EXTENDED ABSTRACT
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Climate change and population predictions: Spatial variability in populations at risk for sea level rise

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Considerable popular and scientific attention has been given to the potential impacts of climate change. Chief among these concerns are the consequences for the human population. Indeed, significant technical and conceptual advances have been made in recent years to understand the interrelationship between human populations and the environment by several teams of researchers (e.g., McGranahan et al. 2007; O'Neill et al. 2001). Despite this progress and the compelling political and scientific motivations to understand the demographic implications of climate change, the study of the two areas has not intersected to produce meaningful localized estimates of the demographic implications of climate change. For example, research on climate often makes a case for the likely impacts of global warming on human populations, yet the resulting climate change scenarios are not related to current or future population estimates. Extant research also has tended to focus at the national or regional scale, thus masking spatial variability in climate impacts on populations at the sub-national scale. Further, demographically-oriented research on the environment tends to focus on the human contribution to climate change; population estimates are used to improve, for example, pollution scenarios on emissions. There is little to no work on the future populations in these areas, their composition, migration patterns, or other population characteristics. This information is critical for understanding the vulnerability of specific population groups, for planning mitigation and adaptation strategies, and for informing policy. The current study makes an important contribution to multiple fields by exploiting discipline-specific tools, placing climate and population models on the same temporal scale, and by producing population projections at a socially and politically meaningful spatial scale (i.e., the county level).

Our objective is to demonstrate the value of examining spatial variability in time-correlated climate and population projections at the sub-national scale. We demonstrate the methodological approach by focusing on sea level rise and total population size for a select sample of counties in low-lying coastal zones within the United States. We restrict the analysis to regions affected by one climate change outcome, sea level rise, and we limit our projections to total population size. Our intention is to develop a larger research agenda to pursue the impacts of a range of geophysical events related to climate change (e.g., land use degradation, increased hazards) on current and future populations, and most critically, determine the implications for specific population groups (e.g., age-, race-, and income-specific groups) within the United States and across the globe. Our initial results show the potential of this type of detailed demographic projection for local populations.

Data & Analysis

Climate-Change Scenarios

The balance of scientific evidence now shows that anthropogenic emissions of greenhouse gases are having a discernible effect on the Earth's climate. Global average air and ocean temperatures have increased, with global average temperatures projected to climb between 1.4 and 5.8 degrees C by the end of this century (IPCC 2007). Widespread melting of ice and snow has occurred as a result of global warming and is evidenced, in part, by the observed shrinking of the Artic sea ice extent. When combined, these changes have resulted in sea level rise at an average rate of 1.8mm/yr since 1961, and 3.1 mm/yr since 1993. Recent IPCC scenarios show that the rise of global average sea level by 2100 will be in the range from 18-38 to 26-59 cm depending on the emissions scenario (IPCC 2007).

The anticipated climate changes have important consequences for the human population given settlement patterns. As temperatures increase and sea level rises at faster rates than previously observed, a substantial number of persons currently live in coastal areas considered at high risk for sea level rise, flooding and storm surges (Small et al. 2004). Recent studies show that more than 10 percent of the world's population live in the world's low elevation coastal zones (a contiguous zone along the coast less than 10 m above sea level), with a larger share of the population (14 percent) in developing countries living in this area compared to more developed regions (10 percent) (McGranahan et al. 2007). Although research has begun to bring together climate change scenarios and population projections, investigations in the geophysical sciences continue to use static estimates of current population, while the demography arena has focused on coarse, brush-stroke models of population projections at the region- or country-level without regard for local or spatial variability. The current approach uses this past research as a point of departure to examine questions about localized impacts of climate change.

