.0001
DAVIS	-0.383	0.030	<.0001
HARKERS	-0.062	0.015	<.0001
HARLOWE	-0.188	0.019	<.0001
MARSHALL	-0.212	0.025	<.0001
MERRIMON	-0.293	0.024	<.0001
MOREHEAD	0.053	0.009	<.0001
NEWPORT	-0.098	0.012	<.0001
SEALEVEL	-0.392	0.034	<.0001
SMYRNA	-0.258	0.025	<.0001
STACY	-0.391	0.040	<.0001
STRAITS	-0.244	0.015	<.0001
WHITE OAK	0.148	0.009	<.0001
LOTSIZE	1.01E-07	1.37E-07	0.4602
LOTSIZE2	1.46E-12	3.89E-13	0.0002
SQFT	0.001	1.15E-05	<.0001
SQFT2	-7.66E-08	2.12E-09	<.0001
AGE	-0.002	3.40E-04	<.0001
AGE2	1.62E-05	3.64E-06	<.0001
BATHRM	0.279	0.013	<.0001
BATHRM2	-0.025	0.002	<.0001
OCEAN	0.665	0.015	<.0001
SOUND	0.497	0.008	<.0001
DIST	-8.07E-05	8.67E-06	<.0001
DIST2	1.58E-08	2.25E-09	<.0001
ELEV	0.001	0.001	0.3144
ELEV2	-1.92E-04	4.02E-05	<.0001

Notes: Number of observations is 27,789. Dependent variable is the log of assessed property values. Category omitted for township is Beaufort. Adjusted R^2 is 0.6898.

The simulated property value losses are shown in Table 3-10 for the entire county including both residential and non-residential properties. Without discounting, the residential property value loss in Carteret County ranges from $44 million (0.48%) to $488 million (2.58%), and the non-residential property value loss ranges from $25 million (0.73%) to $230 million (3.21%). Based on a 2% discount rate, the residential property value loss ranges from $26 million (0.29%) to $292 million (1.54%), and the non-residential property value loss ranges from $15 million (0.44%) to $137 million (1.92%). Based on a 7% discount rate, the residential property value loss ranges from $7 million (0.08%) to $84 million (0.44%), and the non-residential property value loss ranges from $4 million (0.13%) to $40 million (0.55%).

Table 3-10: Present Value of Property Value Losses for Carteret County

Residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$43.35	0.48%	$25.91	0.29%	$12.19	0.13%	$7.47	0.08%
2030-Mid	$46.37	0.51%	$27.71	0.31%	$13.04	0.14%	$7.98	0.09%
2030-High	$50.96	0.56%	$30.45	0.34%	$14.33	0.16%	$8.78	0.10%
2080-Low	$120.79	0.64%	$72.18	0.38%	$33.97	0.18%	$20.80	0.11%
2080-Mid	$206.69	1.09%	$123.52	0.65%	$58.13	0.31%	$35.59	0.19%
2080-High	$487.96	2.58%	$291.60	1.54%	$137.23	0.73%	$84.02	0.44%
Non-residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$24.98	0.73%	$14.93	0.44%	$7.02	0.21%	$4.30	0.13%
2030-Mid	$26.17	0.76%	$15.64	0.46%	$7.36	0.21%	$4.51	0.13%
2030-High	$28.48	0.83%	$17.02	0.50%	$8.01	0.23%	$4.90	0.14%
2080-Low	$64.26	0.90%	$38.40	0.54%	$18.07	0.25%	$11.07	0.15%
2080-Mid	$144.06	2.01%	$86.09	1.20%	$40.51	0.57%	$24.81	0.35%
2080-High	$229.85	3.21%	$137.35	1.92%	$64.64	0.90%	$39.58	0.55%

Notes: 2030-Low, 2030-Mid, and 2030-High represent an 11 cm, a 16 cm, and a 21 cm increase in sea level by 2030, respectively. Similarly, 2080-Low, 2080-Mid, and 2080-High represent a 26 cm, a 46 cm, and an 81 cm increase in sea level by 2080, respectively. Dollars are measured in million. Reported are the percent to the total property values.

Bertie County

Bertie County represents a rural and underdeveloped county in the data. The total property value is about $1 billion which is only about 5% of the total property value for Dare County. Less confidence is placed on the estimates given data limitations. The structural information on property such as square foot and age is available for only a very small number of observations and thus excluded in the data set. More than half of the observations are located outside one mile from the shoreline.

The variable definitions and summary statistics for a total of 3,279 residential properties within one mile from the shoreline are given in Table 3-11. The average residential property value is about $48,684, which is quite low compared to the previously considered counties. There are no ocean front properties in the county, but about four percent of the observations in the sample have an estuarine water frontage. The mean distance to nearest shoreline is about 2065 feet and the elevation of the properties is on average 29 feet above see level. The baseline hedonic regression results are reported in Table 3-12.

Table 3-11: Definitions and Summary Statistics for the Bertie Residential Property Data

Variable	Description	Mean	Standard Deviation
AV	Real assessed property value as of May 2006	48683.61	49588.56
COLERAIN	Colerain township (= 1)	0.10	0.30
INDIAN	Indian Woods township (= 1)	0.03	0.18
MERRY	Merry Hill township (=1)	0.10	0.30
SNAKEBITE	Snake Bite township (=1)	0.00	0.03
WHITES	Whites township (=1)	0.12	0.33
LOTSIZE	Total lot size measured in square feet	22410.90	11731.85
MULTISTR	Multistory house (= 1)	0.08	0.28
SOUND	On sound front (= 1)	0.04	0.19
DIST	Distance to nearest shoreline measured in feet	2064.59	1450.03
ELEV	Elevation of property measured in feet	28.91	13.59

Note: The number of observations is 3,279.

Table 3-12: Estimation Results for the Bertie Residential Hedonic Model

Variable	Coefficient	Standard Error	P-value
Constant	9.976	0.088	<.0001
COLERAIN	-0.090	0.077	0.2426
INDIAN	-0.269	0.091	0.003
MERRY	-0.160	0.056	0.0043
MITCHELL	0.486	0.451	0.2813
ROXOBEL	-0.100	0.059	0.0914
SNAKEBITE	3.62E-05	5.70E-06	<.0001
WHITES	-4.86E-10	1.07E-10	<.0001
WOODVILLE	1.014	0.057	<.0001
LOTSIZE	0.769	0.094	<.0001
LOTSIZE2	-2.30E-04	4.81E-05	<.0001
MULTISTR	3.15E-08	8.96E-09	0.0004
SOUND	0.005	0.005	0.3673
DIST	-3.54E-05	8.25E-05	0.6679
DIST2	9.976	0.088	<.0001
ELEV	-0.090	0.077	0.2426
ELEV2	-0.269	0.091	0.003
ELEV*DIST	-0.160	0.056	0.0043

Notes: Number of observations is 3,279. Dependent variable is the log of assessed property values. Category omitted for township is Windsor. Adjusted R^2 is 0.1514.

The estimated hedonic price function is used to simulate the property value loss, and the results are shown in Table 3-13. The loss of property values in Bertie County is relatively smaller than those of the other counties discussed above. Without discounting, the residential property value loss in Bertie County ranges from $3 million (0.29%) to $12 million (0.51%), and the non-residential property value loss ranges from $1 million (0.32%) to $26 million (2.99%). Based on a 2% discount rate, the residential property value loss ranges from $2 million (0.17%) to $7 million (0.30%), and the non-residential property value loss ranges from $1 million (0.19%) to $16 million (1.79 %). Based on a 7% discount rate, the residential property value loss ranges from $1 million (0.05%) to $2 million (0.09%), and the non-residential property value loss ranges from $0.2 million (0.06%) to $4 million (0.52%).

Table 3-13: Present Value of Property Value Losses for Bertie County

Residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$3.23	0.29%	$1.93	0.17%	$0.91	0.08%	$0.56	0.05%
2030-Mid	$3.91	0.35%	$2.34	0.21%	$1.10	0.10%	$0.67	0.06%
2030-High	$4.34	0.39%	$2.59	0.24%	$1.22	0.11%	$0.75	0.07%
2080-Low	$9.98	0.43%	$5.96	0.26%	$2.81	0.12%	$1.72	0.07%
2080-Mid	$11.73	0.51%	$7.01	0.30%	$3.30	0.14%	$2.02	0.09%
2080-High	$11.66	0.51%	$6.97	0.30%	$3.28	0.14%	$2.01	0.09%
Non-residential	Discount Rate							
	No Discounting		2%		5%		7%	
SLR Scenario	$ (millions)	%	$ (millions)	%	$ (millions)	%	$ (millions)	%
2030-Low	$1.35	0.32%	$0.81	0.19%	$0.38	0.09%	$0.23	0.06%
2030-Mid	$1.55	0.37%	$0.92	0.22%	$0.43	0.10%	$0.27	0.06%
2030-High	$2.04	0.49%	$1.22	0.29%	$0.57	0.14%	$0.35	0.08%
2080-Low	$4.26	0.49%	$2.55	0.29%	$1.20	0.14%	$0.734	0.08%
2080-Mid	$9.11	1.05%	$5.45	0.63%	$2.56	0.29%	$1.569	0.18%
2080-High	$26.02	2.99%	$15.55	1.79%	$7.32	0.84%	$4.48	0.52%

Notes: 2030-Low, 2030-Mid, and 2030-High represent an 11 cm, a 16 cm, and a 21 cm increase in sea level by 2030, respectively. Similarly, 2080-Low, 2080-Mid, and 2080-High represent a 26 cm, a 46 cm, and an 81 cm increase in sea level by 2080, respectively. Dollars are measured in million. Reported are the percent to the total property values.

Conclusions

In this section we estimate the impacts of sea level rise on property values for four coastal counties in North Carolina. The sea level rise scenarios considered include an 11 cm increase by 2030, a 16 cm increase by 2030, a 21 cm increase by 2030, a 26 cm increase by 2080, a 46 cm increase by 2080, and an 81 cm increase by 2080. The results indicate that low-lying developed areas in the northern section of the coastline are especially vulnerable to the impacts from sea level rise. The magnitude of the impacts also depends on the level of development in the areas. The central parts of coastline are also at risk, while the southern parts are generally at lower risk. The estimated results are quite sensitive to the discount rate used.

Care must be taken with the interpretation of the results. The current study focuses on the loss of property value from permanent inundation. Temporary inundation caused by high tides and storms occurs much sooner in time than permanent flooding, and the discounted present value of the costs associated with it can be quite large relative to those associated with permanent flooding. Measuring the impacts of temporary flooding requires additional data such as the distribution of the partial damage extents due to storm surge, frequency and intensity of storms, and timing of storms. Flood insurance may change the estimated loss, although the insurance covers only the structures (not the land) and does not cover the loss due to sea level rise. The current flood insurance coverage is limited to $250,000 for single family residence.

We also do not consider the adaptation that coastal communities and property owners undertake as they observe sea level rise over time. They may decide to relocate their communities in response to sea level rise or pursue beach nourishment. There might be additional costs associated with increased distance to the shoreline for new development. The value of lost public infrastructure is another component that is not included in the current study, although it likely to be small especially in the rural areas.

A large portion of undeveloped land in coastal North Carolina is wetlands that provide a wide range of amenities such as habitat for fish and wildlife, flood protection, water quality improvement, opportunities for recreation, education and research, and aesthetic values. These functions and services are economically and ecologically valuable. These values are unlikely to be captured in the assessed property values.

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4. Impacts on Recreation and Tourism

In this section of the study we estimate the impacts of sea-level rise induced reductions in beach width on beach recreation demand. Climate change-induced sea-level rise will have negative impacts on beach recreation and beach recreation-dependent communities. Sea-level rise exacerbates coastal erosion and can eventually eliminate a recreation site. The data limit our ability to consider other geological and behavior factors. For example, we do not consider the effects of new beach recreation sites created by littoral drift of sand, beach nourishment or beach retreat. All impacts are presented in 2004 dollars.

The concept of consumer surplus is the basis for the theoretical definition of the economic costs of climate change. Consumer surplus is the difference between what the consumer is willing (and able) to pay and the market price or cost of the product. Consumer surplus is also called net willingness to pay since it is willingness to pay net of the costs. In the case of beach recreation, if the traveler is willing to pay \$100 for a beach trip and the out-of-pocket expenditures are \$25 then the consumer surplus is \$75. The consumer surplus is the value of the recreation experience to the recreationist, while the out-of-pocket expenditures represent the initial, direct economic impact of the trip on the local beach economy (additional, "multipler," economic impacts on the local beach economy may also arise based on the direct economic impacts of the initial expenditures). Hereafter, we refer to consumer surplus as willingness to pay, or WTP.

Estimation of WTP from demand curves is relatively straightforward if market data exist to estimate the demand curves. Without market data, a number of methodologies have been developed to estimate WTP for environmental, and other, non-market goods. The travel cost method is a revealed preference approach that is most often used to estimate the benefits of outdoor recreation. The travel cost method begins with the insight that the major cost of outdoor recreation is the travel and time costs incurred to get to the recreation site. Since individuals reside at varying distances from the recreation site, the variation in distance and the number of trips taken are used to estimate a demand curve for the recreation site. The demand curve is then used to derive the WTP associated with using the site. With data on appropriate demand curve shift variables (i.e., independent variables such as beach width), the economic benefits (i.e., changes in WTP) associated with changes in the shift variables (i.e., changes in beach width) can be derived.

While recreation demand is able to capture a large portion of the recreation benefits, additional recreational benefits are capitalized in the property values of residents. These and other amenity values of coastal property are considered separately in section 3 in this report. A more thorough treatment of this issue would consider the joint location and intensity (i.e., trips) decisions of beach recreation. However, this analysis is beyond the scope of the current project.

We use two sets of data. The first includes information on beach trips to southern North Carolina beaches (excluding the Outer Banks). The second includes information on shore-based fishing trips for the entire North Carolina coast. We use the random utility site-selection model version of the travel cost method. In this model, it is assumed that individuals choose recreation sites based on tradeoffs among trip costs and site characteristics (e.g., beach width, catch rates). Combined with trip frequency models we estimate the potential change in the economic value per beach trip, the potential change in the number of beach trips and potential changes in beach trip expenditures due to reductions in beach width arising from sea-level rise.

We use average beach width data obtained from the U.S. Army Corps of Engineers (USACE) and other sources. These are described in section 2 of this report. Since these estimates are at the aggregate beach level, an average over miles of beach, there is potential for measurement error. We assume that the measurement error is not correlated with the true beach width and is not correlated with other variables in the model. Under these conditions any measurement error in beach width will not bias our results.[5]

Another assumption that we adopt is the lack of adaptation in terms of beach nourishment. Each of the beaches that we consider is bordered inland by highways and roads. We assume that beach erosion proceeds to the highway or road and, at that point, the sandy beach has vanished. This is the most extreme assumption but it allows us to estimate of the maximum loss of recreation values that might be expected. Periodic beach nourishment occurs in North Carolina but these efforts are costly. We discuss some estimates of the cost of beach nourishment that might be expected to avoid the loss of recreation value in the concluding section of this report.

Southern Beaches

Data

The study area includes beaches in five southern North Carolina counties. Bogue Banks, a barrier island, is located in Carteret County, and encompasses a twenty-four mile stretch of beach communities. Topsail Island, a barrier island, is located in both Pender and Onslow Counties and encompasses a twenty-two mile stretch of beach communities. New Hanover County encompasses a thirteen mile stretch of beach communities and lies between Pender and Brunswick County. The Brunswick County Beaches are located between the Cape Fear River and the South Carolina border and encompass a twenty-four mile stretch of beach communities.

We use beach recreation data from a recent USACE funded study (Herstine et al., 2005). The target survey population was chosen based upon the results of an on-site survey conducted during the summer of 2003 at the study area beaches. One finding from the on-site survey is that the vast majority of day users (approximately 73% of all day users) traveled 120 miles or less to get to the beach. For this study, day users are defined as those who leave their home, enjoy the beach and return home afterwards, without spending the night. Overnight users spend at least one

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[5] Also, as a referee points out, we have no measure of sand or beach quality. Beach width may serve as a proxy for these variables.

night away from home. Locals are those who live within walking or biking distance of the beach.

A telephone survey of all types of beachgoers, day users, overnight users and locals, was administered by the Survey Research Laboratory at the University of North Carolina at Wilmington. Survey Sampling, Inc. provided telephone numbers within the study area. The telephone survey was conducted during May 2004. The telephone survey response rate is 52 percent.

Of the telephone survey respondents 1509 stated that they had considered going to an oceanfront beach in North Carolina during the last year (2003). Of this number, 1186 (79%) actually took an oceanfront beach trip to the North Carolina coast in 2003. Of these, 79% took an oceanfront beach trip to the southern North Carolina beaches in 2003. Approximately 80% of the respondents stated that 2003 was a typical year in terms of their oceanfront beach trips to the southern North Carolina coast. Of those who reported that 2003 was not a typical year in terms of oceanfront beach trips to the southern North Carolina coast, 75% would normally have taken more trips. Of all respondents who took at least one trip to the southern North Carolina coast, 96% planned to take at least one oceanfront beach trip to this area in 2004. After deleting cases with missing trip information, missing income, missing distance or distance beyond the study site the remaining sample size is 632.

