Spatial Hedonic Models for Measuring the Impact of Sea-Level Rise on Coastal Real Estate[1]

April 2009

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[1] The authors thank Joel Smith, David Chapman, Michael Hanemann, Sasha Mackler, and seminar participants at Ecosystem Sustainability and Health of Threatened Marine Environments, Terengganu, Malaysia, the 21st International Conference of the Coastal Society, and the Southern Economic Association 2008 Annual Meetings for their helpful comments. This research was funded by the National Commission on Energy Policy and the University of North Carolina Research Competitiveness Fund.
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Abstract This study uses a unique integration of geospatial and hedonic property data to estimate the impact of sea-level rise on coastal real estate in North Carolina. North Carolina's coastal plain is one of several large terrestrial systems around the world threatened by rising sea-levels. High-resolution topographic LIDAR (Light Detection and Ranging) data are used to provide accurate inundation maps for all properties that will be at risk under six different sea-level rise scenarios. A simulation approach based on spatial hedonic models is used to provide consistent estimates of the property value losses. Results indicate that 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 are especially at high risk from sea-level rise.

Keywords Climate change, coastal real estate, sea-level rise, spatial hedonic models

Introduction

Coastal areas in the U.S. include some of the most developed areas in the nation and represent the nation's wealth of natural and economic resources. In 2003, approximately 153 million people (53 percent of the total population) lived in the nation's coastal fringe that makes up 17 percent of its contiguous land area (National Oceanic and Atmospheric Administration (NOAA) 2005). The 673 coastal counties have seen an increase of 33 million people since 1980 (NOAA 2005). Population growth has been accompanied by unparalleled growth in property values. The value of coastal real estate has appreciated at an average 7 percent per year over the last 50 years. According to the Heinz Center (2000), a typical coastal property is worth from 8% to 45% more than an otherwise comparable inland property.

While population growth and coastal development produce numerous economic benefits, the relatively dense populations and valuable coastal properties are vulnerable to substantial risks associated with climate change and sea-level rise including coastal flooding, shoreline erosion, and storm damages.[3] Recent scientific research shows that the global sea-level is expected to rise 9 to 59 centimeters over the next century (Intergovernmental Panel on Climate Change (IPCC) 2007). The amount of developed property along the North Carolina coastline has steadily increased over the last several decades due to a strong preference for coastal locations. The number of building permits in Carolina Beach, North Carolina between 2001 and 2005 exceeds the number of permits issued over the previous 20 years, and the average selling price for residential properties in Wrightsville Beach, North Carolina has increased 420 percent since 2001 (*Raleigh News & Observer*, "Beach Prices Ride Crest," 29 May 2005). Rapid development coupled with soaring property values brought greater vulnerability to rising sea-level.

[3] The Heinz Center (2000) estimated that the average cost of coastal erosion losses to property owners will be $530 million per year for the next several decades.

This study attempts to estimate the potential impact of sea-level rise on coastal real estate in four counties of North Carolina – New Hanover, Dare, Carteret, and Bertie – which represent a cross-section of the state's coastline in geographical distribution and economic development (Figure 1). Coastal North Carolina has been identified as one of the most vulnerable regions to climate change in the U.S (Titus and Richman 2001). The study area covers from high-development to rural-economies with shoreline dominated by estuarine to marine environments. Property parcel data were obtained from each county tax office which maintains the assessed value and other structural characteristics of property. High-resolution topographic LIDAR data were used to provide accurate inundation maps for all property that will be at risk under different sea-level rise scenarios. Adjusting for regional subsidence, a range of modest sea-level rise scenarios based on the IPCC projection was considered. Additional geospatial attributes were developed to describe the distance of a property to shoreline and property elevation and entered into a database of corresponding property values. Using the geospatial and property data, spatial autoregressive models are estimated to provide consistent estimates of the hedonic parameters, which will be used in the simulation models to estimate the impact of sea-level rise on coastal real estate.

Since the work by Yohe et al. (1995) the literature on the cost of sea-level rise has grown, but the growth has been rather slow. Most of the recent additions to the literature estimate the annual inundation cost at a national or global scale (Darwin and Tol 2001; Yohe et al. 1996; Yohe et al. 1999). Utilizing the estimated nationwide acreage losses for various sea-level rise scenarios and average property values, most of the recent literature provides the estimated annual losses for the entire U.S. Estimates of the cost of sea-level rise at a regional or local level are important for planning a long-term policy response to the threat of sea level rise. Parsons and

Powell (2001) estimate the economic costs of beach retreat for Delaware over the next 50 years using a more disaggregated unit of observation than the previous studies in the literature. Using micro-level property transaction data, this study estimates the cost of beach retreat in Delaware in the next 50 years to be about $291 million in present value (2000 USD). Michael (2007) uses data from three communities on the Chesapeake Bay to estimate the loss from episodic flooding as well as complete inundation. The study finds that increased flood damage is much larger than the cost of inundation, suggesting that previous studies may be substantially underestimating the economic costs of sea-level rise in the U.S. This measure is perhaps a more fundamental concept that will provide evidence on the economic vulnerability of coastal real estate to rising sea-levels.