Case Selection

While it is often difficult to disentangle the impacts of climate change on human populations from other driving forces (e.g., the impact of rising temperatures on human health), the potential effects of sea level rise are unequivocal and will undoubtedly cause an immediate and important impact on population (i.e., increased vulnerability, displacement, and migration). With this in mind, we use sea level rise scenarios (1m and 4m rise) to define 'at-risk' locations within the continental U.S. Areas of potential inundation are derived from Mulligan's (2007) analysis of 90m remote sensing data from the Shuttle Radar Topography Mission (SRTM V3 data with corrections applied by the Consortium for Spatial Information) coupled with the coastlines and water body dataset derived from the NASA SRTM Water Body dataset. After compiling, mosaicking and projecting the dataset to an equal-area projection, we intersect the maps of predicted sea-level rise with county political boundaries within a GIS to determine the areas with the greatest amount of inundated land (Figure 1). From this step, we produce a rank of the counties with the highest degree of impact in terms of overall area inundated and percent of county inundated (Table 1). Our study sample, therefore, represents five areas that consistently appear at the top of the rankings as those most impacted by either 1m or 4m sea level rise.

Five areas, comprised of several contiguous counties, have been selected based on sea level impacts in addition to population size and composition. The reader will quickly note the absence of New Orleans and other southern areas that were impacted by Hurricane Katrina. While these counties were estimated to experience significant damage from sea level rise, methodological problems arise because of the timing of Katrina (2005) and the baseline population estimate (2000). Although the 2000 population estimates for areas hit by Katrina are accurate for this date, the areas experienced dramatic out-migration which makes forecasting area population dubious at best and completely unreasonable at worst.

In total, 24 counties are analyzed. All selected areas are estimated to experience at least a 1-meter rise in sea level, with some counties experiencing greater impact (in square kilometers damaged). The selected areas are distributed across the United States and capture five distinct place types: (1) the California cluster is an area rich in agricultural production and has a large immigrant and Latino population; (2) the Florida cluster is a popular retirement destination and an immigration destination for distinct Latino groups; (3) the counties within the New Jersey cluster have a tradition of industrial production; (4) the South Carolina cluster has a relatively large African American population and is within the southern region that has, in recent decades, experienced population growth through internal migration; and (5) the Virginia cluster is a high density area that is comprised of a largely professional population. Combined, the selected areas represent various geographic and demographic profiles that characterize the nation.

Population Projections

Annual population forecasts are estimated through 2030 by projecting forward the 2000 population baseline estimate according to county migration, fertility and mortality rates reported by the U.S. Census Bureau (2001) and the National Center for Health Statistics (2001a, 2001b). We use migration rates that have been adjusted to address census undercounts among specific age and race groups by a team of researchers headed by Dr. Paul Voss (Voss et al. 2004). In the current study, county estimates available through the national organizations are compared with estimates reported by state organizations as well as 2005 population estimates.

This strategy, like all forecasts, is imperfect. Weaknesses arise from error in the population baseline estimates themselves and error in the assumptions underlying the forecasts. In terms of the estimates, census data are reliable but not without error; certain populations are undercounted. Regarding underlying assumptions, forecasts are based on trends believed to be valid for the projection horizon. Future growth, however, may depart from historical patterns. Despite the imperfections, population forecasts are critical for analysts and service providers interested in the implications of climate change, like sea level rise. The projections are not intended to be perfect predictions of what will come. Rather, population projections are scenarios of what could happen given model assumptions. The employed model assumes that current rates of natural increase and migration will generally persist through 2030. This assumption is inaccurate given that factors affecting these sources of population growth can change, yet it is reasonable given that we do not have a strong sense of precisely what exogenous factors might arise and how they might alter trends in population growth.

Results

Study results include estimates of the population impacted by sea level rise for each of the selected study areas. Preliminary results suggest that the magnitude of the estimated impact ranges between the counties from 11,821 to about 3.3 million people. In addition, the dynamics of migration are analyzed. The top destinations (out-migration) and sending counties (in-migration) in 1990 and 2000 for a subsample of the selected counties with the largest metropolitan area are examined. This analytical strategy illustrates that the effects of sea level rise are not only experienced by the county that lost suitable land, but the impacts extend to counties that will need to house the uprooted population and to counties that would have sent migrants to the no longer inhabitable areas. Moreover, the population implications of sea level rise are further compounded by the connectedness of places that are directly affected by sea level rise; some of the top receiving and sending counties will also experience a loss of inhabitable land due to sea level rise.