The telephone survey elicited information on whether respondents took day trips only or a mix of day and overnight trips.[6] Two-hundred twenty eight members of the sample took only day trips. Four hundred and four members took both day and overnight trips. There exists a variety of approaches to overnight trips (Parsons 2003). The problem is that the WTP for the recreation trip or a characteristic of the trip may be biased with multiple purpose trips. The bias may be positive if the beach trip is a minor reason for taking the overnight trip. For example, vacationers may spend more time at an amusement park or shopping than at the beach. Since we are unable to distinguish between day trips and overnight trips for this sub-sample, we estimate separate models for (i) day trippers and (ii) day and overnight trippers. In the day and overnight trippers model we assume that beach recreation is the primary purpose of the trip and attribute all of the WTP to that purpose; however, estimating separate models for day trippers (only) and day/overnight trippers allows WTP to differ across the two types of recreation households.

Beach trip data was elicited by asking respondents who had actually taken oceanfront beach trips to the North Carolina coast in 2003 how many of their oceanfront beach trips were to the southern North Carolina coast from the Beaufort/Morehead City area in Carteret County to the South Carolina border. The average annual number of trips is 22 for day trippers and 11 for day and overnight trippers (Table 4-1). We did not gather information about the number of days spent at the beach so that we must aggregate over the number of trips and not days. Otherwise, the subsamples are similar. The average number of children is less than one, 68% of the sample

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[6] It is preferable to spit the sample into day users and overnight users. The mixture of the day and overnight trips for the second group of users is an unfortunate constraint imposed by data limitations.

is married, 40% is male and 90% is white. The average age is 44 and the average number of years schooling is 13. The average household income is $57 thousand for day trippers and $61 thousand for day and overnight trippers.

Table 4-1: Beach Recreation Participants Characteristics

	Day Trippers		Day and Overnight Trippers	
	Mean	Std.Dev.	Mean	Std.Dev.
Trips	21.89	47.11	10.60	21.55
Children	0.72	1.02	0.77	1.06
Married	0.68	0.47	0.68	0.47
Male	0.40	0.49	0.40	0.49
White	0.89	0.32	0.90	0.30
Age	44.42	15.49	43.22	15.11
Education	12.99	1.97	13.19	2.03
Income ($1000)	57.41	26.13	60.69	27.81
Cases	228		404	

A Model of Beach Demand

The beach site selection and characteristic data are presented in Table 4-2. The most popular beaches for day trippers are Atlantic Beach, North Topsail Beach, Wrightsville Beach and Carolina Beach. The most popular beaches for day and overnight trippers are Atlantic Beach, Emerald Isle, Wrightsville Beach and Carolina Beach. Beach characteristic data includes beach width, beach length, the number of parking spaces, the number of public access points and water salinity. Average beach length was found using various USACE project books. Parking access points and parking spaces were also collected from USACE project data. Salinity data was collected from the North Carolina Department of Environment and Natural Resources.

Average beach width was estimated using USACE aerial photography from 2002 and was from the mean high water line to the first line of vegetation. The average beach width is 130 feet.[7] The minimum beach width is 80 feet (Caswell Beach). The maximum width is 400 feet (Fort Fisher). Beach width data for 2030 and 2080 was developed as described in section 2 of this report. All of the beaches lose 50 feet of width by 2030. By 2080, 14 of the 17 beaches have eroded to the road so that beach recreation is not feasible. Wrightsville Beach only has 3 feet of width, Carolina Beach has 28 feet and Fort Fisher has 243 feet.

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[7] In this section of the report beach width is presented in feet since this is the measure supplied by the USACE and to remain consistent with other analyses using these data.

Table 4-2: Beach Site Data Summary

		Proportion of Trips							Average width (feet)		
County	Beach	Day	Day and Overnight	Salinity	Public Access	Parking Spaces	State Park	Length	2004	2030	2080
Carteret	Fort Macon	0.042	0.012	31.87	2	602	1	1.40	90	40	0
Carteret	Atlantic Beach	0.103	0.155	32.17	19	662	0	4.90	135	85	0
Carteret	Pine Knoll Shores	0.039	0.021	32.61	6	195	0	4.80	110	60	0
Carteret	Indian Beach / Salter Path	0.018	0.014	31.92	2	131	0	2.50	90	40	0
Carteret	Emerald Isle	0.096	0.142	32.74	69	550	0	11.50	130	80	0
Onslow-Pender	North Topsail Beach	0.115	0.048	35.89	42	929	0	9.70	82	32	0
Onslow-Pender	Surf City	0.032	0.050	36.02	36	272	0	5.10	90	40	0
Onslow-Pender	Topsail Beach	0.035	0.079	36.13	37	234	0	4.00	110	60	0
New Hanover	Wrightsville Beach	0.153	0.231	36.19	45	1479	0	4.50	160	110	3
New Hanover	Carolina Beach	0.155	0.119	35.16	26	452	0	2.00	185	135	28
New Hanover	Kure Beach	0.023	0.016	34.83	20	223	0	2.80	130	80	0
New Hanover	Fort Fisher	0.019	0.019	35.08	2	240	1	1.90	400	350	243
Brunswick	Caswell Beach	0.028	0.004	31.05	12	103	0	2.80	80	30	0
Brunswick	Oak Island	0.018	0.020	33.31	66	821	0	7.50	120	70	0
Brunswick	Holden Beach	0.019	0.034	34.57	21	200	0	6.80	90	40	0
Brunswick	Ocean Isle Beach	0.081	0.030	35.04	28	341	0	5.30	85	35	0
Brunswick	Sunset Beach	0.025	0.007	34.61	34	260	0	1.20	115	65	0

The site selection model is specified so that beach goers first choose a coastal county and then choose the particular beach to visit within the county. The beach site selection decision depends on travel costs and the beach quality characteristics from Table 4-2. The technical aspects of the linked nested random utility site selection and trip frequency models are described in Haab and McConnell (2003). In this section of the report we focus on conceptual issues. See the Appendix A to this section for a thorough treatment of the empirical model.

Travel distances and time between each survey respondent's home zip code and the zip code of the population center of each beach county were calculated using the ZIPFIP correction for "great circle" distances (Hellerstein et al. 1993). Travel time was calculated by dividing distance by 50 miles per hour. The cost per mile used was \$0.37, the national average automobile driving cost for 2003 including only variable costs and no fixed costs as reported by the American Automobile Association (AAA) (AAA Personal communication, 2005). Thirty-three percent of the wage rate was used to value leisure time for each respondent. The round-trip travel cost is $p = (2 \times c \times d) + (\theta w \times [2 \times d / mph])$ where c is cost per mile, d is one-way distance, θ is the fraction of the wage rate, w, and mph is miles per hour. The average travel cost across all trip choice occasions is \$95 (n = 17 beaches × 202 cases = 3876) for day trippers and \$138 (n = 17 beaches × 404 cases = 6868) for day/overnight trippers.

The nested logit demand models are estimated with the full information maximum likelihood routine in the NLOGIT econometric software (Greene 2002). The results indicate that beach goers behave as expected with respect to trip costs and beach width (Table 4-3). Both day trippers and day/overnight trippers choose beaches that have lower travel costs (i.e., are closer to home) and have wider beaches.[8] Other results are that beach goers are less likely to choose beaches that have greater water salinity and that are state parks. Beachgoers are more likely to choose sites with ample parking. Since the number of parking spaces is positively correlated with

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[8] We also estimated another set of models to determine if the effect of beach width is nonlinear. These models include the square of beach width (divided by a factor of 100) along with the beach width variable. The coefficient on width squared is negative and statistically significant indicating that both day and day/overnight trippers prefer wider beaches up to a certain width. Beyond this optimal beach width (i.e., the width that maximizes trip value), additional width decreases value. Considering the day tripper model, the marginal value of each foot of beach width is approximately $WTP = .5 \times width - .1 \times (width/100)^2$, where WTP is willingness to pay. The optimal beach width is found where this nonlinear function is maximized, $\frac{\partial WTP}{\partial width} = .5 - .2 \times (width/100) = 0$, suggesting that the optimal beach width is 250 feet for recreation (the optimal beach width is about 500 feet for day/overnight users). Since only 1 of the 17 beaches is greater than 250 feet and the NLOGIT software has difficulty with the increasing number of simulated parameters, we leave this issue for future research.

the number of access points and beach length, it is not surprising that the coefficients on these two variables are negative and statistically significant. The coefficient on the inclusive value is statistically different from zero and one in both models which indicates the county-site choice is an appropriate nesting structure.

Table 4-3: Nested Random Utility Site Selection Models

	Day Trippers		Day/Overnight Trippers	
	Coeff.	t-ratio	Coeff.	t-ratio
Travel Cost	-0.083	-28.14	-0.071	-23.50
Width	0.003	8.59	0.015	17.55
Salinity	-0.126	-9.44	-0.137	-8.50
Access	-0.007	-5.06	-0.003	-1.72
State Park	-0.818	-9.55	-3.906	-16.34
Parking Spaces	0.001	23.49	0.001	17.71
Length	-0.026	-2.91	0.010	0.80
IV	0.883	24.17	0.842	21.24
LL	-9621.44		-8915.49	
Pseudo-R^2	0.32		0.26	
Cases	228		404	

The trip frequency models include the demographic variables in Table 4-1 along with the inclusive value from the nested random utility model as independent variables (Table 4-4). The dependent variable is the number of beach trips summed across the 17 beaches. For both subsamples, the number of beach trips increases with the inclusive value. In other words, since beach site quality variables do not vary across respondents, those with lower travel costs take more trips. For day trippers, white beach goers with more children and higher incomes take more trips. For day/overnight trippers, those with higher incomes take more trips.

Table 4-4: Negative Binomial Trip Frequency Models

	Day Trippers		Day/Overnight Trippers	
	Coeff.	t-ratio	Coeff.	t-ratio
Constant	2.18	3.21	3.34	6.68
Children	0.37	4.05	0.05	0.83
Married	-0.11	-0.43	-0.21	-1.44
Male	-0.18	-1.02	-0.10	-0.85
White	0.67	2.26	-0.08	-0.42
Age	0.00	0.62	-0.01	-1.33
Education	-0.02	-0.43	-0.02	-0.72
Income	0.01	1.80	0.02	6.48
IV	0.15	6.67	0.15	8.83
α	1.51	11.79	1.14	14.48
Cases	228		404	

Welfare Simulations

Day Trippers. Predictions and welfare (i.e., WTP) analyses using these models and the simulated data are presented in Worksheets 1 – 4 in Appendix B. Since we assume that beach width changes uniformly along the coast, the proportion of trips to each of the beaches does not change from baseline conditions. The baseline trips fall, but only slightly, with a 50 foot reduction in beach width. Willingness to pay to avoid a 50 foot decrease in beach width is almost $2 per trip. Multiplying the WTP by the predicted number of trips at each site and summing gives an estimate of the WTP to avoid a decrease in beach width of $43 for each beachgoer. The reduction in beach trips is also a component of the cost (i.e., lost welfare) of sea level rise. Summing the product of the WTP for each beach recreation site and the reduction in the number of trips to that site across sites gives an estimate of the WTP to avoid reduced beach trips. In 2030, the WTP is only $0.27 for each beachgoer.

In 2080 sea level rise is predicted to eliminate 14 of the 17 beach recreation sites, therefore the proportion of trips to each of the beaches changes from baseline conditions. Wrightsville Beach trips rise from 20% to 66%, Carolina Beach trips rise from 6% to 23% and Fort Fisher trips rise from 3% to 11%. Note that the predicted beach width at Wrightsville Beach is only 3 feet. It may seem unrealistic for 66% of all beach trips to be congregated on a beach only one yard wide. Since all of the sites currently support beach recreation, it is difficult for the model to predict beyond the range of beach width. Another concern is the impact of congestion on beach trips. Since Wrightsville Beach is a popular beach, the model allocates a large number of trips to a narrow strip of sand (20% to 66%), drastically increasing congestion and reducing the value of each beach trip. Finally, at the erosion rates used to estimate reductions in beach widths, Wrightsville Beach will be eliminated from the choice set in less than 2 years beyond 2080.

Since the basic NRUM can not readily accommodate these details, we pursue the analysis with the assumption that Wrightsville Beach is no longer part of the recreation choice set in 2080 (i.e., it is completely eroded). We assume that in 2080 sea level rise eliminates 15 of the 17 beach recreation sites and the proportion of trips to each of the beaches changes from baseline conditions. Wrightsville Beach trips fall to 0%, Carolina Beach trips rise from 6% to 68% and Fort Fisher trips rise from 3% to 32%.

Without Wrightsville Beach in the choice set the number of beach trips falls by more than 5 trips for each day tripper. Willingness to pay to avoid the decrease in beach width is between $5/trip and $6/trip for the two remaining beaches. Multiplying the WTP by the predicted number of trips at each site and summing gives an estimate of the WTP to avoid a decrease in beach width of $102 for each beachgoer. Summing the product of the WTP for each beach recreation site, calculated at the county level, and the reduction in the number of trips to that site across sites gives the WTP to avoid reduced beach trips due to loss of site access. In 2080 without Wrightsville Beach in the choice set, the WTP is $63 for each beachgoer.

Day/Overnight Trippers. The baseline number of trips falls by more than 10% with sea level rise in 2030 with day/overnight trippers. Willingness to pay to avoid a 50 foot decrease in beach width is $8 per trip. Aggregated over all trips with the decrease in beach width at each site, the WTP to avoid a decrease in beach width is $102 for each day/overnight tripper. In 2030, the WTP to avoid the slight reduction in beach trips due to reduced width is only $0.85 for each day/overnight tripper.

In 2080 for day/overnight trippers Carolina Beach trips rise from 8% to 76% and Fort Fisher trips rise from 3% to 24% assuming that Wrightsville Beach is no longer a viable recreation site with a 3 foot wide beach. The number of beach trips fall by over 4 trips for each day/overnight tripper. Willingness to pay to avoid the decrease in beach width is between \$32/trip and \$34/trip for the two remaining beaches. Multiplying the WTP by the predicted number of trips at each site and summing gives an estimate of the WTP to avoid a decrease in beach width of \$195 for each beachgoer. In 2080, the WTP to avoid the reduction in beach trips is \$34 for each beachgoer.

Willingness to Pay

Aggregation of trips, WTP and expenditures across the population in 2030 and 2080 is conducted assuming (1) no change in population and income and (2) increases in population and income. Smith (2006) estimates that the NC population will increase by 50% from 2000 to 2030 and increase by 100% from 2000 to 2080. Increases in population increase the size of the recreation market. Smith (2006) also estimates that NC per capita personal income will increase by 52% from 2004 to 2030 and increase by 217% from 2004 to 2080. Income increases may increase the number of recreation trips taken and the percentage of the population that engages in beach recreation.

We use the trip frequency model to predict the number of trips with an increase in sample income and find unrealistically high trip estimates (e.g., we predict that some households go to the beach every day with increased income). Therefore, we assume that the household average number of annual trips is constrained by time and equal to the household average number of annual trips in 2003. This assumption likely causes our welfare cost estimates to be underestimated. Note also that increased congestion at eroding beaches, especially in 2080, will lead to lower quality and therefore lower values of ongoing beach trips. This is another factor that causes the recreation costs of sea level rise to be underestimated in this study.

An estimate of the increase in the percentage of the population that takes beach trips is obtained from analysis of the National Survey on Recreation and the Environment (NSRE) (1999-2001) data. The sample is 1086 North Carolina residents. The dependent variable is whether the respondent took an ocean beach trip. Independent variables are respondent characteristics. A probit model is used to estimate the determinants of beach recreation participation (Table 4-5).

Table 4-5: Probit Model of Beach Trip Participation

	Coeff.	t-ratio	Marginal Effect	Mean
ONE	-1.287	-4.26		
HHNUM	0.039	0.71	0.015	2.63
OVER16	0.044	0.60	0.017	1.09
UNDER6	0.044	0.50	0.017	0.25
INCOME	0.004	2.61	0.002	33.52
WHITE	0.396	3.82	0.153	0.81
EDUC2	0.073	4.24	0.029	13.38
MALE	-0.021	-0.26	-0.008	0.41
AGE	-0.008	-3.28	-0.003	45.99
MISSINC	-0.049	-0.43	-0.019	0.40
MISSEDUC	0.920	1.77	0.335	0.01
χ^2	98.98			
Cases	1086			
Percent Beachgoers	0.48			

Beach recreation participation increases with income and education and decreases with age. Whites are more likely to participate. The marginal effect of the independent variable on the dependent variable is the change in the probability of participation from a one unit change in the independent variable. For each $1000 increase in income, recreation participation increases by 0.2%. The marginal effect can be used to forecast changes in beach recreation participation with the caveat that the probit model is nonlinear and the marginal effects are only accurate for small changes in the independent variables. Forecasts for nonmarginal changes in independent variables should only be considered first order approximations.