Such information should provide guidance in long-term land use and planning decisions under sea-level rise. A formal benefit cost analysis of a climate change policy would compare the benefits of avoiding the consequences of climate change with the costs. One component of the benefits of climate change policy is the avoided inundation costs of sea-level rise. The objective of this study is to provide more evidence on the cost of sea-level rise, and to do so in a geographic region for which the cost has not been estimated. The results indicate that the impacts of sea-level rise on coastal property values vary across different portions of the North Carolina coastline. The most significant loss is occurring in Dare County (northern), followed by Carteret (central), New Hanover (southern), and Bertie (rural) counties. Depending on the sea-level rise scenarios, the loss of residential property value in Dare County ranges between 1.24% and 9.45% of the total residential property value. The residential property value at risk in Carteret County ranges from 0.20% to 2.41%. New Hanover and Bertie counties show relatively small impacts with less than one percent loss in residential property value. Overall, the northern part of the North Carolina coastline is comparatively more vulnerable to the effect of sea-level rise than the southern part. Considering just four coastal counties in North Carolina, the present value of residential property loss in 2080 is estimated about $1.2 billion. The result of this study demonstrates that increased inundation and shoreline erosion associated with sea-level rise may result in significant economic losses in coastal real estate in the absence of mitigation and local adaptation policy.

Study Area and Data

North Carolina's coastal plain is one of several large terrestrial systems around the world threatened by rising sea-levels (Moorhead and Brinson 1995; Titus and Richman 2001). Over 5000 km^2 of the land area is below one meter elevation, and rates of sea-level rise in this region are approximately double the global average due to local isostatic subsidence (Poulter and Halpin 2008). 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 2). Continued and projected sea-level rise is expected to significantly impact natural and human systems with global estimates anywhere between 0.3 to 1.1 meters likely (Pfeffer, Harper, and O'Neel 2008).

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

Property parcel spatial and tabular attributes were acquired for four counties – Bertie, Dare, Carteret, and New Hanover – representing a variety of geomorphic and economic resources. The centroid for each property parcel was calculated (restricting its location to within the tax parcel boundary) assuming that it represented average conditions within the property parcel (Figure 3). Oceanfront and estuarine-front properties were identified for all four counties for current sea-level. Attributes were added to these property parcels indicating what type of shoreline position they currently occupy. Distance to shoreline was created for each inundation scenario. We used Euclidean distance to describe the proximity of a property parcel to the shoreline. Property parcel centroids were then used to sample the seven distance surfaces (current and 6-scenarios).

Elevation was sampled and assigned as an attribute to each property parcel using the centroid. The LIDAR-derived Digital Elevation Model (DEM) was used as the source of elevation measures. 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 property parcels in dense urban areas represent an over-estimate for elevation. The six inundation grids representing the new shoreline-ocean interface following sea-level rise was sampled by the property parcel centroids. Attributes reflecting whether a property parcel was inundated were added to each parcel record for the impact analysis.

Six scenarios for future sea-level rise were developed from the recent IPCC report (2007). These scenarios were adjusted for regional subsidence that is geologically important in North Carolina (Tushingham and Peltier 1991). Table 1 presents 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). Figure 4 provides inundation of coastal North Carolina with detailed examples for each of the counties investigated in this study. This particular example uses an 81 cm increase in sea-level rise by 2080 including both eustatic and isostatic sea-level rise. Table 2 presents the summary statistics for data.

Methods

Hedonic price models have been used extensively in urban, regional, environmental and natural resource economics as a non-market valuation technique. Hedonic property models use observations on property values, typically residential properties, to infer values for non-traded attributes such as such as the distance to shoreline, *ceteris paribus*. The hedonic function is typically represented as:

$$R = R(s, n, e), \qquad [1]$$

where R is the property price, which is a function of structural characteristics, s, neighborhood characteristics, n, and environmental amenities, e. Assuming that $R(\bullet)$ is continuously differentiable, the first derivative of [1] with respect to any continuous attributes produces an estimate of the representative households' marginal willingness to pay for an additional unit of that attribute (Rosen 1974). Palmquist (2004) provides a useful summary of the theoretical aspects of the hedonic price models.

There has been a tremendous increase in the availability of spatial data and spatial analysis functionality in recent years. Considerable attention has been given to examining spatial dependence in estimated hedonic equations (Pace and Gilley 1997; Patterson and Boyle 2002;

Kim, Phipps, and Anselin 2003). Property sales prices tend to cluster in space because properties in a neighborhood share similar location amenities or because they have similar structural characteristics due to similar timing of construction. If the relevant spatial dependence is ignored in estimation of the hedonic price function, then the resulting estimates could be inefficient or even inconsistent, and any inference based on the estimates may result in misleading conclusions (Anselin and Bera 1998).

This study estimates the following first-order spatial error hedonic model:

$$\begin{aligned} ln\, R &= \alpha + \sum_i \beta_i s_i + \sum_j \gamma_j n_j + \sum_k \phi_k e_k + \varepsilon \\ \varepsilon &= \lambda W \varepsilon + u, \end{aligned} \qquad [2]$$

where *ln R* is the log of assessed property value, α, β, γ, and ϕ are the unknown parameters to be estimated, ε is an independent random error term, λ is the spatial autoregressive coefficient, *W* is the spatial weighting matrix, and *u* is a vector of independent and identically distributed random error terms. This model assumes that one or more omitted variables in the hedonic equation vary spatially, and thus the error terms are spatially autocorrelated. The OLS estimator remains unbiased in this specification but is no longer efficient due to the nonspherical error covariance. Utilizing the particular structure of the error covariance implied by the spatial process should provide efficient estimators for the unknown parameters of the hedonic price function. The spatial autoregressive error models are estimated via maximum likelihood. The estimation is implemented within the GeoDa v.0.9.5-i (2004) environment in conjunction with ArcView GIS 3.3 extensions.

The first step in this estimation process is to create a spatial weighting matrix which defines a relevant "neighborhood set" for each observation. We use a contiguity matrix that identifies properties within 528 feet in a binary fashion. That is, an element of the spatial weighting matrix, $w_{ij} = 1$ when i and j are located within 528 feet, and $w_{ij} = 0$ otherwise. The specification of the spatial weighting matrix is based on our observations of the spatial extent that may share unobserved characteristics generating spatial dependence. We have experimented with different weighting matrices, but the primary results are largely insensitive to different weighting matrices.[4] Regression diagnostics based on Ordinary Least Squares (OLS) estimation and the Lagrange Multiplier (LM) test statistics indicated that the spatial error model is preferred.[5]

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. 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

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[4] Alternative spatial weights based on social network, distance decay, and *k* nearest neighbors have been considered in the literature in spite of their lesser theoretical appeal. Anselin and Bera (1998) note that the spatial weights should be truly exogenous to the model and the range of dependence allowed by the structure of the weighting matrix should be constrained to avoid identification problems. .

[5] Alternative models to incorporate the spatial dependence include a spatially lagged dependent variable model, which assumes that the spatially weighted sum of neighborhood housing prices enters as an explanatory variable in the hedonic price function. Failing to account for spatial lag dependence leads to biased and inconsistent parameter estimates, whereas failing to account for spatial error dependence leads to inefficiency. For this study, the spatial error model is suggested by the robust LM tests.

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 residential properties that locate within a mile from the coastline.[6] The estimated hedonic price functions are then used to simulate the property value loss for various sea-level rise scenarios. The net loss in property values from sea-level rise in year *t* can be represented by

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

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 risk 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

[6] 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.

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 results are reported for no discounting as well as using a 2% discount rate for sensitivity analysis.

Results

The maximum likelihood (ML) estimation results of the linear and spatial hedonic models are reported in Table 3 and Table 4, respectively. The regression models controls for heterogeneity across townships using a set of binary indicators. Most structural and neighborhood variables are statistically significant at any conventional level of significance, and the coefficient signs are consistent with common findings in the hedonic literature.

Proximity to shoreline has a strong positive effect on property values. Coefficient signs for the distance to nearest shoreline all have negative signs and are statistically significant. However, the results indicate that the coefficients for elevation are insignificant. It suggests that lower elevation of property is likely to provide easy access to coastal water, yet at the 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 between 56.3% (New Hanover) and 77.0% (Carteret) for ocean frontage and between 31.3% (Dare) and 60.8% (Bertie) for estuarine water 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 simulation results under different sea-level rise scenarios are reported in Table 5. A zero discount rate and a 2% discount rate are used to provide the present value of the residential property value loss.

For Dare County, a total of 25,232 residential properties are used in the analysis with the total assessed value of $11 billion. Depending on the sea-level rise scenarios, the number of residential properties at the risk of inundation ranges between 487 (2030-Low) and 3737 (2080-High). Without discounting, the residential property value loss in Dare County ranges from $136 million (1.24% of the total assessed value) to $1040 million (9.45% of the total assessed value). Based on the 2% discount rate, the estimated loss ranges from $81 million (0.74%) to $231 million (2.10%). The results indicate that Dare County has the most significant impact from sea-level rise among the North Carolina coastal counties.

For New Hanover County, a total of 37,414 residential properties are used in the analysis with the total assessed value of $6.8 billion. Depending on the sea-level rise scenarios, the number of residential properties at the risk of inundation ranges between 14 (2030-Low) and 117 (2080-High). Without discounting, the residential property value loss in New Hanover County ranges from $4.4 million (0.07% of the total assessed value) to $29.8 million (0.44% of the total assessed value). Based on the 2% discount rate, the estimated loss ranges from $2.7 million (0.04%) to $6.6 million (0.10%). The results indicate that New Hanover County has a relatively insignificant impact from sea-level rise among the North Carolina coastal counties.

For Carteret County, a total of 26,960 residential properties are used in the analysis with the total assessed value of $4.7 billion. Depending on the sea-level rise scenarios, the number of residential properties at the risk of inundation ranges between 64 (2030-Low) and 921 (2080-

High). Without discounting, the residential property value loss in Carteret County ranges from $9.2 million (0.20% of the total assessed value) to $113.1 million (2.41% of the total assessed value). Based on the 2% discount rate, the estimated loss ranges from $5.5 million (0.12%) to $25.1 million (0.53%). The results indicate that Carteret County has a relatively significant impact from sea-level rise.