Various aggregations of the individual impacts of climate change-induced sea level rise on beach demand are presented in Worksheets 5-7 in Appendix B. Considering that 64% of the general population contacted in the USACE telephone survey participated in some form of beach trip, we estimate that 23% of the general population are day trippers and 41% are day/overnight trippers. We aggregate impacts assuming (1) no increases in population or income and (2) increases in population and income. Under assumption (2) beach recreation participation is forecast to be 37% and 55% for day and day/overnight trippers in 2030 and 54% and 70% in 2080.

The 2000 population of the study region is 1.58 million households. Applying the percentage of recreation participants to the population gives an estimate of the number of beach going households in the study region. In 2003 there are about 365 thousand day trippers and 646 thousand day/overnight trippers. Since the southern NC beaches might reach capacity with increases in recreation demand and decreases in supply, especially in 2080, we estimate the economic effects of sea-level rise with and without changes in recreation participation. We estimate that the number of day trippers increases to 875 thousand in 2030 and 1.7 million in 2080 as both population and participation rates increase (the latter increase due to increases in income). The number of day/overnight trippers increases to 1.3 million in 2030 and 2.2 million in 2080 with increases in population and participation.

The product of the beach trip households and annual trips is an estimate of the total number of beach trips. We assume that total baseline trips remains constant at 8.6 million and 6.9 million for day and day/overnight trippers. With increased population and income the number of day trips increases from 8.6 million in 2003 to 20.6 million in 2030 and 39.9 million in 2080. The number of day/overnight trips increases from 6.9 million in 2003 to 14 million in 2030 to 23.4 million in 2080. Considering the large number of trips and the limited space on the beach, congestion would be a significant problem.

The individual WTP for a beach trip is approximated by assuming that all of the beach sites represent 99% of the beach recreation opportunities for each household (see Worksheets 6 and 7 in Appendix B). This assumption likely overstates the aggregate baseline value of beach recreation but understates the estimate of the percentage change in beach recreation value due to sea level rise. Since our aim is to estimate the change in beach recreation value we proceed with the conservative assumption.

Taking the product of aggregate beach trips and WTP for a beach trip, the baseline value of southern North Carolina beaches is $477 million for day trippers and $445 million for day/overnight trippers in 2003. With an increase in total number of trips due to population and income increases aggregate WTP rises to $1.1 billion in 2030 and $2.2 billion in 2080 for day trippers. For day/overnight trippers, aggregate WTP for beach trips rises to $905 million in 2030 and $1.5 billion in 2080.

The WTP to avoid a decrease in beach width per beach household is $43 for day trippers and $102 for day/overnight trippers in 2030. In 2080 the household WTP to avoid the decrease in beach width is $102 for day trippers and $195 for day/overnight trippers. Aggregating the household values gives an estimate of the aggregate welfare cost of a decrease in beach width of $15.7 million and $66.2 million for day and day/overnight trippers in 2030. In 2080 the welfare cost is $37 million and $125 million for day and day/overnight trippers in 2030.

Taking into account potential increases in population and income, the estimated aggregate welfare costs of a decrease in beach width are larger. The aggregate welfare cost of a decrease in beach width is $37.6 million and $135 million for day and day/overnight trippers in 2030. In 2080 the welfare cost is $172 and $430 million.

Another component of the aggregate welfare cost of sea level rise is the value of beach trips not taken due to a lower quality beach. Taking the product of the difference in beach trips and the value of beach trips provides this estimate. Assuming no change in population or income, aggregate WTP to avoid the decrease in beach trips is $4.86 million and $6.45 million for day and day/overnight trippers in 2030 and $15.1 million and $25 million for day and day/overnight trippers in 2080. With increasing population and income, aggregate WTP to avoid the decrease in beach trips is $11.6 million and $13.1 million for day and day/overnight trippers in 2030 and $69.8 million and $85.3 million for day and day/overnight trippers in 2080.

The total WTP to avoid the decrease in beach width is the sum of the value of the reduction in trip quality and the value of the lost trips. Assuming no changes in population or income, the total WTP to avoid the decrease in beach width is $20.5 million and $72.7 million for day and day/overnight trippers in 2030 and $52.1 million and $150.8 million for day and day/overnight trippers in 2080. The total welfare cost for all beach goers is $93.2 million in 2030 and $202.9 million in 2080.

With increasing population and income, the total WTP to avoid the decrease in beach width is $49.3 million and $148 million for day and day/overnight trippers in 2030 and $242 million and $515 million for day and day/overnight trippers in 2080. The total welfare cost for all beach goers is $197 million in 2030 and $757 million in 2080.

Taking the quotient of the total WTP to avoid the decrease in beach width and the baseline value of beach trips provides an estimate of the percentage change in beach recreation value due to sea level rise. For day trippers, 4.3% of recreation value is lost in 2030 and 11% is lost in 2080. For day and overnight trippers, 16% and 34% of recreation value is lost in 2030 and 2080, respectively. These percentages hold with increases in population and income since the baseline value and the WTP to avoid the decrease in beach width grow at the same rate.

The estimates above are annual welfare costs (i.e., annual aggregate WTP to avoid the decrease in beach width). The present value of the welfare costs are estimated by assuming the impacts are equal to zero in 2004 and increase linearly to 2080. Using a 0% discount rate, the present value of the welfare costs of sea level rise from 2005 to 2080 assuming no increase in population or income is $8.7 billion. Assuming increases in population and income leads to a present value of the welfare costs of $26.8 billion. Using a 2% discount rate, the present value of the welfare costs assuming no increase in population or income is $3.5 billion. Assuming increases in population and income leads to a present value of the welfare costs of $10 billion. Using a 7% discount rate, the present value of the welfare costs assuming no increase in population or income is $711 million. Assuming increases in population and income leads to a present value of the welfare costs of $1.7 billion.

We emphasize that due to the negative effects of increasing congestion on recreation participation and the value of each beach trip, the welfare costs of sea level rise on beach recreation are underestimated.

Economic Impacts

Next we estimate the direct economic impacts of recreationists' reduced trip expenditures on regional economic activity due to climate change-induced sea level rise. The expenditures of beach recreation are obtained from a 2003 survey of Wrightsville Beach visitors in which the average trip expenditure for day and overnight trippers is $164 and $1081 (Imperial, Jones and

Dumas, 2004). The Wrightsville Beach sample included 65% day trippers and 35% overnight trippers. About 54% of the trips in the USACE sample are exclusively day trips. If 35% of the trips in the USACE sample are overnight trips then this suggests that 25% of the trips in the day/overnight trip sample are day trips. Weighting the day/overnight trips by these proportions gives a per trip expenditure estimate for the day/overnight sample of $852.

The economic impacts are much greater when multiplier effects are included. The indirect and induced impact on output within each coastal county is $149 per trip for day trippers and $697 for day/overnight trippers. The total impact on output within the county is the sum of direct, indirect and induced expenditures. The total impact per trip is $313 for day trippers and $1778 for those who take day/overnight trips.

In the aggregate analysis we only consider direct spending (i.e., no multiplier effects) and assume that spending associated with reductions in local beach trips will be replaced by spending associated with other activities within the county. Local residents are defined as those that live within 27 miles of a beach. Twenty-seven miles is the 25th percentile of the minimum one-way travel distance in the USACE sample.

We assume that non-local residents will substitute out of beach trips with a reduction in beach width. Multiplying total non-local trips by expenditures per trip gives an estimate of the baseline beach recreation expenditures that have the potential to change as a result of climate change. The 2004 baseline expenditures is $392 million for day trippers and $4 billion for day/overnight trippers. Assuming increasing population and income, the expenditures on beach trips is $941 million for day trippers and $7.9 billion for day/overnight trippers in 2030. In 2080 the expenditures on beach trips is $1.8 billion for day trippers and $13 billion for day/overnight trippers.

The aggregate change in beach recreation expenditures is equal to the product of the change in the aggregate number of beach trips and trip expenditure. Assuming no changes in population or income, the expenditure change is $7.46 million and $703 million for day and day/overnight trippers in 2030 and $90 million and $1.95 billion for day and day/overnight trippers in 2080. With increases in population and income, the expenditure change is $17.9 million and $1.2 billion for day and day/overnight trippers in 2030 and $418 million and $6.4 billion for day and day/overnight trippers in 2080.

In percentage terms, the change is a 2% reduction in expenditures by day trippers in 2030 and 16% reduction by day/overnight trippers in 2030 with no change in population or income. Allowing for changes in population and income the reduction in expenditures by day trippers and day/overnight trippers is 23% and 48%, respectively, in 2080.

Recreational Fishing

The National Marine Fisheries Service (NMFS) collects recreational fishing data annually with the Marine Recreational Fishery Statistics Survey (MRFSS). The MRFSS is a creel survey with information on fishing location, mode, target species, catch and harvest, and fishing days during the past 2-month and 12-month time periods. Periodically, the NMFS collects additional data from anglers with economic add-on surveys. In the southeast region, economic add-ons have taken place in 1997, 1999 and 2000. An expenditure add-on was conducted in 2006.

The MRFSS add-on surveys requests additional information so that the travel cost method can be employed with the intercept creel survey data. Key information collected is on single-day vs. multiple-day trips and if fishing is the primary purpose of the trip. The travel cost method typically employs only single-day fishing trips (i.e., trips in which the respondent did not spend any nights away from the permanent residence) because overnight trips may have multiple purposes (McConnell and Strand, 1999).

The most comprehensive of the MRFSS southeastern add-on surveys was in 1997 when data on expenditures, household income, location-specific trips, mode-specific trips, target species-specific trips and WTP for various management measures were collected with on-site and telephone follow-up surveys. The 1997 data supports analysis of economic impacts and recreation demand (Haab, Whitehead and McConnell, 2000). In 1999 expenditures data were collected that supports economic impact analysis (Gentner, Price and Steinback, 2001). In 2000 income and other data were collected that supports recreation demand analysis.

Data

We investigated the potential of the 1997 and 2000 MRFSS add-on data to support a shore-based demand model for North Carolina. Unfortunately, too few cases exist (e.g., n = 70). Instead, we adapt the most recently available MRFSS data. In 2005, 105,174 anglers were interviewed in the MRFSS creel survey. 12,104 of these anglers were interviewed in North Carolina. Forty-five percent of the NC anglers fish from the shore and almost all of these shore anglers use hook and line gear (n = 5439). 5368 of these anglers have complete days fished information. The average number of days fished during the past 2 (12) months is 5 (22).

We consider only those anglers who fished in ocean waters (excluding the sounds of coastal NC). This leaves 4676 anglers. In an attempt to focus on day trips and to be consistent with the beach trip data we exclude about one-half of these anglers who reside outside of NC. 109 anglers with bad zip code data were deleted. In a further attempt to consider only day trip anglers we exclude 129 anglers who live greater than 200 miles away from any of the fishing sites. Finally, we lose 170 anglers who visited MRFSS intercept sites with a lack of information that makes it difficult to determine beach widths. 1905 anglers remain. The average number of days fished during the past 2 (12) months is 7 (35).

To summarize, we focus on trips in which (1) the angler was interviewed in North Carolina, (2) the fishing effort occurred in the ocean and (3) the angler fished from either a man-made structure (e.g., a pier or a bridge) or the beach. Further, we consider only hook and line anglers and those North Carolina residents who live within 200 miles of the coast. With these decisions we hope to exclude most anglers who took overnight trips, which can create problems in the demand analysis (McConnell and Strand, 1989).

To measure site quality in the standard NMFS demand model, the catch and keep rate is measured with the 5-year historic targeted harvest of big game fish (e.g., tunas), bottom fish (e.g., spot, groupers), flat fish (e.g., flounders), and small game fish (e.g., mackerels). In contrast, we consider all targeted species in the catch rates for the NC shore fishing model, because most shore anglers do not target specific species. Only twenty-six percent of anglers in our data set target specific species (others target “anything they can catch”). Of these, 26% target spot, 12% target flounder, 11% target kingfish, 11% target seatrout, 8% target bluefish, 8% target striped bass, 6% target Spanish mackerel, 5% target red drum and 5% target king mackerel. Three year (2002-2004) targeted historic catch and keep rates per hour are calculated using MRFSS data at each of the sites to measure site quality.

Sixty-two percent of the anglers fish from manmade structures. The frequency of trips, average respondent travel cost at each site and the three-year historic average catch at each site is presented for the 22 manmade fishing sites (Table 4-6) and the 28 beach fishing sites (Table 4-7). The travel cost variable is measured using the same parameters as in the beach recreation model. Travel costs are computed using “great circle” distance (i.e., “as the crow flies”) from the home zipcode to the zipcode of the city in the nine county zones with the ZIPFIP adjustment for twists and turns in the road.

In the standard NMFS methodology, a measure of time cost is collected in the add-on survey for anglers who forego wages during the trip. Since income is not available with the creel surveys we can assign a time cost equal to zero or use a proxy for income. A time cost of zero would bias our value estimates downward but perhaps not significantly, since less than five percent of MRFSS add-on anglers report that they lost income by taking the trip. Or, we can use the zip-code level median household income from the 2000 Census as a proxy for household income in the measurement of the opportunity cost of time. We choose the latter option, but find that WTP estimates are not significantly different from a model with zero time costs.

A Model of Shore Fishing

In the standard NMFS travel cost demand model anglers are assumed to first choose mutually exclusive species to target and fishing mode and then choose among mutually exclusive fishing sites (aggregated to the county level) based on their attributes. Due to the large number of sites, the model is estimated in two-stages (Haab, Whitehead and McConnell, 2001). In contrast, we focus on the first stage choice of shore anglers between manmade structures (piers and bridges) and beach fishing. In addition, we assume that anglers choose between an Outer Banks trip and a southern NC coast trip. In the second stage decision, anglers choose fishing sites (not aggregated to the county level as in the standard NMFS model). The shore mode-site choice NRUM model follows the standard NMFS methodology where possible with adjustments for North Carolina shore anglers. In particular, the smaller number of choices, 50 instead of 1050, allows the model to be estimated with the full information maximum likelihood routine.

Table 4-6: MRFSS Manmade Shore Fishing Sites

Choice	Intsite	Site Name	County	Frequency	Percent	Travel Cost	Catch
1	1	Seaview Pier	Pender	35	1.84	128.15	0.41
2	279	Sunset Beach Fishing Pier	Brunswick	1	0.05	158.22	3.17
3	282	Yaupon Beach Fishing Pier	Brunswick	9	0.47	153.56	0.48
4	388	Ocean Isle Pier	Brunswick	2	0.1	153.56	0.80
5	394	Nags Head Fishing Pier	Dare	178	9.34	143.20	0.82
6	415	Avalon Pier Kitty Hawk Area	Dare	111	5.83	143.70	0.43
7	417	Bogue Inlet Fishing Pier	Carteret	167	8.77	127.70	1.36
8	419	Frisco Pier	Dare	28	1.47	146.18	0.05
9	423	Hatteral Fishing Pier	Dare	17	0.89	146.18	0.20
10	424	Holden Beach Fishing Pier	Brunswick	17	0.89	151.51	1.04
11	427	Jeanette's Ocean Fishing Pier	Dare	6	0.31	143.20	0.00
12	433	Outer Banks Pier South Nags Head	Dare	22	1.15	143.70	0.17
13	434	Oceanana Fishing Pier	Carteret	13	0.68	127.98	0.04
14	441	Sportsmans Pier	Carteret	133	6.98	127.98	0.79
15	443	Triple "S" Fishing Pier	Carteret	137	7.19	127.98	1.07
16	445	Jolly Rogers Pier	Pender	42	2.2	128.15	0.83
17	448	Surf City Ocena Pier	Pender	23	1.21	128.15	1.85
18	450	Oregon Inlet Bridge	Dare	12	0.63	143.70	0.57
19	452	Kure Beach Pier	New Hanover	65	3.41	146.00	0.48
20	522	Long Beach Fishing Pier	Brunswick	3	0.16	153.27	3.67
21	670	Avon Fishing Pier	Dare	77	4.04	154.48	0.47
22	902	Carolina Beach Pier	New Hanover	81	4.25	146.00	0.65

Table 4-7: MRFSS Beach and Bank Fishing Sites

Choice	Intsite	Site Name	County	Frequency	Percent	Travel Cost	Catch
23	262	Oregon Inlet South	Dare	21	1.1	143.70	0.23
24	264	Cape Point	Dare	91	4.78	154.79	0.18
25	265	Hatteras Inlet	Dare	32	1.68	146.18	0.15
26	274	Kure Beach	New Hanover	31	1.63	146.00	0.05
27	391	Holden Beach	Brunswick	14	0.73	151.51	0.55
28	396	Ft Fisher State Beach	New Hanover	6	0.31	146.00	0.48
29	400	Ocracoke Inlet Beach N. & S.	Hyde	7	0.37	146.18	0.06
30	415	Avalon Pier Kitty Hawk Area	Dare	5	0.26	143.70	2.00
31	468	Ft Macon State Park	Carteret	97	5.09	127.98	0.12
32	494	Emerald Isle Public Access Area	Carteret	21	1.1	127.70	0.50
33	500	Oregon Inlet North Shore	Dare	155	8.14	143.70	0.21
34	521	Hatteras Inlet Beach	Hyde	10	0.52	146.18	0.10
35	525	Access at New River Inlet Drive	Onslow	3	0.16	128.15	0.17
36	574	Beach Access Ramp 20	Dare	5	0.26	143.20	0.40
37	575	Beach Access Ramp 23	Dare	16	0.84	154.48	0.20
38	576	Beach Access 27	Dare	3	0.16	154.48	0.34
39	577	Beach Access 30	Dare	21	1.1	154.48	0.02
40	578	Beach Access Ramp 34	Dare	6	0.31	154.48	0.09
41	579	Beach Access Ramp 38	Dare	21	1.1	154.48	0.13
42	672	New River Inlet, Topsail Island	Onslow	96	5.04	128.15	0.19
43	689	Carolina Beach NW Extension	New Hanover	4	0.21	146.00	0.13
44	705	Calvin Street Kill Devil Hills	Dare	18	0.94	143.70	0.00
45	706	1st Street Kill Devil Hills	Dare	22	1.15	143.70	0.00
46	801	Public Access E. Gulfstream S. Nags Head	Dare	5	0.26	143.70	0.00
47	802	Public Access E. Bonnett St Nags Head	Dare	10	0.52	89.64	0.00
48	803	Public Access E. Forest St Nagshead	Dare	2	0.1	89.64	0.00
49	808	Ramp 49 Frisco	Dare	3	0.16	95.55	0.03
50	900	South Topsail Beach Bank	Pender	1	0.05	78.85	0.00

The theory behind the NRUM is that anglers consider fishing sites based on the utility (i.e., satisfaction) that each site provides. Anglers will tend to choose fishing sites that provide the most utility. The NRUM exploits the empirical observation that anglers tend to choose fishing sites with relatively low travel costs and relatively high chances of fishing success.