For Bertie County, a total of 2,460 residential properties are used in the analysis with the total assessed value of $160 million. Depending on the sea-level rise scenarios, the number of residential properties at the risk of inundation ranges between 0 (2030-Low) and 16 (2080-High). Without discounting, the residential property value loss in Bertie County ranges from $0 (0.00% of the total assessed value) to $0.91 million (0.57% of the total assessed value). Based on the 2% discount rate, the estimated loss ranges from $0 (0.00%) to $0.2 million (0.13%). The loss of residential property values in Bertie County is relatively smaller than those of the other counties discussed above.

Discussion

This study estimates the impact of sea-level rise on coastal real estate in four coastal counties including the three most populous (Dare, New Hanover, and Carteret) on the North Carolina coast. The results indicate that the magnitude of the impacts depends on the geographic location and the level of development in the areas. 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.

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 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 a single family residence.

It is important to point out that a large portion of undeveloped land in coastal North Carolina is wetlands that provide a wide range of services 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. Since these values are unlikely to be fully reflected in the private property values, the estimated impacts in this study provide only a limited measure of total economic costs associated with sea-level rise.

These estimates can help inform the land use and planning policy under climate change and sea-level rise. 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. This study develops estimates of the property value costs of sea level rise (i.e. costs of a "do-nothing" policy). However, this study does 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 or hardening. The property value impacts can be mitigated by the mining and deposition of replacement sand on eroded beaches and shorelines. 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 is likely to be small especially in the rural areas. A comprehensive benefit-coast analysis of climate change policy would inform policy makers about the economic efficiency of such policy.

References

Anselin, L., and A. Bera. 1998. "Spatial Dependence in Linear Regression Models with an Introduction to Spatial Econometrics," in A. Ullah and D. Giles, eds., *Handbook of Applied Economic Statistics*.

Christensen, N. L. 2000. Vegetation of the Coastal Plain of the Southeastern United States. Pages 397-448 *in* M. Barbour and W. D. Billings, editors. Vegetation of North America. Cambridge University Press, Cambridge, UK.

Darwin R., and R. Tol. 2001. Estimates of the Economic Effects of Sea Level Rise, *Environmental and Resource Economics* 19:113–129.

Earnhart, D. 2001. Combining Revealed and Stated Preference Methods to Value Environmental Amenities at Residential Locations. *Land Economics* 77: 12-29.

Heinz Center for Science, Economics and Environment. 2000. Evaluation of Erosion Hazards Summary prepared for Federal Emergency Management Agency.

Henman, J., and B. Poulter. In Review. Inundation of Freshwater Peatlands by Sea-level Rise: Uncertainty and Potential Carbon Cycle Feedbacks.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis* United Nations: New York, NY.

Kim, C., T. Phipps, and L. Anselin. 2003. "Measuring the Benefits of Air Quality Improvement: A Spatial Hedonic Approach." *Journal of Environmental Economics and Management*, 45: 24-39.

Michael, J. 2007. Episodic Flooding and the Cost of Sea-Level Rise. *Ecological Economics* 63: 149-59.

Milon, J., J. Gressel and D. Mulkey. 1984. Hedonic Amenity Valuation and Functional Form Specification. *Land Economics* 60: 378-87.

Mooney, S. and L. Eisgruber. 2001. The Influence of Riparian Protection Measures on Residential Property Values: The Case of the Oregon Plan for Salmon and Watersheds. *Journal of Real Estate Finance and Economics* 22(2): 273-286.

Moorhead, K. K., and M. M. Brinson. 1995. Response of Wetlands to Rising Sea-level in the Lower Coastal Plain of North Carolina. *Ecological Applications* 5:261-271.

National Oceanic and Atmospheric Administration. 2005. Population Trends along the Coastal United States: 1980-2008. U.S. Department of Commerce.

Pace, K., and O. Gilley. 1997. “Using the Spatial Configuration of the Data to Improve Estimation.” *Journal of Real Estate Finance and Economics* 14: 333-40.

Palmquist, R. "Property Value Models," in K-G Maler and J. Vincent, eds., *Handbook of Environmental Economics*, volume 2, North Holland, 2004.

Parsons, G. and M. Powell. 2001. Measuring the Cost of Beach Retreat. *Coastal Management* 29:91-103.

Paterson, R., and K. Boyle. 2002. “Out of Sight, Out of Mind? Using GIS to Incorporate Visibility in Hedonic Property Value Models.” *Land Economics* 78: 417-25.

Pfeffer, W., J. Harper, S. O'Neel. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science* 321:1340-134.

Poulter, B., N. L. Christensen, and P. N. Halpin. 2006. Carbon Emissions from a Temperate Peat Fire and its Relevance to Interannual Variability of Trace Atmospheric Greenhouse Gases. *Journal of Geophysical Research* 111:doi:10.1029/2005JD006455

Poulter, B., and P. N. Halpin. 2008. Raster Modelling of Coastal Flooding from Sea Level Rise, International Journal of Geographical Information Science, 22(2):167-182.

Rosen, S. 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* 82(1): 34-55.

Schafale, M. P., and A. S. Weakley. 1990. Classification of the Natural Communities of North Carolina: Third Approximation. *in*. North Carolina Natural Heritage Program.

Shabman, L. and M. Bertelson. 1979. The Use of Development Value Estimates for Coastal Wetland Permit Decisions. *Land Economics* 55: 213-22.

Titus, J. G., and C. Richman. 2001. Maps of Lands Vulnerable to Sea-level Rise: Modeled Elevations along the US Atlantic and Gulf coasts. *Climate Research* 18:205-228.

Tushingham, A. M., and W. R. Peltier. 1991. A New Global Model of Late Pleistocene Deglaciation Based upon Geophysical Predictions of Post Glacial Relative Sea-level Change. *Journal of Geophysical Research* 96:4497-4523.

Yohe, G., J. Neumann and J. Ameden. 1995. Assessing the Economic Cost of Greenhouse-induced Sea Level Rise: Methods and Application in Support of a National Survey, *Journal of Environmental Economics and Management* 29: S78–S97.

Yohe, G., J. Neumann, P. Marshall and H. Ameden. 1996. The Economic Cost of Greenhouse Induced Sea Level Rise for Developed Property in the United States, *Climatic Change* 32: 387–410.

Yohe, G., J. Neumann and P. Marshall. 1999. The Economic Damage Induced by Sea Level Rise in the United States. In: R. Mendelsohn and J. Neumann, Editors, *The Impact of Climate Change on the United States Economy*, Cambridge University Press.

Table 1 Summary of Sea-Level Rise for the Low, Mid, and High Climate Change Scenarios

Year	Scenario	Projected Sea-Level Rise (SLR) Measured in Meters
2030	Low	0.11
	Mid	0.16
	High	0.21
2080	Low	0.26
	Mid	0.46
	High	0.81

Note: Projected sea-level rise includes both eustatic and isostatic components.

Table 2 Summary Statistics for the Hedonic Data

Variables	Dare (n=25232)		New Hanover (n=37414)		Carteret (n=26960)		Bertie (n=2460)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Property Value ($)	436465.630	306911.500	180834.710	153222.490	174242.150	144394.380	65297.360	54715.330
2030-Low Inundation (=1)	0.019	0.138	0.000	0.019	0.002	0.049	0.000	0.000
2030-Mid Inundation (=1)	0.023	0.150	0.000	0.021	0.003	0.054	0.001	0.029
2030-High Inundation (=1)	0.028	0.164	0.001	0.024	0.004	0.059	0.002	0.040
2080-Low Inundation (=1)	0.034	0.180	0.001	0.025	0.004	0.067	0.002	0.040
2080-Mid Inundation (=1)	0.067	0.250	0.001	0.030	0.011	0.105	0.005	0.070
2080-High Inundation (=1)	0.148	0.355	0.003	0.056	0.034	0.182	0.007	0.080
Distance in feet to shoreline	1381.340	963.381	1793.960	1263.580	1132.160	950.897	2112.190	1443.550
Elevation above SL in feet	7.971	7.119	26.025	11.906	12.788	8.003	29.192	13.025
Ocean front (=1)	0.073	0.260	0.007	0.082	0.028	0.165		
Sound front (=1)	0.109	0.311	0.016	0.127	0.138	0.345	0.032	0.176
Lot size measured in acres	0.405	0.568	0.382	0.413	0.647	0.949	0.854	1.133
Age of house	21.536	16.937	24.423	21.873	28.820	23.143		
Number of bedrooms	3.472	1.009						
Number of bathrooms			2.258	0.847	2.023	0.805	1.472	0.610
Structure square footage			1817.800	800.193	1732.700	738.363		
Air conditioning (=1)	0.909	0.288	0.921	0.269				
Multistory (=1)	0.500	0.500	0.299	0.458			0.139	0.346
Fireplace (=1)			0.659	0.474				
Detached garage (=1)			0.077	0.267				
Hardwood floor (=1)	0.066	0.249						

Note: Omitted are 12, 4, 14, and 6 townships for Dare, New Hanover, Carteret and Bertie County, respectively.

Table 3 ML Estimation Results for Linear Hedonic Models

Variables	Dare		New Hanover		Carteret		Bertie	
	Coeff.	Std. Dev.	Coeff.	Std. Dev.	Coeff.	Std. Dev.	Coeff.	Std. Dev.
Constant	**11.990	0.029	**10.791	0.014	**10.548	0.027	**10.321	0.109
Log of distance to shoreline	**-0.062	0.003	**-0.014	0.002	**-0.041	0.003	**-0.058	0.014
Elevation above SL in feet	0.001	0.001	**-0.010	4.43e-04	**0.005	0.001	-0.003	0.004
Elevation squared	**-1.1e-04	2.3e-05	**1.1e-04	7.2e-06	**-3.0e-04	3.7e-05	6.5e-05	5.9e-05
Ocean front (=1)	**0.695	0.009	**0.563	0.014	**0.657	0.014		
Sound front (=1)	**0.300	0.008	**0.349	0.009	**0.494	0.008	**0.596	0.070
Lot size measured in acres	**0.220	0.008	**3.8e-06	1.3e-07	**-0.026	0.006	**0.245	0.025
Lot size squared	**-0.025	0.001	**-0.014	0.001	**0.008	0.001	**-0.026	0.004
Age of house	**-0.004	3.4e-04	**-0.006	1.7e-04	**-0.003	3.1e-04		
Age of house squared	1.0e-06	3.9e-06	**4.2e-05	1.9e-06	**2.7e-05	3.3e-06		
Number of bedrooms	**0.220	0.009						
Number of bedrooms squared	**-0.005	0.001						
Number of bathrooms			**0.194	0.006	**0.318	0.012	**0.593	0.076
Number of bathrooms squared			**-0.014	0.001	**-0.032	0.002	*-0.042	0.020
Structure square footage			**0.001	3.6e-06	**0.001	1.1e-05		
Structure square footage squared			**-2.2e-05	3.8e-07	**-6.1e-05	2.0e-06		
Air conditioning (=1)	**0.149	0.008	**0.091	0.005				
Multistory (=1)	**0.166	0.005	0.004	0.003			**0.379	0.033
Fireplace (=1)			**0.133	0.003				
Detached garage (=1)			**0.040	0.004				
Hardwood floor (=1)	**0.144	0.008						
Log Likelihood	-6680.560		5245.290		-10344.900		-1890.490	