The utility function is a linear function of the travel costs, the square root of the catch rate and beach width. The NRUM is estimated using the full information maximum likelihood PROC MDC in SAS and presented in Table 4-8. The full information maximum likelihood routine estimates the two stages of choice jointly.

Table 4-8: NRUM Site Selection Model

	Coeff.	t-ratio
Travel Cost	-0.036	-22.72
Square root of catch	0.600	9.56
Width	0.00504	12.66
IV	0.534	17.74
McFadden's R^2	0.11	
Cases	1905	
Sites	50	
Sample size	95,250	

The likelihood that an angler would choose a fishing site is negatively related to the travel cost and positively related to the historic targeted catch rate. In addition to the variables described above the model includes the beach width (measured as described in Section 2 of this report) as an independent variable. Beach width is positively related to site choice (Table 4-8). In other words, beach anglers prefer a wider beach. Various other model specifications (e.g., including a squared width term and width +/- one standard deviation) were investigated to test the sensitivity of results to the simple linear specification. The simple linear specification is statistically preferred. The parameter estimates on the mode-specific inclusive value is between 0 and 1 and statistically different from zero and one which indicates that the nested model is appropriate.

Willingness to Pay

A large number of WTP estimates can be developed from the model including the loss of access to fishing sites, changes in catch rates and changes in beach width (see Appendix A). The change in WTP per trip from a change in the catch rate of one fish per hour at each site is $16.80. The change in WTP per trip from an increase in beach width of 10 meters is $1.41. Both results seem to be of an appropriate magnitude which lends validity to the model.

The WTP loss resulting from reduced beach width is estimated by calculating the change in angler utility using the beach width data in Table 4-9. Beaches with negative width, choice numbers 23 and 50 in 2030 and 23, 29 and 50 in 2080, are removed from the choice set. The change in WTP per trip in 2030 is $3.90. The change in WTP per trip in 2080 is $4.46. The change in WTP per trip with zero time costs is about 25% lower: $2.94 in 2030 and $3.38 in 2080.

Table 4-9: Beach Widths (meters)

Choice	Intsite	Site Name	County	2005	2030	2080
23	262	Oregon Inlet South	Dare	27.17	-4.34	-9.59
24	264	Cape Point	Dare	46.88	15.37	10.12
25	265	Hatteras Inlet	Dare	39.11	7.60	2.34
26	274	Kure Beach	New Hanover	211.47	179.95	174.70
27	391	Holden Beach	Brunswick	225.65	194.14	188.88
28	396	Ft Fisher State Beach	New Hanover	225.65	194.14	188.88
29	400	Ocracoke Inlet Beach N. & S.	Hyde	36.51	5.00	-0.25
30	415	Avalon Pier Kitty Hawk Area	Dare	310.36	278.84	273.59
31	468	Ft Macon State Park	Carteret	81.31	49.80	44.55
32	494	Emerald Isle Public Access Area	Carteret	84.87	53.35	48.10
33	500	Oregon Inlet North Shore	Dare	59.53	28.02	22.77
34	521	Hatteras Inlet Beach	Hyde	83.26	51.75	46.49
35	525	Access at New River Inlet Drive	Onslow	94.83	63.32	58.07
36	574	Beach Access Ramp 20	Dare	82.32	50.80	45.55
37	575	Beach Access Ramp 23	Dare	49.87	18.36	13.10
38	576	Beach Access 27	Dare	60.12	28.61	23.36
39	577	Beach Access 30	Dare	45.02	13.51	8.26
40	578	Beach Access Ramp 34	Dare	50.37	18.86	13.60
41	579	Beach Access Ramp 38	Dare	47.73	16.21	10.96
42	672	New River Inlet, Topsail Island	Onslow	55.03	23.51	18.26
43	689	Carolina Beach NW Extension	New Hanover	122.39	90.88	85.63
44	705	Calvin Street Kill Devil Hills	Dare	276.45	244.93	239.68
45	706	1st Street Kill Devil Hills	Dare	77.36	45.85	40.60
46	801	Public Access E. Gulfstream S. Nags Head	Dare	37.45	5.94	0.68
47	802	Public Access E. Bonnett St Nags Head	Dare	144.28	112.77	107.51
48	803	Public Access E. Forest St Nagshead	Dare	50.97	19.46	14.21
49	808	Ramp 49 Frisco	Dare	60.87	29.36	24.11
50	900	South Topsail Beach Bank	Pender	30.41	-1.10	-6.35

We aggregate WTP values over North Carolina ocean fishing trips (personal communication, NMFS).[9] We present annual and 2-month survey wave values. Wave 2 is March and April, wave 3 is May and June, wave 4 is July and August, wave 5 is September and October and wave 6 is November and December. The MRFSS data collected in NC does not include trips from wave 1 (January and February) so we do not aggregate over these months.

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[9] Aggregating over all trips, single-day trips and multiple-day trips, may be an overestimate or underestimate of total willingness to pay. Estimation of willingness to pay values for overnight trips using the standard NMFS methodology tends to produce upwardly biased estimates of willingness to pay (McConnell and Strand, 1999) because the standard NMFS methodology employs the assumption that the purpose of the entire trip is fishing when only a fraction of the multi-day trip may be devoted to this activity (e.g, a family vacation).

Table 4-10: Lost Willingness to Pay Due to Changes in Beach Width

		Lost Willingness to Pay ($ millions)			
		No Change in Trips		50% more trips	100% more trips
Wave	NC Shore/Ocean Fishing Trips (2005)	2030	2080	2030	2080
2	333,250	1.30	1.52	1.95	2.28
3	877,127	3.42	4.00	5.13	6.00
4	988,237	3.85	4.51	5.78	6.76
5	1,269,847	4.95	5.79	7.43	8.69
6	243,042	0.95	1.11	1.42	1.66
Total	3,711,503	14.47	16.92	21.71	25.39

The baseline (without climate change) total number of trips in 2030 and 2080 is estimated as simple 50% and 100% increases in trip estimates. We use this simple approach for several reasons. First, Milon (2000) uses the MRFSS participation data and forecasts fishing participation out to 2025. He finds that participation, measured as the percentage of the population that takes at least one marine recreational fishing trip, will decline slightly. Second, an analysis of the NSRE saltwater fishing participation data finds that income increases do not significantly affect participation. In light of these results, we assume that the number of trips per angler stays constant while the number of participants increases with population, with a constant participation rate. Our estimates of future trips are significantly lower than a forecast that uses the trend line from the 1981-2005 aggregate MRFSS data obtained from the NMFS website to forecast trips into the future. Our simple estimate is 9% lower in 2030 and 32% lower in 2080. Therefore, our estimates of the economic effects of climate change on marine recreational fishing are conservative.

A limitation of the NRUM model is that it holds the number of fishing trips constant. That is, with the loss of a fishing site anglers are assumed to substitute to other sites or fishing modes. This assumption may be appropriate for many events and policies that have a minor impact on the fishing experience. But for lost beach fishing sites it would not be surprising if the aggregate number of fishing trips declines. A practical approach to estimating this effect is with a trip intensity model in which angler trips are regressed on the inclusive value (i.e., an index of site-mode utility values), which is constructed for each angler from the parameters of the NRUM, and other individual angler characteristics (as in the beach recreation model). If trips are positively related to the utility of fishing then a change in fishing conditions which lowers utility will lead to fewer trips taken.

The “demand” model is a negative binomial model estimated with Proc GENMOD in SAS. The negative binomial model accounts for the integer values of the dependent variable. The dependent variable in the negative binomial trip intensity model is the annual number of fishing days. Note that these are not necessarily equivalent to single-day trips since single-day trippers may also take multiple-day fishing trips over the course of a year.

The demand model does a reasonable job of explaining the variation in fishing days according to the model chi-squared statistic. Shore anglers increase trips as the inclusive value increases. More intuitively, trips increase as travel costs decrease and catch rates increase. The dispersion coefficient is statistically different from zero which suggests the negative binomial distribution fits the data well. The regression model is used to simulate the number of fishing days that anglers would experience with the loss of beach width. The number of fishing days falls by 6% in 2030 and 7% in 2080. However, the differences in trips are not statistically significant. Given these small effects and their lack of statistical significance we do not consider the impact of lost fishing days further.[10]

Assuming that the number of shore trips is constant between 2005 and 2080, aggregate WTP loss across all five waves is $14 million in 2030 and $17 million in 2080. Assuming that the number of shore trips increases by 50% between 2005 and 2030, aggregate WTP loss across all five waves is $22 million. Assuming that the number of shore trips increases by 100% between 2005 and 2080, aggregate WTP loss across all five waves is $25 million.

As in the beach analysis, the individual WTP for a North Carolina shore fishing trip is approximated by assuming that all of the fishing sites represent 99% of the fishing opportunities. Taking the product of aggregate fishing trips (Table 4-10) and WTP for a North Carolina fishing trip ($128), the annual baseline value of North Carolina shore fishing sites is $475 million. The lost recreational fishing value due to sea level rise is 3% in 2030 and 3.5% in 2080. As in the beach analysis, the percentage values are likely conservative estimates since the aggregate WTP estimate is a likely overestimate.

The present value of the welfare costs are estimated by assuming the impacts of sea level rise are equal to zero in 2004 and increase linearly to 2080. Using a 0% discount rate, the present value of the welfare costs are $981 million assuming no change in population and $1.45 billion assuming an increase in population. Using a 2% discount rate, the present value of the welfare costs are $430 million assuming no change in population and $645 million assuming an increase in population. With a 7% discount rate, the estimates of the present value of the welfare costs are $101 million and $151 million assuming an increase in population.

Conclusions

In this section we develop estimates of the economic effects of climate change-induced sea level rise on beach recreation. We focus on beach and fishing trips since the data is readily available. We find that the total welfare cost of climate change-induced sea level rise to beach recreationists is between $93 million and $197 million in 2030 and between $223 million and $826 million in 2080 for the southern NC beaches.

The present value of the welfare costs assuming no increase in population or income is $9.2 billion, $3.7 billion and $722 million with 0%, 2% and 7% discount rates. Assuming increases in population and income leads to a present value of the welfare costs of $28.5 billion, $10.6 billion and $1.76 billion with 0%, 2% and 7% discount rates.

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[10] These results are available upon request.

Beach trip spending by non-local North Carolina residents would also change significantly with climate change-induced sea level rise. Total spending by those who only take day trips would fall by 2% in 2030 and 23% in 2080 compared to 2004. Those who take both day and overnight trips would spend 16% less in 2030 and 48% less in 2080.

The aggregate annual welfare cost to shore anglers in all of NC is between $15 million and $22 million in 2030, depending upon the assumed effect of population increases on trips. The aggregate welfare cost is between $17 million and $25 million in 2080.

The present value of the welfare costs to shore anglers is between $981 million and $1.47 billion using a 0% discount rate, depending upon the assumed effect of population increases on trips. The present value of the welfare costs is between $430 million and $645 million using a 2% discount rate. With a 7% discount rate, the range of the present value of welfare costs is $101 million to $151 million. Angler spending would not change significantly as beach anglers move to other beach sites to fish or fish from piers or bridges.

Several caveats are in order. First, these estimates are incomplete. The beachgoers estimates do not include Outer Banks beach trips. The economic effects of sea level rise on the tourist and recreation economy in this area of NC is likely to be substantial. The impacts on shore anglers are muted since piers are a good substitute for fishing from the beach. However, pier fishing in NC is becoming more limited as coastal property values rise. Some of the piers in the 2005 data are no longer available as substitute fishing sites. Also, boat anglers might be affected by sea-level rise if marinas must be relocated. Our analysis does not include these impacts.

Second, a limitation of the MRFSS and USACE data is that they include information on recreation participants only. Another potential impact of sea-level rise is its negative effect on participation. Marine recreational anglers may choose another recreation activity, such as freshwater fishing, if shore based fishing becomes unavailable. Beachgoers may choose another recreation activity as congestion increases (e.g., in 2030) and as beach capacity constraints are reached (e.g., in 2080). Future research could explore the possibility of using a participation site choice model with the day trippers in the USACE data to determine the magnitudes of these effects.

Third, analysis of events in the far distant future is subject to much uncertainty. Our uncertainty arises in the rudimentary participation modeling. We make forecasts of future beach trips based on increases in population and income. We make forecasts of future fishing trips based on increases in population. We ignore demographic change. For example, recreation participation is typically higher for those between 25 and 64 years of age. If the population ages during the next 25 and 75 years, recreation participation rates will fall.

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Appendix A: The Linked Site Selection – Trip Frequency Model

Consider an individual who considers a set of *j* recreation sites. The individual utility from the trip is decreasing in trip cost and increasing in trip quality:

$$u_i = v_i(y - c_i, q_i) + \varepsilon_i$$

where *u* is the individual utility function, *v* is the nonstochastic portion of the utility function, *y* is the per-trip recreation budget, *c* is the trip cost, *q* is a vector of site qualities, *ε* is the error term, and *i* is a member of *s* recreation sites, *s* = 1, … , *i* , … *J*. The random utility model assumes that the individual chooses the site that gives the highest utility:

$$\pi_i = \Pr(v_i + \varepsilon_i > v_s + \varepsilon_s \ \ \forall\, s \neq i)$$

where *π* is the probability that site *i* is chosen. If the error terms are independent and identically distributed extreme value variates then the conditional logit site selection model results:

$$\pi_i = \frac{e^{v_i}}{\sum_{s=1}^{J} e^{v_s}}$$

The conditional logit model restricts the choices according to the assumption of the independence of irrelevant alternatives (IIA). The IIA restriction forces the relative probabilities of any two choices to be independent of other changes in the choice set. For example, if a quality characteristic at site *j* causes a 5% decrease in the probability of visiting site *j* then the probability of visiting each of the other *k* sites must increase by 5%. This assumption is unrealistic if any of the *k* sites are better substitutes for site *j* than the others.

The nested logit model relaxes the IIA assumption. The nested logit site selection model assumes that recreation sites in the same nest are better substitutes than recreation sites in other nests. Choice probabilities for recreation sites within the same nest are still governed by the IIA assumption.

Consider a two-level nested model.[11] The site choice involves a choice among *M* groups of sites or nests, *m* = 1, … , *M*. Within each nest is a set of J_m sites, *j*= 1, … , J_m. When the nest chosen, *n*, is an element in *M* and the site choice, *i*, is an element in J_n and the error term is distributed as generalized extreme value the site selection probability in a two-level nested logit model is:

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[11] The notation follows Morey (1999).

$$\pi_{ni} = \frac{e^{v_{ni}/\theta_m}\left[\sum_{j=1}^{J_n} e^{v_{nj}/\theta_n}\right]^{\theta_n - 1}}{\sum_{m=1}^{M}\left[\sum_{j=1}^{J_m} e^{v_{mj}/\theta_m}\right]^{\theta_m}}$$

where the numerator of the probability is the product of the utility resulting from the choice of nest *n* and site *i* and the summation of the utilities over sites within the chosen nest *n*. The denominator of the probability is the product of the summation over the utilities of all sites within each nest summed over all nests. The dissimilarity parameter, $0 \leq \theta_m \leq 1$, measures the degree of similarity of the sites within the nest. When the dissimilarity parameters are constrained to be equal, the nested site selection probability simplifies to:

$$\pi_{ni} = \frac{e^{v_{ni}/\theta}\left[\sum_{j=1}^{J_n} e^{v_{nj}/\theta}\right]^{\theta - 1}}{\sum_{m=1}^{M}\left[\sum_{j=1}^{J_m} e^{v_{mj}/\theta}\right]^{\theta}}$$

As the dissimilarity parameter approaches zero the alternatives within each nest become less similar to each other when compared to sites in other nests. If the dissimilarity parameter is equal to one, the nested logit model collapses to the conditional logit model where $M \times J_m = J$.

Welfare analysis is conducted with the site selection models by, first, specifying a functional form for the site utilities. It is typical to specify the utility function as linear:

$$\begin{aligned} v_{ni}(y - c_{ni}, q_{ni}) &= \alpha(y - c_{ni}) + \beta' q_{ni} \\ &= \alpha y - \alpha c_{ni} + \beta' q_{ni} \\ &= -\alpha c_{ni} + \beta' q_{ni} \end{aligned}$$

where α is the marginal utility of income. Since αy is a constant it will not affect the probabilities of site choice and can be dropped from the utility function.

The next step is to recognize that the inclusive value is the expected maximum utility from the cost and quality characteristics of the sites. The inclusive value, *I*, is measured as the natural log of the summation of the nest-site choice utilities:

$$\begin{aligned} IV(c, q; \alpha, \beta) &= \ln\left(\sum_{m=1}^{M}\left[\sum_{j=1}^{J_m} e^{v_{mj}/\theta_m}\right]^{\theta_m}\right) \\ &= \ln\left(\sum_{m=1}^{M}\left[\sum_{j=1}^{J_m} e^{(-\alpha c_{mj} + \beta' q_{mj})/\theta_m}\right]^{\theta_m}\right) \end{aligned}$$

Hanemann (1999) shows that the per choice occasion welfare change from a change in cost and/or quality characteristics is:

$$WTP = \frac{IV(c,q;\alpha,\beta) - IV(c+\Delta c, q+\Delta q;\alpha,\beta)}{\alpha}$$

where willingness to pay, *WTP,* is the compensating variation measure of welfare. Haab and McConnell show that the willingness to pay for a quality change (e.g., changes in beach width) can be measured as

$$WTP(\Delta q_k \mid ni) = \frac{\beta_k \Delta q_{k|ni}}{\alpha}$$

where q_k is one element of the q vector at site i in nest n. Willingness to pay for the elimination of a recreation site from the choice set (e.g., beach erosion that eliminates the sandy beach) is

$$WTP(i \mid n) = \frac{\ln\left[\left(1-\Pr(i \mid n)\right)^{\theta_n} \Pr(n) + \left(1-\Pr(n)\right)\right]}{\alpha}$$

where $\Pr(i \mid n)$ is the unconditional probability of choosing site i given that nest n is chosen and $\Pr(n)$ is the unconditional probability of choosing nest n. Willingness to pay for elimination of a entire nest is

$$WTP(n) = \frac{\ln\left(1-\Pr(n)\right)}{\alpha}$$

since $\Pr(i \mid n) = 1$ when the entire nest of sites is eliminated. Haab and McConnell show that the value of eliminating the entire nest is greater than the sum of the value of all of the individual sites within the nest. The intuition is that, losing each site within a nest is less valuable because a number of good substitutes remain available within the nest. Therefore, the value of the whole is greater than the sum of its parts.

These welfare measures apply for each choice occasion, in other words, trips taken by the individuals in the sample. If the number of trips taken is unaffected by the changes in cost and/or quality, then the total willingness to pay is equal to the product of the per trip willingness to pay and the average number of recreation trips, $\bar{x}$.

If the number of trips taken is affected by the changes in cost and/or quality then the appropriate measure of aggregate welfare must be adjusted by the change in trips. There are several methods of linking the trip frequency model with the site selection model (Herriges, Kling and Phaneuf, 1999; Parsons et al., 1999), we choose the original approach that includes the inclusive parameter as a variable in the trip frequency model (Bockstael, Hanemann and Kling, 1987)[12]:

$$x = x\left[IV\left(c, q; \alpha, \beta\right), y, z\right]$$

where $x[\cdot]$ is a trip frequency model and z is a vector of individual characteristics that affect trip frequency. These models are typically estimated with count (i.e, integer) data models such as the Poisson or negative binomial models (Haab and McConnell 2002, Parsons 2003).

Trips under various welfare scenarios can be simulated by substitution of the cost and/or quality changes into the trip frequency model:

$$x(\Delta) = x\left[IV\left(\Delta c, \Delta q; \alpha, \beta\right), y, z\right]$$

The total willingness to pay of a quality change that might affect the number of trips is aggregated over the number of trips:

$$TWTP(\Delta q_k) = \sum_{m=1}^{M} \sum_{j=1}^{J_m} \left(\left[\bar{x}_{mj}(\Delta)\right] WTP(\Delta q_k \mid mj) + \left[\bar{x}_{mj} - \bar{x}_{mj}(\Delta)\right] WTP(m \mid j)\right)$$

The first component of the willingness to pay is the product of the average number of trips taken with the quality change and the value of the quality change. The second component of the willingness to pay is the product of the difference in trips and the willingness to pay for a trip to a particular site.

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[12] This is also referred to as a participation model in the literature.

Appendix B: Worksheets

Worksheet 1: Change in Value with Sea Level Rise 2030 for Day Trippers

Worksheet 2: Change in Value with Sea Level Rise 2080 for Day Trippers

Worksheet 3: Change in Value with Sea Level Rise 2030 for Day/Overnight Trippers

Worksheet 4: Change in Value with Sea Level Rise 2080 for Day/Overnight Trippers

Worksheet 5: Key to Worksheets 6 and 7

Worksheet 6: Impacts on Recreation with Current Income and Population

Worksheet 7: Impacts on Recreation with Increased Income and Population

Worksheet 1: Change in Value with Sea Level Rise 2030 for Day Trippers

				(a)	(b)	(c)	(d)	(e)=(b)×(c)	(f)=[(a)-(b)]×(d)
Beach	Baseline Conditional Nest Choice	Baseline Conditional Site Choice	Predicted Site Choice with Decrease in Beach Width	Baseline Trips	Trips with a Decrease in Beach Width	Willingness to Pay to Avoid Decrease in Beach Width per Trip	Willingness to Pay for Beach Site per Trip	Willingness to Pay for Decrease in Beach Width	Willingness to Pay for Loss of Beach Site
Fort Macon	0.30	0.03	0.03	0.75	0.74	1.86	0.34	1.37	0.01
Atlantic Beach	0.30	0.10	0.10	2.26	2.22	1.86	0.76	4.12	0.03
Pine Knoll Shores	0.30	0.04	0.04	0.88	0.87	1.86	0.39	1.61	0.01
Indian Beach / Salter Path	0.30	0.06	0.06	1.50	1.47	1.86	0.59	2.74	0.02
Emerald Isle	0.30	0.07	0.07	1.62	1.58	1.86	0.62	2.95	0.02
North Topsail Beach	0.21	0.10	0.10	2.46	2.41	1.86	0.60	4.48	0.03
Surf City	0.21	0.07	0.07	1.63	1.59	1.86	0.54	2.96	0.02
Topsail Beach	0.21	0.04	0.04	0.92	0.90	1.86	0.37	1.67	0.01
Wrightsville Beach	0.32	0.20	0.20	4.78	4.68	1.86	0.85	8.71	0.08
Carolina Beach	0.32	0.06	0.06	1.39	1.36	1.86	0.57	2.54	0.02
Kure Beach	0.32	0.03	0.03	0.77	0.75	1.86	0.35	1.40	0.01
Fort Fisher	0.32	0.03	0.03	0.66	0.64	1.86	0.30	1.20	0.00
Caswell Beach	0.17	0.03	0.03	0.72	0.71	1.86	0.29	1.32	0.00
Oak Island	0.17	0.04	0.04	0.92	0.90	1.86	0.35	1.67	0.01
Holden Beach	0.17	0.03	0.03	0.80	0.78	1.86	0.32	1.46	0.01
Ocean Isle Beach	0.17	0.03	0.03	0.74	0.73	1.86	0.30	1.35	0.00
Sunset Beach	0.17	0.03	0.03	0.79	0.77	1.86	0.31	1.43	0.00
Total				23.58	23.11		7.83	42.99	0.27

Worksheet 2: Change in Value with Sea Level Rise 2080 for Day Trippers

				(a)	(b)	(c)	(d)	(e)=(b)×(c)	(f)=[(a)-(b)]×(d)
Beach	Baseline Conditional Nest Choice	Baseline Conditional Site Choice	Predicted Site Choice with Decrease in Beach Width	Baseline Trips	Trips with a Decrease in Beach Width	Willingness to Pay to Avoid Decrease in Beach Width per Trip	Willingness to Pay for Beach Site per Trip	Willingness to Pay for Decrease in Beach Width	Willingness to Pay for Loss of Beach Site
Fort Macon	0.30	0.03	0.00	0.75	0.00		4.27	0.00	3.21
Atlantic Beach	0.30	0.10	0.00	2.26	0.00		4.27	0.00	9.66
Pine Knoll Shores	0.30	0.04	0.00	0.88	0.00		4.27	0.00	3.77
Indian Beach / Salter Path	0.30	0.06	0.00	1.50	0.00		4.27	0.00	6.41
Emerald Isle	0.30	0.07	0.00	1.62	0.00		4.27	0.00	6.91
North Topsail Beach	0.21	0.10	0.00	2.46	0.00		2.43	0.00	5.98
Surf City	0.21	0.07	0.00	1.63	0.00		2.43	0.00	3.96
Topsail Beach	0.21	0.04	0.00	0.92	0.00		2.43	0.00	2.23
Wrightsville Beach	0.32	0.20	0.00	4.78	0.00		2.50	0.00	11.94
Carolina Beach	0.32	0.06	0.68	1.39	12.45	5.48		68.21	0.00
Kure Beach	0.32	0.03	0.00	0.77	0.00		0.25	0.00	0.19
Fort Fisher	0.32	0.03	0.32	0.66	5.86	5.85		34.28	0.00
Caswell Beach	0.17	0.03	0.00	0.72	0.00		2.27	0.00	1.64
Oak Island	0.17	0.04	0.00	0.92	0.00		2.27	0.00	2.08
Holden Beach	0.17	0.03	0.00	0.80	0.00		2.27	0.00	1.82
Ocean Isle Beach	0.17	0.03	0.00	0.74	0.00		2.27	0.00	1.69
Sunset Beach	0.17	0.03	0.00	0.79	0.00		2.27	0.00	1.79
Total				23.58	18.31		42.75	102.49	63.27

Worksheet 3: Change in Value with Sea Level Rise 2030 for Day/Overnight Trippers

				(a)	(b)	(c)	(d)	(e)=(b)×(c)	(f)=[(a)-(b)]×(d)
Beach	Baseline Conditional Nest Choice	Baseline Conditional Site Choice	Predicted Site Choice with Decrease in Beach Width	Baseline Trips	Trips with a Decrease in Beach Width	Willingness to Pay to Avoid Decrease in Beach Width per Trip	Willingness to Pay for Beach Site per Trip	Willingness to Pay for Decrease in Beach Width	Willingness to Pay for Loss of Beach Site
Fort Macon	0.29	0.00	0.00	0.01	0.01	10.77	0.01	0.08	0.00
Atlantic Beach	0.30	0.10	0.10	1.08	0.96	10.77	0.87	10.30	0.10
Pine Knoll Shores	0.30	0.03	0.03	0.33	0.30	10.77	0.38	3.19	0.01
Indian Beach / Salter Path	0.30	0.04	0.04	0.45	0.40	10.77	0.48	4.27	0.02
Emerald Isle	0.30	0.12	0.12	1.27	1.13	10.77	0.93	12.14	0.13
North Topsail Beach	0.20	0.09	0.09	0.93	0.83	10.77	0.62	8.92	0.06
Surf City	0.21	0.06	0.06	0.67	0.59	10.77	0.58	6.40	0.04
Topsail Beach	0.21	0.05	0.05	0.50	0.45	10.77	0.48	4.80	0.03
Wrightsville Beach	0.36	0.22	0.22	2.39	2.12	10.77	1.07	22.85	0.28
Carolina Beach	0.32	0.08	0.08	0.89	0.79	10.77	0.82	8.52	0.08
Kure Beach	0.32	0.03	0.03	0.27	0.24	10.77	0.32	2.60	0.01
Fort Fisher	0.32	0.03	0.03	0.27	0.24	10.77	0.32	2.58	0.01
Caswell Beach	0.15	0.02	0.02	0.19	0.16	10.77	0.21	1.77	0.00
Oak Island	0.17	0.04	0.04	0.47	0.42	10.77	0.43	4.54	0.02
Holden Beach	0.17	0.03	0.03	0.31	0.27	10.77	0.32	2.92	0.01
Ocean Isle Beach	0.17	0.02	0.02	0.25	0.22	10.77	0.27	2.42	0.01
Sunset Beach	0.17	0.03	0.03	0.35	0.31	10.77	0.35	3.34	0.01
Total				10.62	9.44		8.46	101.65	0.85

Worksheet 4: Change in Value with Sea Level Rise 2080 for Day/Overnight Trippers

				(a)	(b)	(c)	(d)	(e)=(b)×(c)	(f)=[(a)-(b)]×(d)
Beach	Baseline Conditional Nest Choice	Baseline Conditional Site Choice	Predicted Site Choice with Decrease in Beach Width	Baseline Trips	Trips with a Decrease in Beach Width	Willingness to Pay to Avoid Decrease in Beach Width per Trip	Willingness to Pay for Beach Site per Trip	Willingness to Pay for Decrease in Beach Width	Willingness to Pay for Loss of Beach Site
Fort Macon	0.29	0.00	0.00	0.01	0.00		5.92	0.00	0.05
Atlantic Beach	0.30	0.10	0.00	1.07	0.00		5.92	0.00	6.36
Pine Knoll Shores	0.30	0.03	0.00	0.33	0.00		5.92	0.00	1.97
Indian Beach / Salter Path	0.30	0.04	0.00	0.45	0.00		5.92	0.00	2.64
Emerald Isle	0.30	0.12	0.00	1.27	0.00		5.92	0.00	7.50
North Topsail Beach	0.20	0.09	0.00	0.93	0.00		2.73	0.00	2.54
Surf City	0.21	0.06	0.00	0.67	0.00		2.73	0.00	1.82
Topsail Beach	0.21	0.05	0.00	0.50	0.00		2.73	0.00	1.37
Wrightsville Beach	0.36	0.22	0.00	2.38	0.00		3.07	0.00	7.32
Carolina Beach	0.32	0.08	0.76	0.89	4.60	31.65		145.53	
Kure Beach	0.32	0.03	0.00	0.27	0.00		0.19	0.00	0.05
Fort Fisher	0.32	0.03	0.24	0.27	1.45	33.81		49.09	
Caswell Beach	0.15	0.02	0.00	0.18	0.00		1.39	0.00	0.26
Oak Island	0.17	0.04	0.00	0.47	0.00		1.39	0.00	0.66
Holden Beach	0.17	0.03	0.00	0.30	0.00		1.39	0.00	0.42
Ocean Isle Beach	0.17	0.02	0.00	0.25	0.00		1.39	0.00	0.35
Sunset Beach	0.17	0.03	0.00	0.35	0.00		1.39	0.00	0.48
Total				10.60	6.05		48.00	194.62	33.78