* Indicates significance at 5% level.
** Indicates significance at 1% level.

Table 4 ML estimation Results for Spatial Hedonic Models

Variables	Dare		New Hanover		Carteret		Bertie	
	Coeff.	Std. Dev.	Coeff.	Std. Dev.	Coeff.	Std. Dev.	Coeff.	Std. Dev.
Constant	**12.105	0.030	**10.794	0.014	**11.017	0.029	**10.419	0.124
Log of distance to shoreline	**-0.064	0.003	**-0.014	0.002	**-0.066	0.003	**-0.071	0.017
elevation above SL in feet	0.001	0.001	**-0.010	4.4e-04	**0.009	0.001	**-0.001	0.004
elevation squared	**-8.0e-05	2.3e-05	**1.1e-04	7.2e-06	**-3.8e-04	4.1e-05	**4.1e-05	6.8e-05
Ocean front (=1)	**0.634	0.008	**0.563	0.014	**0.770	0.020		
Sound front (=1)	**0.313	0.008	**0.349	0.009	**0.481	0.009	**0.608	0.077
Lot size measured in acres	**0.262	0.008	**3.9e-06	1.3e-07	**0.066	0.006	**0.244	0.024
Lot size squared	**-0.028	0.001	**-0.014	0.001	**-0.003	0.001	**-0.027	0.003
Age of house	**-0.006	3.2e-04	**-0.006	1.7e-04	**-0.007	2.8e-04		
Age of house squared	**1.9e-05	3.6e-06	**4.2e-05	1.9e-06	**4.1e-05	3.0e-06		
Number of bedrooms	**0.194	0.009						
Number of bedrooms squared	**-0.004	0.001						
Number of bathrooms			**0.194	0.006	**0.177	0.010	**0.599	0.072
Number of bathrooms squared			**-0.014	0.001	**-0.020	0.002	**-0.056	0.019
Structure square footage			**0.001	3.6e-06	**0.001	8.7e-06		
Structure square footage squared			**-2.2e-05	3.8e-07	**-4.8e-05	1.6e-06		
Air conditioning (=1)	**0.138	0.007	**0.090	0.005				
Multistory (=1)	**0.141	0.005	0.004	0.003			**0.298	0.033
Fireplace (=1)			**0.133	0.003				
Detached garage (=1)			**0.040	0.004				
Hardwood floor (=1)	**0.128	0.008						
Lambda (λ)	**0.326	0.006	**0.047	0.006	**0.545	0.004	**0.287	0.022
Log Likelihood	-5485.164		5280.014		-6591.235		-1811.514	

* Indicates significance at 5% level.
** Indicates significance at 1% level.

Table 5 Inundation Loss of Coastal Residential Properties

	Total	No Discounting					
		2030-Low	2030-Mid	2030-High	2080-Low	2080-Mid	2080-High
Dare	$11,012.90	$136.01	$162.58	$196.14	$237.77	$475.78	$1,040.36
*(n)	25,232	487	580	699	849	1,686	3,737
**(%)		1.24%	1.48%	1.78%	2.16%	4.32%	9.45%
New Hanover	$6,765.75	$4.44	$5.01	$6.35	$7.34	$10.07	$29.75
*(n)	37,414	14	16	22	24	33	117
**(%)		0.07%	0.07%	0.09%	0.11%	0.15%	0.44%
Carteret	$4,697.57	$9.20	$10.95	$12.85	$16.19	$39.41	$113.05
*(n)	26,960	64	78	95	120	296	921
**(%)`		0.20%	0.23%	0.27%	0.34%	0.84%	2.41%
Bertie	$160.63	$0.00	$0.19	$0.28	$0.28	$0.75	$0.91
*(n)	2,460	0	2	4	4	12	16
**(%)		0.00%	0.12%	0.17%	0.17%	0.47%	0.57%

	Total	2% Discounting					
		2030-Low	2030-Mid	2030-High	2080-Low	2080-Mid	2080-High
Dare	$11,012.90	$81.28	$97.15	$117.21	$52.79	$105.63	$230.98
*(n)	25,232	487	580	699	849	1,686	3,737
**(%)		0.74%	0.88%	1.06%	0.48%	0.96%	2.10%
New Hanover	$6,765.75	$2.65	$2.99	$3.80	$1.63	$2.24	$6.61
*(n)	37,414	14	16	22	24	33	117
**(%)		0.04%	0.04%	0.06%	0.02%	0.03%	0.10%
Carteret	$4,697.57	$5.50	$6.55	$7.68	$3.60	$8.75	$25.10
*(n)	26,960	64	78	95	120	296	921
**(%)`		0.12%	0.14%	0.16%	0.08%	0.19%	0.53%
Bertie	$160.63	$0.00	$0.12	$0.17	$0.06	$0.17	$0.20
*(n)	2,460	0	2	4	4	12	16
**(%)		0.00%	0.07%	0.10%	0.04%	0.10%	0.13%

Notes: Dollars are measured in million. * The number of inundated properties. ** The percentage of the total property values.