Worksheet 5: Key to Worksheets 6 and 7

Row	
(1)	Beach recreation participant household income (in thousands)
(2)	Beach recreation participation rate
(3)	Household population of study region
(4)	Beach going households
(5)	Baseline trips
(6)	Total number of annual trips
(7)	Trips with decrease in beach width
(8)	Total number of annual trips with decrease in beach width
(9)	Change in total number of annual trips with decrease in beach width
(10)	Individual WTP for beach trips per trip
(11)	Individual WTP to avoid a decrease in beach width per beach household
(12)	Baseline Aggregate Beach Trip Value
(13)	Aggregate WTP for decrease in beach width
(14)	Aggregate WTP for decrease in beach trips
(15)	Total Aggregate WTP to avoid a decrease in beach width
(16)	Percentage of Lost Aggregate WTP from decrease in beach width
(17)	Beach recreation expenditures per trip
(18)	Baseline nonlocal trips
(19)	Percentage of nonlocal trips
(20)	Baseline nonlocal trips
(21)	Total nonlocal beach recreation Expenditures
(22)	Nonlocal trips per household with decrease in beach width
(23)	Nonlocal trips with decrease in beach width
(24)	Total nonlocal beach recreation expenditures with decrease in beach width
(25)	Aggregate change in nonlocal beach recreation expenditures
(26)	Aggregate change in beach recreation expenditures

Worksheet 6: Impacts on Recreation with Current Income and Population

		2030		2080	
Row	Calculation	Day Trippers	Day/Overnight Trippers	Day Trippers	Day/Overnight Trippers
(1)	Table 4-1	$57.41	$60.69	$57.41	$60.69
(2)	Survey Response	23.09%	40.91%	23.09%	40.91%
(3)	Survey Response	1,580,000	1,580,000	1,580,000	1,580,000
(4)	(2) × (3)	364,800	646,400	364,800	646,400
(5)	Worksheets 1-4	23.58	10.62	23.58	10.62
(6)	(4) × (5)	8,601,984	6,864,768	8,601,984	6,864,768
(7)	Worksheets 1-4	21.88	9.44	18.31	6.05
(8)	(4) × (7)	7,981,824	6,102,016	6,679,488	3,910,720
(9)	(6) - (8)	620,160	762,752	1,922,496	2,954,048
(10)	Note (a)	$55.48	$64.86	$55.48	$64.86
(11)	Worksheets 1-4	$43	$102	$102	$195
(12)	(6) × (10)	$477,238,072	$445,248,853	$477,238,072	$445,248,853
(13)	(4) × (11)	$15,686,400	$66,249,536	$37,081,920	$125,802,368
(14)	(9) × (10)	$4,855,853	$6,452,882	$15,053,144	$24,991,246
(15)	(13) + (14)	$20,542,253	$72,702,418	$52,135,064	$150,793,614
(16)	(15) ÷ (12)	4.3%	16.32%	10.92%	33.87%
(17)	Another Study	$163.87	$851.65	$163.87	$851.65
(18)	Table 4-1	12.62	8.14	12.62	8.14
(19)	(18) ÷ (5)	0.52	0.87	0.52	0.87
(20)	(4) × (18) × (19)	2,393,964	4,577,676	2,393,964	4,577,676
(21)	(17) × (20)	$392,298,880	$3,988,577,765	$392,298,880	$3,988,577,765
(22)	Table 4-9	12.38	6.86	9.72	4.25
(23)	(4) × (22) × (19)	2,348,436	3,857,844	1,843,845	2,390,064
(24)	(17) × (23)	$384,838,207	$3,285,532,843	$302,150,880	$2,035,498,006
(25)	(21) - (24)	$7,460,673	$703,044,922	$90,148,000	$1,953,079,759
(26)	(25) ÷ (21)	1.90%	15.72%	22.98%	47.79%

(a) An approximation of the total site value: $WTP(n) = \dfrac{\ln\left(1 - \Pr(n)\right)}{\alpha}$; where Pr($n$) = .99

Worksheet 7: Impacts on Recreation with Increased Income and Population

		2030		2080	
Row	Calculation	Day Trippers	Day/Overnight Trippers	Day Trippers	Day/Overnight Trippers
(1)	Table 4-1	$87.10	$92.08	$182.13	$192.53
(2)	Survey Response	36.93%	55.48%	53.55%	69.84%
(3)	Smith (2006)	2,370,000	2,370,000	3,160,000	3,160,000
(4)	(2) × (3)	875,176	1,314,770	1,692,027	2,207,020
(5)	Worksheets 1-4	23.58	10.62	23.58	10.62
(6)	(4) × (5)	20,636,641	13,962,855	39,898,007	23,438,555
(7)	Worksheets 1-4	21.88	9.44	18.31	6.05
(8)	(4) × (7)	19,148,843	12,411,427	30,981,023	13,352,473
(9)	(6) - (8)	1,487,799	1,551,428	8,916,985	10,086,083
(10)	Note (a)	$55.48	$64.86	$55.48	$64.86
(11)	Worksheets 1-4	$43	$102	$102	$195
(12)	(6) × (10)	$1,144,920,843	$905,630,775	$2,213,541,428	$1,520,224,677
(13)	(4) × (11)	$37,632,568	$134,750,753	$171,994,590	$429,530,286
(14)	(9) × (10)	$11,649,463	$13,125,084	$69,819,990	$85,328,259
(15)	(13) + (14)	$49,282,031	$147,875,836	$241,814,580	$514,858,545
(16)	(15) ÷ (12)	4.3%	16.32%	10.92%	33.87%
(17)	Another Study	$163.87	$851.65	$163.87	$851.65
(18)	Table 4-1	12.62	8.14	12.62	8.14
(19)	(18) ÷ (5)	0.52	0.87	0.52	0.87
(20)	(4) × (18) × (19)	5,743,252	9,310,936	11,103,761	15,629,676
(21)	(17) × (20)	$941,146,705	$7,929,658,644	$1,819,573,315	$13,311,013,570
(22)	Table 4-9	12.38	6.86	9.72	4.25
(23)	(4) × (22) × (19)	5,634,031	7,846,809	8,552,184	8,160,457
(24)	(17) × (23)	$923,248,660	$6,682,734,885	$1,401,446,392	$6,949,853,204
(25)	(21) - (24)	$17,898,045	$1,246,923,759	$418,126,923	$6,361,160,366
(26)	(25) ÷ (21)	1.90%	15.72%	22.98%	47.79%

(a) An approximation of the total site value: $WTP(n) = \frac{\ln(1-\Pr(n))}{\alpha}$; where Pr(*n*) = .99.

5. Impacts on Business and Industry

In section 5 of this report we estimate the economic impacts of changes in tropical storm and hurricane wind speeds due to climate change. Table 2-5 in Section 2 presents the estimated maximum sustained wind speeds for three scenarios: 1996 (baseline), 2030, and 2080, for four example counties: Bertie, Carteret, Dare, and New Hanover. The windspeeds in Table 2-5 are converted to their equivalent Saffir-Simpson scale hurricane categories[13], presented in Table 5-1. The wind speeds in Table 2-5 and hurricane categories in Table 5-1 corresponding to the "MAX" model run for the baseline 1996 storm (hurricane Fran) are most consistent with the observed wind speeds in the field in 1996 (NWS-NHC, 2007); hence, we use the "MAX" model runs for our impact analysis. The hurricane categories for the MAX model runs in Table 5-1 correspond to tropical storm through weak category 3 storms, relatively low-intensity storms for which agricultural, forestry, commercial fisheries, and general "business interruption" impacts would likely be the predominate categories of economic impacts (i.e., instead of massive damage to structures and infrastructure). Economic impact estimates by impact category are discussed below.

Table 5-1: Saffir-Simpson scale hurricane categories for baseline and climate change scenarios (TS = tropical storm, 1 = category 1 hurricane, 2 = category 2 hurricane, etc.)

	Category 3 Hurricane (Hurricane Fran) Baseline Scenario			Climate Change Scenarios					
	1996	1996	1996	2030	2030	2030	2080	2080	2080
County	MIN	MID	MAX	MIN	MID	MAX	MIN	MID	MAX
Bertie	TS	TS	TS	TS	TS	TS	TS	TS	TS
Carteret	TS	1	1	TS	1	2	TS	1	2
Dare	TS	TS	TS	TS	TS	1	TS	TS	1
New Hanover	1	1	2	1	1	2	1	1	3

Note: Although hurricane Fran was recorded as a "category 3" storm at landfall in New Hanover county, based on maximum sustainable winds recorded in the county, the wind speed model found that the maximum sustainable winds averaged across all locations in the county was a strong category 2, as reported in Table 5-1.

Although low-intensity storms cause less physical damage to structures and infrastructure than do high-intensity storms, low-intensity storms occur with much greater frequency, especially in North Carolina. The cumulative economic impacts of frequent low-intensity storm strikes can rival the impacts of infrequent high-intensity storm strikes (Burrus et al. 2002). To properly account for the impacts of wind damage due to climate change, estimates of changes in both storm severity (maximum sustained winds) and storm frequency (or, estimates of shifts in the maximum sustained wind speed frequency distribution) are necessary. However, the climate models used for this study do not produce estimates of changes in storm frequency or shifts in the wind speed frequency distribution. In the absence of information on changes in storm frequency, we assume that the annual frequencies of hurricane strikes are equal to the average annual hurricane strike frequencies for North Carolina from 1851 to 2006, based on the observed

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[13] On the Saffir-Simpson scale, see http://www.nhc.noaa.gov/aboutsshs.shtml.

numbers of hurricane strikes as described in Blake, et al. (2005) and NWS-NHC (2007), presented in Table 5-2. For the present study, only the annual strike frequency of category 3 storms, 0.0705, is relevant, because the climate models produced estimates of changes in storm severity (wind speeds) for category 3 storms only.

Table 5-2: Observed annual hurricane strike frequencies for North Carolina by Saffir-Simpson scale hurricane category.

Hurricane Category	1	2	3	4	5
Number of Strikes in North Carolina 1851-2006	23	13	11	1	0
Annual Frequency	0.1474	0.0833	0.0705	0.0064	0.0000

We combine the storm severity (wind speed) estimates with the strike frequency data for category 3 storms by assuming that the strike frequency remains unchanged under climate change while the storm severities change across scenarios as shown in Table 5-1. In effect, we are assuming that the storm strike frequency distribution remains unchanged as climate change occurs, but just before a given storm strikes the coast, its severity is adjusted based on the storm severity change estimates of the climate change models. We estimate the present value of the economic impacts of expected increases in hurricane severity under climate change for a given pre-climate change category of storm (category 3 storms) assuming no change in pre-climate change strike frequency. The primary categories of economic impacts for low-intensity storm strikes are “business interruption,” agriculture, forestry and commercial fisheries.

Business Interruption Impacts

“Business interruption” is a reduction in economic output due to temporary lack of utility service, employee absenteeism, supply chain interruption, and disruption of consumer access to businesses due to temporary flooding, etc. Business interruption has been found to have a significant impact on economic activity following natural disasters (Webb et al. 2000, Burrus et al. 2002). The regional economic impacts of low intensity storms arise mainly through business interruption rather than through damage to structures and infrastructure. Business interruption impacts are important for the present study because the estimated changes in storm intensity in the study region due to climate change are changes among low intensity hurricane categories. In contrast to the economic impacts of structural damage associated with high-intensity storm events, business interruption impacts caused by low-intensity storms are typically not offset by large inflows of extra-regional funds from insurers and government disaster assistance programs (where available and utilized, business interruption insurance may offset some of these impacts).

Burrus et al. (2002) measured the business interruption impacts of three low intensity hurricanes striking Wilmington, North Carolina, between 1996 and 1998. Hurricane Bertha was classified as a category 1 hurricane, Bonnie a category 2 storm, and Fran a moderate category 3 hurricane; hence, these storms span the range of low-intensity hurricanes. Based on a survey of regional businesses, Burrus et al. calculated the “Full-Day Equivalents Lost” (FDEL) by industry sector attributable to each of the three hurricanes for New Hanover County, NC. A FDEL for a given industry is the average number of full working days lost as a result of a storm strike. For example, if survey respondents in a particular industry were, on average, at half of normal operations for four days following a category 2 storm strike, then the FDEL for that industry for category 2 storms would be 0.5 × 4 days = 2 FDEL. Examples of industry-specific FDEL for New Hanover County, NC, by hurricane category are presented in Table 5-3.

Table 5-3: Industries with Full-Day Equivalents Lost

Industry Sector Name	Hurricane Bertha (Cat 1) FDEL	Hurricane Bonnie (Cat 2) FDEL	Hurricane Fran (Cat 3) FDEL	Industry Average FDEL
Boat Building and Repairing	6.54	32.21	104.46	47.74
Amusement and Recreation Services	9.94	17.78	89.03	38.92
Food Stores	12.92	27.08	23.25	21.08
Social Services	0.00	6.25	51.75	19.33
New Residential Structures	12.96	6.33	34.25	17.85
Electrical Repair Service	1.00	4.00	42.50	15.83
Furniture & Home Furnishings Stores	8.58	4.92	31.58	15.03
Other Nonprofit Organizations	16.75	14.56	13.13	14.81
Real Estate	10.74	8.24	11.72	10.23
Miscellaneous Retail	8.02	4.19	14.27	8.83
Canvas Products	5.00	5.00	14.00	8.00
Credit Agencies	6.31	2.88	14.35	7.85
Radio and TV Broadcasting	2.00	8.75	12.38	7.71
Hotels and Lodging Places	0.83	0.60	21.35	7.59
⋮	⋮	⋮	⋮	⋮
Observation-Weighted Means Over ALL Sectors	3.75	4.66	12.61	7.01

The industry-specific FDEL estimates in Burrus et al. (2002) are assumed to hold for the other counties in eastern North Carolina. However, baseline industry output/revenue is allowed to vary across industries as well as across counties. For each county considered in this study, detailed industry output/revenue data were obtained from the IMPLAN (version 2.0.1025, 2003 database and structural matrix) regional economic impact modeling software database (MIG 2005).

Since tropical storms produce little business interruption in the study region, we assume that the business interruption impacts of tropical storms are negligible. The business interruption impacts for category 1 through category 3 hurricanes are estimated by applying the industry-specific FDEL estimates to the average daily output/revenue for that industry and county. For example, if a given industry in Carteret County is struck by a category 2 hurricane, the industry is assumed to lose a *number of days* of output/revenue equal to the FDEL for the corresponding industry in the Burrus et al. study. However, the output/revenue figure *per day* is unique for that industry and county, based on the IMPLAN data. For each county and hurricane category, FDEL are multiplied by average daily output/revenue by industry sector, and the resulting products are summed across sectors to obtain economic impacts. Due to the manner in which FDEL are defined, the conservative interpretation of these economic impacts is that they represent total economic impacts, including all "multiplier" effects due to indirect and induced impacts. Economic impact estimates by county and climate change scenario are presented in Table 5-4.

Table 5-4: Business interruption impacts of a single storm strike in 2004, by county and scenario (Millions of 2004-year dollars)

County	Category 3 Hurricane (Hurricane Fran 1996) Baseline Scenario MAX model run	Climate Change Scenarios	
		2030 MAX model run	2080 MAX model run
Bertie	negligible	negligible	negligible
Carteret	$20	$24	$24
Dare	negligible	$30	$30
New Hanover	$85	$85	$208

For each county, the business interruption impacts of climate change *per storm strike* are measured by the *change* in impacts across model scenarios in Table 5-4, assuming 1996 impacts as a baseline. Impact estimates are presented on a "per pre-climate change category 3 storm event" basis. For example, if a category 3 (baseline, pre-climate change) storm with Fran's track struck in 2004, it would be expected to reduce business output by $85 million in New Hanover County. If a 2080-strength storm with Fran's track struck New Hanover County in 2004, it would be expected to reduce business output by $208 million in the county. Hence, the *change* (increase) in business output losses is estimated to be $208 million - $85 million = $123 million in additional losses per storm event, measured in year 2004 dollars. Similar estimates of the incremental damage per storm strike due to climate change can be made for other counties and climate change scenarios.

To estimate the incremental damage of climate change over time, the incremental damages per storm event derived from Table 5-4 are multiplied by the frequency of category 3 storm strikes per year (Table 5-2) and cumulated over years. If we interpolate the incremental damages per storm strike between scenario years in Table 5-4, the present values of incremental damage due to climate change between 2004 and 2080 for 0%, 2%, 5% and 7% discount rates are presented in Table 5-5. The effect of larger discount rates on losses is more pronounced for New Hanover County because the climate models suggest that a relatively large proportion of the climate change impacts for this county occur relatively far into the future, where discounting has a larger impact.

Table 5-5: Present Value of Business Interruption Losses 2004-2080 Due to Increased Severity of Category 3 (Only) Hurricane Strikes Without Regional Economic & Population Growth.[1]

	Discount Rate			
	0% (No Discounting)	2%	5%	7%
County	2004 $ (millions)	2004 $ (millions)	2004 $ (millions)	2004 $ (millions)
Bertie	negligible	negligible	negligible	negligible
Carteret	$18	$8	$3	$2
Dare	$134	$60	$24	$15
New Hanover	$221	$70	$14	$6

[1] Assumes (1) annual strike frequency of category 3 hurricanes remains at historical average (1851 to 2006) of 0.0705 per year (see text); (2) linear increases in climate change impacts from 2004 to 2030, and from 2030 to 2080.

There are several caveats to consider. First, the business interruption impacts in Table 5-5 are based on the assumption that regional population, economic output, and industry structure remain at 2003 levels from 2004 to 2080. Of course, this is unlikely, and we can instead project growth in population and economic output into the future and estimate the changes in climate change impacts. It is difficult to project regional economic growth and changes in industry structure, but if we assume that the regional business output grows in proportion to projected increases in state population and U.S. per capita personal income, then the present values of incremental damage due to climate change between 2004 and 2080 for various discount rates are as presented in Table 5-6.

Table 5-6: Present Value of Business Interruption Losses 2004-2080 Due to Increased Severity of Category 3 (Only) Hurricane Strikes With Regional Economic & Population Growth.[1]

	Discount Rate			
	0% (No Discounting)	2%	5%	7%
County	2004 $ (millions)	2004 $ (millions)	2004 $ (millions)	2004 $ (millions)
Bertie	negligible	negligible	negligible	negligible
Carteret	$58	$22	$7	$4
Dare	$438	$168	$53	$29
New Hanover	$946	$284	$54	$20

[1] Assumes (1) annual strike frequency of category 3 hurricanes remains at historical average (1851 to 2006) of 0.0705 per year (see text); (2) linear increases in climate change impacts from 2004 to 2030, and from 2030 to 2080; (3) population growth rates as per IPCC Special Report on Emissions Scenarios SRES A1 population projection; (4) economic growth based on United States Energy Information Agency projected growth rate in U.S. per capita GDP.

Second, the business interruption loss estimates presented in Tables 5-5 and 5-6 do not include losses from tropical storms or category 1, 2, 4, or 5 hurricanes that may become more severe due to climate change. The climate change models used in this study produced estimates of storm severity impacts for category 3 hurricanes only, and the impacts reported in Tables 5-5 and 5-6 reflect increased severity of category 3 hurricanes only.

Third, the losses presented in Tables 5-5 and 5-6 do not reflect any damage due to increased frequency of tropical storm and hurricane strikes caused by climate change. The loss estimates reflect category 3 hurricane storm strike frequency held constant at its historical value as of 2006. If climate change increases storm frequency as well as storm severity, then the losses are underestimates. If climate change decreases storm frequency while increasing storm severity, then the losses are overestimates.

Fourth, there is an assumption of linearity in the estimate of business interruption loss which may tend to understate the potential damages. The linearity comes into play in two ways:

(1) Damage may be a convex function of the fraction of a day – loosing 9/10 of a day is more than 9 times as damaging as losing 1/10 of day (which may be essentially zero loss).
(2) Damage may be a convex function of the number of full days equivalents lost –losing 4 days may be more than 4 times more serious than losing 1 day.

Although the model is linear in full day equivalents lost, the relationship between full day equivalents and wind speed is non-linear, and we believe this to be the key non-linearity with respect to hurricane damage. In our analysis, a given increase in wind speed results in a more than proportional increase in full day equivalents lost, which, when multiplied by fixed output losses per full day equivalent, makes the relationship between wind speed and damage (output losses) non-linear. Although it is possible that damage is non-linear in the number of full day equivalents lost, we believe that the effect of this non-linearity would be small relative to the effect of the non-linearity captured by the analysis. Nevertheless, this is a topic for future research.

Fifth, the business interruption impacts do not include impacts on basic resource industries: agriculture and forestry (which are important for Bertie and Carteret Counties) and commercial fisheries (which is important for Dare County). Economic impacts for these industries are considered separately below.

Agriculture Sector Impacts

The North Carolina Agricultural Statistics Service (NCASS) is a joint venture between the North Carolina Department of Agriculture & Consumer Services and the United States Department of Agriculture's National Agricultural Statistics Service. NCASS publishes current and historical statistics concerning agriculture in North Carolina (Murphy 2006). NCASS has produced County Damage Reports that provide estimates of crop and livestock losses due to tropical storms and hurricanes since 1996 (NCASS 2006).

Agricultural hurricane damage statistics for the case study counties considered in this report and statewide totals, 1996-2006, are presented in Table 5-7. There is great variation in damage across counties for a given storm. This variation is due to differences in the types and intensity of crops and livestock raised across counties and differences in distances to the coast. Across storms, damages across counties differ for an additional reason—differences in storm tracks and landfall dates. Some storms cross counties that have large agricultural sectors, while other storms do not. Some storms make landfall at times when crops are more vulnerable to high winds and flood waters, other storms make landfall at times when crops are less vulnerable. Damages differ across years for a given county and hurricane category due to differences in the intensity of agriculture within a county over time and differences in agricultural commodity prices from year to year.

Table 5-7: North Carolina Agricultural Hurricane Damage Statistics

			Agriculture Sector Damages				
Storm Name	Date	Storm Category	Bertie (2004 $'s)	Carteret (2004 $'s)	Dare (2004 $'s)	New Hanover (2004 $'s)	NC Statewide Totals (2004 $'s)
Bertha	1996	Cat 2	$10,893,115	$4,091,257	$0	$233,075	$206,685,166
Fran	1996	Cat 3	$2,775,410	$2,436,815	$2,333,688	$1,117,130	$793,706,645
Bonnie	1998	Cat 2/(3)	$3,429,983	$7,715,530	$1,823,119	$624,400	$210,431,851
Dennis	1999	TS/Cat 1	$0	$6,880,463	$0	$21,678	$47,743,241
Floyd	1999	Cat (2)/3	$12,311,920	$8,807,432	$7,065,549	$169,465	$881,938,012
Irene	1999	Cat 1	$6,154,031	$0	$2,878,837	$0	$32,191,125
Bonnie & Charlie	2004	TS & TS	$582,414	$1,795,434	$0	$119,876	$56,512,720
Frances*	2004	TS	$0	$0	$0	$0	$54,913,000
Ivan*	2004	TS	$0	$0	$0	$0	$21,313,391
Ophelia	2005	Cat 1	$0	$2,111,824	$0	$0	$18,700,586
Tammy	2005	TS	$3,959,350	$196,712	$0	$0	$48,888,235
Ernesto	2006	TS	$0	$1,294,801	$0	$44,670	$55,685,149
Alberto*	2006	TS	NA	NA	NA	NA	NA

Source: NCASS 2006.

* Storm entered North Carolina from the West, causing little damage to coastal counties in the eastern, coastal portion of the state.

NA = not available.

TS = tropical storm.

TS/Cat 1 = storm intensity borderline between tropical storm / category 1, category 1 assumed based on damage.

2/(3) = storm intensity borderline between category 2 / category 3, category 2 assumed based on damage.

(2)/3 = storm intensity borderline between category 2 / category 3, category 3 assumed based on damage.

Despite the variation, some patterns emerge. In general, higher intensity storms produce greater damages. Damages for each county and statewide damages averaged across storms within each hurricane category are presented in Table 5-8. As hurricanes increase in intensity, average damages rise. This pattern is not seen for every pair of hurricane categories for every county due to idiosyncrasies of the limited data set. Indeed, even for the statewide totals, average damages for a category 1 hurricane are lower than average damages for a tropical storm. However, the increases in average statewide damages between category 1 and category 2 hurricanes, and again between category 2 and category 3 hurricanes, are substantial.

Table 5-8: Average North Carolina Agricultural Hurricane Damage Statistics

Storm Category	Bertie (2004 $'s)	Carteret (2004 $'s)	Dare (2004 $'s)	New Hanover (2004 $'s)	NC Statewide Totals (2004 $'s)
Tropical Storm	$1,513,921	$1,095,649	$0	$54,849	$53,695,368
Category 1	$2,051,344	$2,997,429	$959,612	$7,226	$32,878,317
Category 2	$7,161,549	$5,903,393	$911,559	$428,738	$208,558,508
Category 3	$7,543,665	$5,622,123	$4,699,619	$643,298	$837,822,329

Based on differences in average North Carolina crop and livestock damages from tropical storms and hurricanes between 1996 and 2006, it appears that a tropical storm or category 1 hurricane strike causes $30-$50 million (in 2004 dollars) in crop and livestock damage. A category 2 storm causes an average of $200 million in damage, or $150 million in incremental damage beyond the damage that would be caused by a category 1 hurricane strike. A category 3 storm causes an average of $800 million in damage, or $600 million in incremental damage beyond the damage that would be caused by a category 2 strike.

Forest Sector Impacts

The North Carolina Division of Forest Resources normally conducts forest damage assessments when any agent (e.g., insect, disease, natural disaster) damages 1000 or more acres of forestland (Trickel 2006). Many of the tropical storms and hurricanes that have threatened North Carolina have done scattered damage, but not enough to conduct a full-scale assessment. Most storms have been relatively weak tropical storms or hurricanes that fell apart quickly after making landfall and have not caused sufficient forest damage to require a damage assessment. Two notable storms that caused significant damage to North Carolina forests and for which damage assessments are available are hurricanes Fran and Isabel (Trickel 2003).

The level and geographic distribution of forest damage depend heavily on the relationship between the storm track and the geographic distribution of forest land and tree maturity. In addition, timber and wood pulp prices vary greatly over time. Because of the variations in timber prices and the volume and geographic distribution of standing timber, it is difficult to estimate the "average" impact of a hurricane of given severity, much less the incremental impact of increased severity, without substantially more data. In this study, we simply use the difference in damages caused by hurricane Isabel, a category 2 hurricane, and hurricane Fran, a category 3 storm, to illustrate the potential impacts of increasing storm severity on forest damages. By comparing the damages from these two storms, we obtain some idea of the incremental impact of increasing storm severity in the likely range of severities considered by this climate change study.

On September 6, 1996, Hurricane Fran made landfall as a Category 3 hurricane near Wilmington, NC, and cut northwest across the Northern Coastal Plain of North Carolina before passing into Virginia. The circulation and radius of maximum winds were large and hurricane force winds likely extended over much of the North Carolina coastal areas of Brunswick, New Hanover, Pender, Onslow and Carteret counties. At landfall, the maximum sustained surface winds were estimated at 115 miles per hour. The North Carolina Forest Service conducted a Timber Damage Assessment (Thompson and Doggett, 1996) that found varying degrees of damage to 8.2 million acres of forestland, representing 44% of all commercial forest land in the state. The number of forest acres falling into each of four damage classes (based on percentage of trees destroyed) by county and for the state overall is shown in Table 5-9. The majority of damaged trees were completely uprooted rather than simply broken. The estimated value of lost timber was $1.2 billion ($1.39 billion in 2004 dollars).

Table 5-9: Acreage of Timberland Damaged and Timber Damage Value in North Carolina by Percentage Damage Class, Hurricane Fran

	Percentage of Trees Destroyed					
County	1-25%	26-50%	51-75%	76-100%	Total Damaged Acres	Total Damage Value (2004 dollars)
Bertie	142 acres	-	-	-	142 acres	$21,939
Carteret	48,889 acres	-	-	-	48,889 acres	$5,794,113
Dare	-	-	-	-	0 acres	$0
New Hanover	14,714 acres	19359 acres	8,425 acres	7,105 acres	49,603 acres	$14,515,303
NC Statewide Total	6,480,668 acres	1,391,168 acres	333,034 acres	52,055 acres	8,255,925 acres	$1,496,044,962

On September 18, 2003, Hurricane Isabel made landfall as a Category 2 hurricane near Cedar Island, NC, and cut northwest across the Northern Coastal Plain of North Carolina before passing into Virginia. Hurricane force winds were recorded in the area northeast of a line extending from Onslow County to Vance County. Maximum sustained winds of 100 miles per hour with higher gusts were recorded in this area. Sustained winds above 39 miles per hour were also recorded throughout the rest of North Carolina's Coastal Plain and throughout the Piedmont.

A Forest Damage Appraisal was conducted by the North Carolina Division of Forest Resources for the 26 counties most affected by Hurricane Isabel (Trickel 2003). In comparison to the study for hurricane Fran, the Isabel study provided a more extensive description of appraisal methodology and findings. The appraisal was based on data from two surveys: an aerial survey using east-west flight lines located 10 minutes (roughly 10 miles) apart, and a ground survey using a 10-mile block grid over the 26 county area.

A total of 833,192 acres of timber sustained some level of damage. Of the damaged hardwoods located on ground survey plots 85 percent were blown over. Most hardwood damage occurred in bottomlands, swamps and drainages where saturated soils provided less support. Seventy eight percent of the damaged pines were blown over.

The number of forest acres falling into each of four damage classes (based on percentage of trees destroyed) by county and for the state overall is shown in Table 5-10. Average timber values per acre before the storm were multiplied by mean percentage damage for each damage class and acreage in that damage class before aggregating over damage classes to obtain dollar damages. Total timber damage in the state was estimated to be $578 million in 2004 dollars. A sufficient number of samples were taken over the entire area to achieve a 95 percent confidence level. More than a quarter of the timber damage (volume and value) from Hurricane Isabel occurred in Bertie County, one of the representative counties selected for this study.

Table 5-10: Acreage of Timberland Damaged and Timber Damage Value in North Carolina by Percentage Damage Class, Hurricane Isabel

	Percentage of Trees Destroyed					
County	1-25%	26-50%	51-75%	76-100%	Total Damaged Acres	Total Damage Value (2004 dollars)
Bertie	61,655 acres	80,076 acres	44,255 acres	-	185,986 acres	$159,335,554
Carteret	2820 acres	-	-	-	2820 acres	$1,064,431
Dare	31,832 acres	-	-	-	31,832 acres	$8,027,868
New Hanover	-	-	-	-	0 acres	-
NC Statewide Total	425,713 acres	310,619 acres	96,860 acres	-	833,192 acres	$578,387,092

To summarize results for the forest sector, hurricane Fran, a category 3 storm, damaged ten-times as many forest acres as Isabel, a category 2 hurricane. Dollar-denominated damage was two and a half times larger when expressed in equivalent year dollars. Isabel may have done more damage if she had preceded Fran, as Fran may have “cleared out” some weak trees. If so, then the *incremental* damage of a category 3 storm in comparison to a category 2 storm would be smaller. Even if this were the case, it appears that the incremental increase in forest damage associated with increased storm severity in the hurricane category 2 to category 3 range is substantial in North Carolina, perhaps equivalent to a doubling of dollar-valued damage, or about $500 million in incremental damage in 2004 dollars.

Commercial Fishing Sector Impacts

Although work is underway at the North Carolina Division of Marine Fisheries (NCDMF) to assess the impacts of hurricanes on North Carolina fisheries, it is still work in progress. Consistent time series data do not exist on the costs or damages to commercial fishing operations caused by tropical storms and hurricanes (Bianchi 2006). As a result, it is not possible at this time to estimate the impacts of increased storm intensity on North Carolina commercial fisheries. However, two recent case studies, summarized below, shed some light on the economic impacts of hurricanes on the commercial fishing sector.

Hurricane Disaster Relief Program Study--Hurricanes Dennis, Floyd and Irene impacted North Carolina during late August through October 1999. North Carolina’s fishing industry suffered extensive damage from the hurricanes and associated floods. Fishing gear, vessels, and shore side structures were damaged and lost. Many of the approximately 5000 active commercial fishermen could not fish for periods ranging from days to months. Infrastructure supporting both commercial and recreational fishing was damaged and destroyed. Following Hurricane Floyd in 1999, the NCDMF was charged with dispersing Hurricane Disaster Relief

Program funds to commercial fishermen. During this process NCDMF collected estimates of fishing gear lost and damages incurred. However, the emergency relief program data were self-reported by the fishermen, without independent validation to ensure that the data were correct.

A follow-up survey of all fishermen who received money during the Hurricane Disaster Relief Program was conducted in 2004 to determine the efficacy of the program and to determine the lasting impacts of the hurricanes on the economic viability of the fishermen (Cheuvront 2005). A total of 983 commercial fishermen out of 1207 total applicants to the Hurricane Disaster Relief Program received compensation for losses attributable to Hurricane Floyd. In 2004, a random sample of 350 of those who received payments was selected to participate in the follow up survey.

Most of the survey respondents (78%) said they had to replace fishing gear as a result of the hurricanes of 1999. Losses consisted primarily of fishing gear (crab pots, gill nets, pound nets), or parts of these gears such as buoys. Thirty-one percent of the fishermen reported damage to their boats or fishing business property. Electronics and other boat gear were listed most frequently. Many boats were damaged after breaking away from their moorings and running aground. Some boats were damaged by debris striking or falling on them. There were also reports of damage to docks and fishing gear storage buildings. Shellfish lease holders suffered economic losses when shellfish beds were covered with sand or destroyed by the heavy water action. Many pound net fishermen lost their gear, because they did not have enough time to retrieve it once it was clear the storms were headed for the North Carolina coast.

In addition to gear losses, nearly all of the fishermen (99.6%) reported lost income as a result of the hurricanes. Fishermen who said they lost income reported losing between $700 and $120,000, with average losses of $12,672 (2004 dollars adjusted using the GDP implicit price deflator). The 983 fishermen who received compensation received approximately $7.75 million in total compensation.