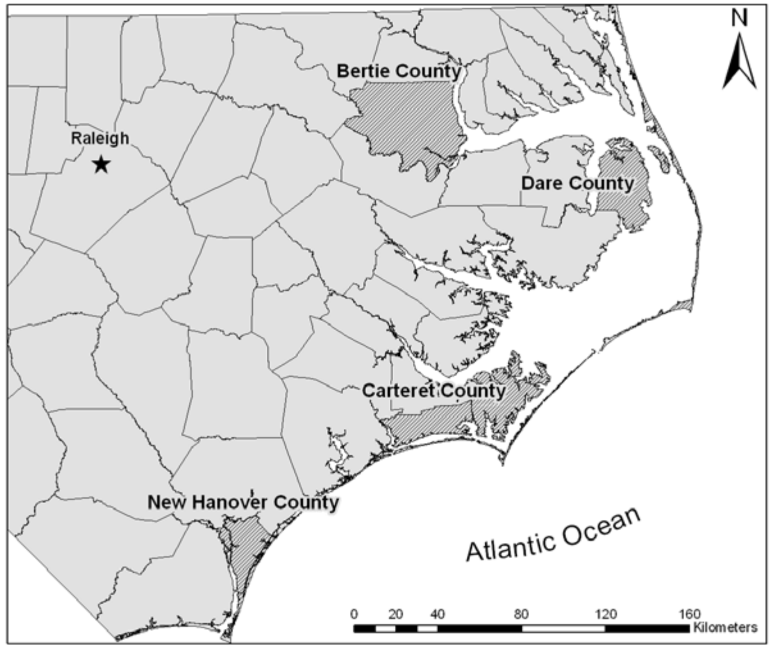

Figure 1 Location of NC Counties Analyzed for Property Impacts

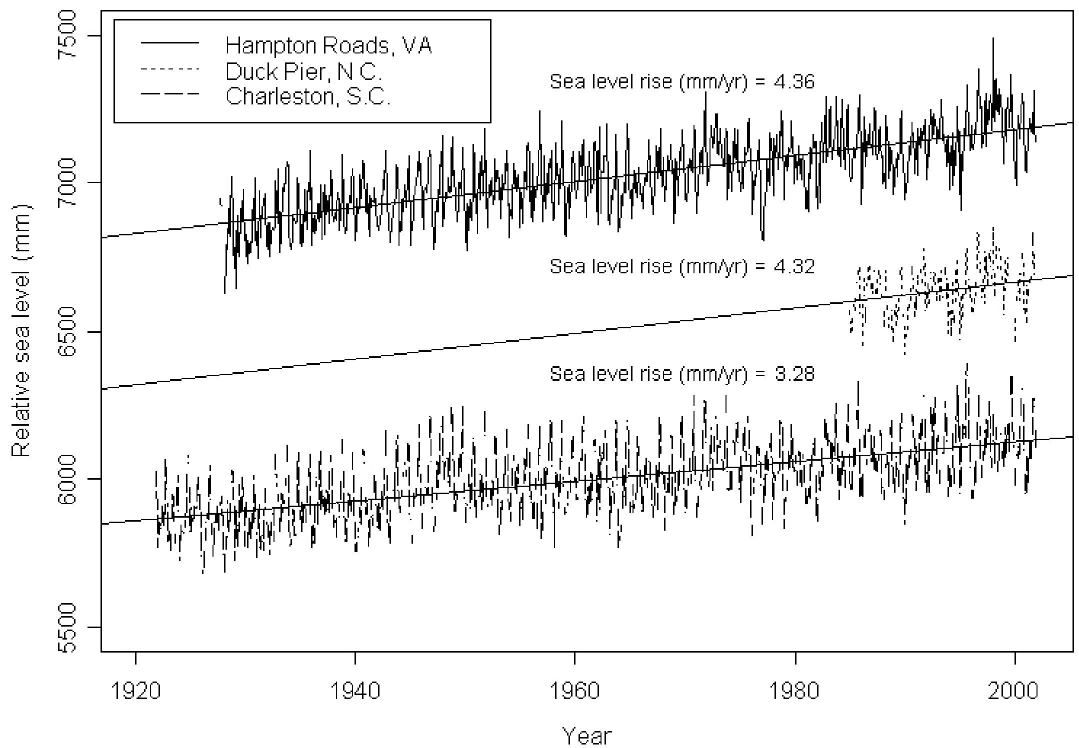

Figure 2 Observed Rates of Sea-Level Rise along the Southeast Coast

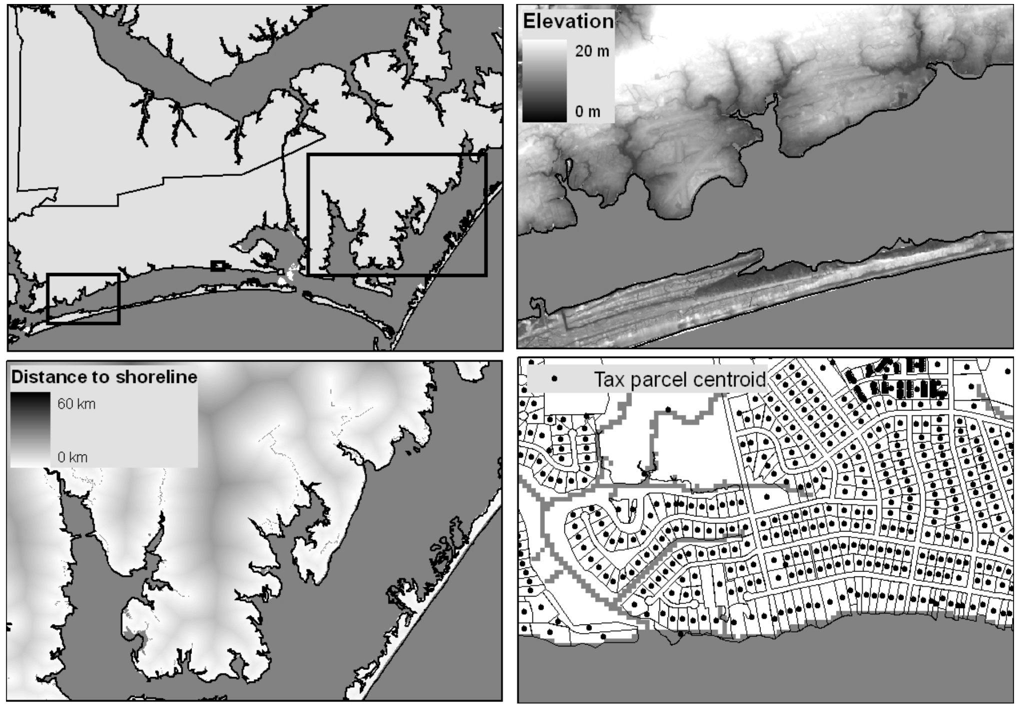