Successful North Carolina commercial fishermen are adaptable and have changed their fishing practices as conditions warrant. The majority (88%) of survey respondents who were fishing prior to the hurricanes were still involved in commercial fishing at the time of the follow up survey. Although many fishermen had changed target species or fishing gear between the hurricanes of 1999 and the survey in 2004, very few reported changing as a direct result of the hurricanes.

In summary, the hurricane season of 1999 imposed significant costs on North Carolina’s commercial fisheries. This survey likely underestimates total costs, as it examined only those fishermen who received assistance from the state. Other fishermen did not apply for program assistance, had their losses covered by private insurance, or did not have losses that qualified for reimbursement. Although costly, the hurricane season of 1999 does not appear to have been a direct cause of significant changes in commercial fishing practices or employment.

Time Series Studies of NC Commercial Fisheries Landings--A statistical study by the NCDMF using commercial fishery landings data to determine the impacts of individual hurricanes on particular fisheries is currently underway (Burgess 2006). Preliminary results for the hard blue crab and striped mullet fisheries indicate that commercial fisheries can be impacted in different ways. The hard blue crab harvest increased immediately following Hurricane Floyd in 1999 but then decreased in following years. Statistical intervention analysis found that mean hard blue crab landings decreased significantly ($p<.05$) in the years following the 1999 hurricane season by 21 million pounds (valued at $0.63/lb. in 2004). It appears that Hurricane Floyd increased fresh water input to the estuary, which aggregated the crab population, making it susceptible to over-harvest in 1999. The subsequent reduction in harvests may be due to a lower standing stock of crabs resulting from over-harvest immediately following the hurricane.

In contrast, a large reduction in mullet landings was seen for some hurricane years but not others, and the effect was not persistent. Intervention analysis showed a significant decrease of 1 million pounds (valued at $0.45/lb. in 2004) in 1999 when Hurricanes Dennis, Floyd, and Irene impacted North Carolina, but no significant impacts for Hurricanes Fran (1996) or Isabel (2003). When reductions in mullet landings occur, they are likely due to fishermen missing the opportunity to fish for mullet during the brief mullet spawning season.

In the case of the bay scallop fishery, it appears that a red tide occurring in 1987 increased the vulnerability of the previously resilient scallop resource to large environmental disturbances, including hurricanes (NCDMF 2006). For example, it appears that Hurricane Floyd in 1999 may have caused a significant reduction in the stock of scallops. Hurricane rainfall reduces estuarine salinity, increasing bay scallop mortality. Hurricane rainfall may have prolonged the recovery period following the red tide event. During the recovery period, bay scallop harvests were 61% to 93% below the long term average of 29,732 bushels per year, a loss of approximately $140 thousand to $235 thousand per year.

To summarize results for the commercial fishing sector, consistent time series data do not exist on the costs or damages to commercial fishing operations caused by tropical storms and hurricanes. As a result, it is not possible at this time to estimate the impacts of increased storm intensity on North Carolina commercial fisheries. Results from limited case studies indicate that commercial fisheries suffer economic losses primarily in the form of damaged fishing gear and reductions in the number of safe fishing days. In addition, there is some evidence that the populations of some target species may fall following hurricanes, further reducing the profitability of fishing. Increased storm severity due to climate change would likely increase the magnitude of these losses to some extent, but it is difficult to quantify without better data from multiple storm events of varying severity.

Conclusions

The impacts of climate change on economic output due to business interruption vary across county and climate change scenario, ranging from negligible impacts for Bertie county to $946 million for New Hanover County. Due to limitations in the output of the climate change models, these estimates reflect increases in severity in category 3 hurricanes only, assuming that the strike frequency of the storms remains unchanged from its historical average in 2006, and completely neglecting possible increases in severity of tropical storms and category 1, 2, 4 and 5 hurricanes. Though limited, these results show the incremental losses due to climate change that could result from a storm strike similar to hurricane Fran, a well-know category 3 storm that struck North Carolina in 1996. The results answer the question: "How much worse would hurricane Fran have been if it had been influenced by climate change." The wide range of estimates across counties is due to differences in population, industry structure, distance to the coast, and prior hurricane damage history (on which damage estimates are based). Although coastal residents may reduce these potential damages to some extent through adaptations such as better storm water management and utility line hardening, set against this are current demographic and development trends indicating that coastal populations and infrastructure will likely increase disproportionately in the future, placing more business and infrastructure at risk.

Although coastal property owners may take adaptive actions to reduce the potential damages associated with climate change by increasing their insurance coverage or the physical integrity of their structures, such actions are influenced by current economic incentives. For example, if insurance is made available at subsidized rates by state (e.g., state wind insurance pools) or federal (e.g., federal flood insurance) programs, property owners may undertake less structural mitigation. Similarly, the details of insurance policy premium and deductible schedules may have significant impacts on adaptive behavior. For example, Burrus et al. (2002) find that wind insurance deductibles must increase greatly for structural mitigation to be cost effective for many coastal NC residents, and changes in hurricane intensity affect mitigation decisions only in the neighborhood of category 3 storms, as weaker storms do not cause sufficient damage to necessitate mitigation, and stronger storms always cause damage beyond the typical insurance deductible, which is insured.

The incremental increase in agricultural and forest damage due to increased storm severity resulting from climate change varies by county due to differences across counties in urbanization and location relative to storm tracks. The data are not sufficient to produce county-level estimates. Based on differences in state-wide crop and livestock damage across storms for tropical storms and hurricanes between 1996 and 2006, it appears that on the order of $150 million (2004 dollars) in additional agricultural damage would occur per storm event should climate change increase storm severity from category 1 to category 2, or $750 million in additional damage should storm severity increase from category 1 to category 3. Based on state-wide data, the incremental increase in forest damage associated with increased storm severity due to climate change could be substantial in North Carolina, perhaps equivalent to a doubling of dollar-valued damage, or about $500 million in incremental damage per storm event in 2004 dollars. These estimates assume no growth in these sectors of the economy. Although the per unit value of output in these sectors will likely increase in the future, the amount of land devoted to agriculture and forestry will likely decline given current development trends, making the net effects of future growth uncertain.

Consistent time series data on the costs or damages to commercial fishing operations caused by tropical storms and hurricanes do not exist. Results from the existing, limited, case studies indicate that commercial fisheries suffer economic losses primarily in the form of damaged fishing gear and reductions in the number of safe fishing days, but the magnitude of these losses is very uncertain.

Future research should consider climate change scenarios which consider changes in the *frequency* of storm events as well as changes in intensity. Anticipated impacts depend on both changes in frequency and changes in intensity. Even with small anticipated changes in intensity, anticipated impacts might still be large should substantial changes in frequency occur. This is especially the case for business interruption impacts, and impacts on agriculture, fisheries and recreation, all of which are affected by even low intensity storms—a doubling of the number of tropical storm strikes per year, even if they did not increase in intensity, could substantially increase economic costs in these sectors.

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6. Conclusions

Current scientific research shows that global sea level is expected to rise significantly over the next century (Rahmstorf 2006, IPCC 2007). The relatively dense development and abundant economic activity along the North Carolina coastline is vulnerable to risk of coastal flooding, shoreline erosion and storm damages. This study has three purposes. Two of the purposes focus on sea-level rise. We estimate the impacts of sea level rise on property values and coastal recreation and tourism values. A third purpose is to consider the impacts of coastal storm activity on the local economies.

We estimate the impacts of sea level rise on property values in New Hanover, Dare, Carteret, and Bertie counties. A simulation approach based on the hedonic property model is developed to estimate the impacts of sea level rise on property values. A related purpose of this study is to estimate the impacts of sea level rise on coastal recreation and tourism. Sea-level rise exacerbates coastal erosion and can eventually eliminate beach recreation sites. We estimate the effects of sea-level rise on beach recreation at the southern North Carolina beaches and recreational fishing that takes place on the entire coast.

A third purpose of this study is to estimate the impacts of increased storm activity on business interruption. Changes among low-intensity hurricane categories are the most likely results of climate change. Estimates of business interruption impacts on economic output are presented by county for three climate change scenarios. Although scarce data limit the ability to estimate economic impacts for the vulnerable natural resource sectors, preliminary, order of magnitude assessments are developed, where possible.

These estimates can help inform climate change policy. For example, a formal benefit cost analysis of a climate change policy would compare the benefits of avoiding climate change with the costs. One component of the benefits of climate change policy is the avoided costs of sea level rise. In this study we develop estimates of the property value costs and recreation and tourism costs of sea level rise. However, we have to this point ignored adaptation to climate change, such as beach nourishment. The property value, recreation and tourism impacts can be mitigated by the mining and deposition of replacement sand on eroded beaches. A comparison of beach nourishment benefits to its costs would inform policy makers about the economic efficiency of beach nourishment.

In the rest of this concluding chapter, we summarize our analysis of the benefits (i.e., avoided costs) of sea-level rise, consider the costs of adaptation to sea level rise, summarize our analysis of changes in local economic activity from storm activity and sea level rise and offer some concluding remarks. Note that in this section of the report we focus our analysis with a 2% discount rate. Sensitivity of this choice to a range of discount rates is presented in the individual chapters.

Benefits of Avoiding Sea-Level Rise

The property value analysis indicates that the impacts of sea level rise vary among different portions of the North Carolina coastline. Overall, the northern part of the North Carolina coastline is comparatively more vulnerable to sea level rise than the southern part. Low-lying and heavily developed areas in the northern coastline of North Carolina (i.e., Outer Banks) are especially at high risk from sea level rise. Considering four coastal counties, including the three most populous on the North Carolina coast, the present value of lost residential property value in 2080 is $3.2 billion discounted at a 2% rate. The present value of lost nonresidential property value in 2080 is $3.7 billion at a 2% rate.

The coastal recreation and tourism analysis indicates that there are substantial losses from reduced opportunities of beach trips and fishing trips. The present value of the lost recreation benefits assuming no increase in future population or per capita income is $3.5 billion when discounted at a 2% rate for the southern NC beaches. The present value of the lost recreational fishing benefits is $430 million using a 2% discount rate.

An estimate of the total recreation benefits that would be lost due to sea level rise is the sum of the beachgoer and angler benefits. The present value of lost benefits is $3.9 billion with a 2% discount rate. Note that this estimate overstates benefits to the extent that anglers are included in the southern beaches sample and understates benefits since the Outer Banks is not included in the beaches sample. The former factor likely results in a minor overstatement while the latter likely results in a potentially significant understatement of lost benefits.

Considering both the property value impacts and the recreation and tourism impacts, the lost economic value due to sea level rise in North Carolina is on the order of $10.8 billion in present value terms with a 2% discount rate.

Costs of Adaptation

Beach nourishment can be used to mitigate the damages to property values and coastal recreation and tourism due to sea-level rise (Jones and Mangun, 2001). According to data from the Program for the Study of the Developed Shoreline at Duke University (which has recently moved to Western Carolina University), annual beach nourishment costs in North Carolina have averaged $4.37 million (2004 dollars) from 1961 to 2006 (http://psds.wcu.edu/) for a total cost of $315 million. The number of NC beaches annually nourished ranges from one to seven.

Using the same data up to 1996, Trembanis, Pilkey and Valverde (1999) estimate that the cost of nourishing all 138 miles of North Carolina shoreline is $831 million every 10 years (2004 dollars). Trembanis, Pilkey and Valverde (1999) explicitly state that their estimates do not address the increasing nourishment needs from sea level rise. Assuming that the annual cost is $83.1 million, the present value of annual beach nourishment costs from 2004 to 2080 without sea level rise is $3.3 billion when discounted at a 2% rate.

While these estimates are informative, they do not address the increased scope of beach nourishment necessary to mitigate sea-level rise. According to personnel at the Wilmington District of the U.S. Army Corps of Engineers, a rule of thumb is that one cubic yard per running foot of beach is needed to replace each foot of eroding beach. A one mile long stretch of beach would require 10,560 cubic yards per mile to replace the (approximate) average annual two feet of erosion per mile used in this study. Trembanis, Pilkey and Valverde (1999) report an average cost of $6 per cubic yard on east coast barrier beaches (2004 dollars). Given 138 miles of beach, the annual cost to replace two feet of eroded beach due to climate change-induced sea level rise is an additional $8.74 million. Given this estimate, the present value of annual beach nourishment costs to mitigate sea level rise from 2004 to 2080 is $348 million when discounted at a 2% rate.

The total cost of maintenance of beach width with beach nourishment is the sum of the baseline cost and the additional cost due to sea level rise. The present value of annual beach nourishment costs from 2004 to 2080 is $3.65 billion with a 2% discount rate. Only 10.5% of these costs are due to climate change-induced sea level rise.

A further issue is the possibility of increasing future nourishment costs. In Trembanis, Pilkey and Valverde (1999) the average cost of sand production is assumed to be constant. As offshore sand deposits are more difficult to find, the cost of mining and transporting sand is likely to rise with the increasing demand for nourishment projects. Titus et al. (1991) estimate the "cumulative cost of sand to protect the United States' open coast." The cost range varies by assumptions made about increasing dredging costs, technological improvement, increasing energy costs and economies of scale. Their low cost estimates assume that future costs are equal to historic costs and are consistent with the cost assumptions in Trembanis, Pilkey and Valverde (1999).

Titus et al. (1991) present four cumulative sand cost estimates: (1) low initial cost and constant average cost, (2) low initial cost and increasing average cost, (3) high initial cost and constant average cost and (4) high initial cost and increasing average cost. Cost estimates increase by 64% from scenario (1) to (2), 68% from scenario (2) to (3) and 78% from scenario (3) to (4). These estimates suggest that the nourishment costs reported above might be substantially biased downward if technological improvement and economies of scale do not materialize, energy costs rise and new sand deposits are found to be inadequate in terms of quantity and quality.

The baseline estimate of the costs of adaptation (i.e., the additional beach nourishment costs to avoid climate change-induce sea level rise), $348 million, is 32% of the estimate of the total real estate and recreation costs of sea level rise ($10.8 billion). However, considering scenarios (2) to (4) from Titus et al. (1991), the costs of adaptation could be anywhere from 53% to 100% of the real estate and recreation costs.

Economic Impacts

Another category of impacts considered in this study is lost economic output in coastal areas. One type of lost output is business interruption from increased hurricane severity (i.e., increased wind speed). The impacts of increased hurricane severity on business interruption from 2030-2080 vary across county and climate change scenario, ranging from negligible impacts for Bertie County to $946 million for New Hanover County. Due to limitations in the output of the climate change models, these estimates reflect increases in severity in category 3 hurricanes only, assuming that the strike frequency of the storms remains unchanged from its historical average in 2006, and completely neglecting possible increases in severity of tropical storms and category 1, 2, 4 and 5 hurricanes.

Though limited, these results show the incremental losses due to climate change that could result from a storm strike similar to hurricane Fran, a well-known category 3 storm that struck North Carolina in 1996. The results answer the question: "How much worse would hurricane Fran have been if it had been influenced by climate change." Although coastal residents may reduce these potential damages to some extent through adaptations such as better storm water management and utility line hardening, set against this are current demographic and development trends indicating that coastal populations and infrastructure will likely increase disproportionately in the future, placing more business and infrastructure at risk.

The incremental increase in agricultural and forest damage due to increased storm severity resulting from climate change varies by county due to differences in urbanization and location relative to storm tracks. Based on differences in state-wide crop and livestock damage across storms for tropical storms and hurricanes between 1996 and 2006, on the order of $150 million (2004 dollars) in additional agricultural damage would occur per storm event should climate change increase storm severity from category 1 to category 2, or $750 million in additional damage should storm severity increase from category 1 to category 3.

Based on state-wide data, the incremental increase in forest damage associated with increased storm severity due to climate change could be substantial in North Carolina, perhaps equivalent to a doubling of dollar-valued damage, or about $500 million in incremental damage per storm event (2004 dollars). Although the per unit value of output in these sectors will likely increase in the future, the amount of land devoted to agriculture and forestry will likely decline given current development trends, making the net effects of future growth uncertain.

Another type of lost economic output is reductions in tourist expenditures due to sea level rise and loss of beach recreation sites (lost output due to reductions in tourism caused by increased storm severity is included under business interruption losses above). Beach trips and the resulting spending by non-local North Carolina residents would change significantly with the loss of beach recreation sites. We estimate that total spending by those who only take day trips would fall by 2% in 2030 and 23% in 2080 compared to 2004. Those who take both day and overnight trips would spend 16% less in 2030 and 48% less in 2080 due to decreased beach trips.

Concluding Remarks

The impacts of climate change on North Carolina coastal resources are substantial and wide-ranging. The costs of climate change-induced sea level rise are substantial whether they materialize in the form of lost property value and lost recreation opportunities or beach nourishment costs. To the extent that climate change increases the frequency and intensity of hurricanes, reductions in business activity and damages will also be substantial.

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