Figure 3 Examples of Data Sampling for Property Values for Carteret County (a), LIDAR Elevation Surface (b), Distance to Shoreline (c), and Tax Parcel Centroids (d)

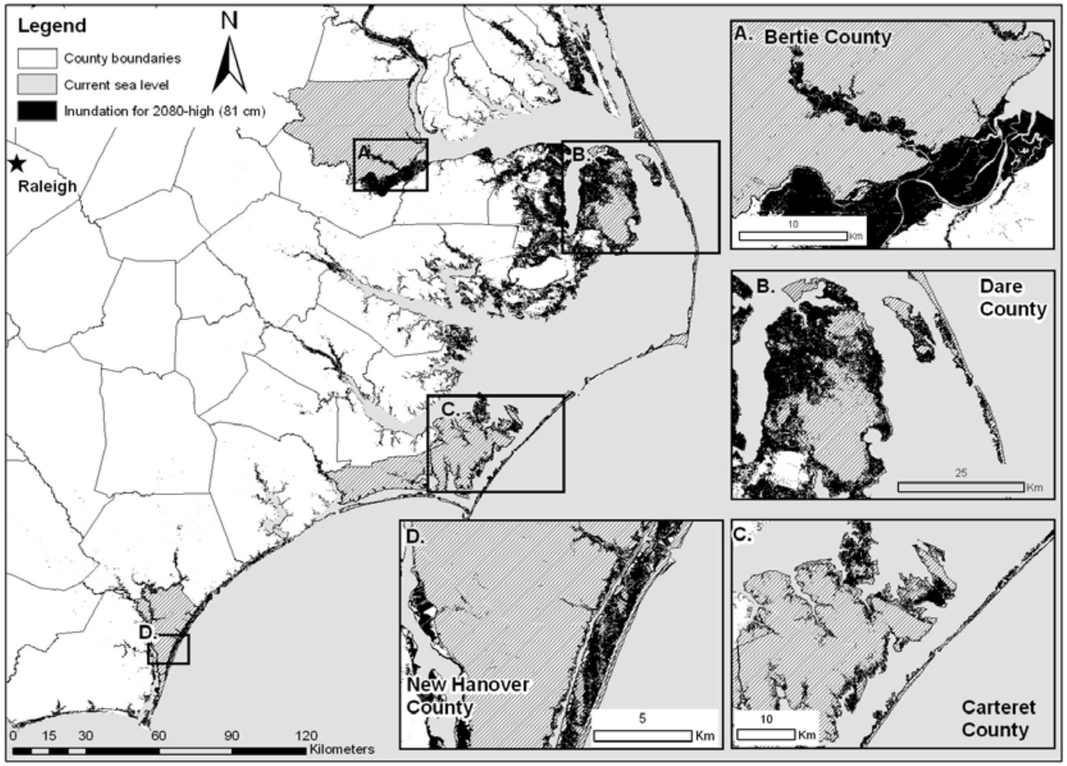

Figure 4 Inundation of Coastal North Carolina with the High Scenario for the Year 2080