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Table 1: Rank of counties by extent of area inundated and proportion of county flooded for sea level rise scenarios of 1m and 4m

	sea level rise - 1m				sea level rise - 4m			
rank	inundated area (sq km)		proportion of county		inundated area (sq km)		proportion of county	
1	Cameron	Louisiana	Iberia	Louisiana	Walton	Florida	Cameron	Louisiana
2	Vermilion	Louisiana	Cameron	Louisiana	Cumberland	New Jersey	Walton	Florida
3	Terrebonne	Louisiana	Vermilion	Louisiana	Iberia	Louisiana	Terrebonne	Louisiana
4	Plaquemines	Louisiana	Plaquemines	Louisiana	Cameron	Louisiana	Vermilion	Louisiana
5	Lafourche	Louisiana	Lafourche	Louisiana	Nueces	Texas	Lafourche	Louisiana
6	Hyde	North Carolina	Jefferson	Louisiana	Vermilion	Louisiana	Plaquemines	Louisiana
7	St. Mary	Louisiana	Terrebonne	Louisiana	St. Mary	Louisiana	Cumberland	New Jersey
8	Beaufort	South Carolina	Hyde	North Carolina	St. Bernard	Louisiana	Palm Beach	Florida
9	St. Bernard	Louisiana	St. Bernard	Louisiana	Terrebonne	Louisiana	St. Mary	Louisiana
10	Jefferson	Louisiana	St. Charles	Louisiana	Lafourche	Louisiana	Jefferson	Texas
11	Charleston	South Carolina	Poquoson	Virginia	St. John the Bapt	Louisiana	Hyde	North Carolina
12	Dorchester	Maryland	St. Mary	Louisiana	Iberia	Louisiana	St. Bernard	Louisiana
13	Carteret	North Carolina	Beaufort	South Carolina	St. Charles	Louisiana	Brazoria	Texas
14	St. Charles	Louisiana	Dorchester	Maryland	Hyde	North Carolina	Carteret	North Carolina
15	Solano	California	Cape May	New Jersey	Currituck	North Carolina	Iberia	Louisiana
16	San Joaquin	California	Carteret	North Carolina	Jefferson	Texas	Chambers	Texas
17	Camden	Georgia	St. John	Louisiana	Plaquemines	Louisiana	Charleston	South Carolina
18	Monroe	Florida	Currituck	North Carolina	Jefferson	Louisiana	St. Martin	Louisiana
19	Chatham	Georgia	Glynn	Georgia	Chambers	Texas	Beaufort	South Carolina
20	Glynn	Georgia	Chatham	Georgia	Carteret	North Carolina	Matagorda	Texas
21	King	Washington	Somerset	Maryland	Poquoson	Virginia	Collier	Florida
22	Accomack	Virginia	Hudson	New Jersey	Orleans	Louisiana	Dorchester	Maryland
23	Brazoria	Texas	McIntosh	Georgia	Chatham	Georgia	Jefferson	Louisiana
24	Jefferson	Texas	Iberia	Louisiana	Washington	North Carolina	St. Charles	Louisiana
25	Chambers	Texas	Accomack	Virginia	Bristol	Rhode Island	Brevard	Florida
26	Atlantic	New Jersey	Camden	Georgia	Tyrrell	North Carolina	Calcasieu	Louisiana
27	Iberia	Louisiana	Northampton	Virginia	Dorchester	Maryland	St. John	Louisiana
28	St. Martin	Louisiana	Orleans	Louisiana	Virginia Beach	Virginia	Camden	Georgia
29	McIntosh	Georgia	Cumberland	New Jersey	Beaufort	South Carolina	Chatham	Georgia
30	Calcasieu	Louisiana	Atlantic	New Jersey	St. James	Louisiana	Georgetown	South Carolina
31	Yolo	California	Chambers	Texas	Hudson	New Jersey	San Joaquin	California
32	St. John	Louisiana	Solano	California	Pamlico	North Carolina	Yolo	California
33	Cape May	New Jersey	Virginia Beach	Virginia	Galveston	Texas	Lee	Florida
34	Cumberland	New Jersey	Pamlico	North Carolina	Portsmouth	Virginia	Tyrrell	North Carolina
35	Colleton	South Carolina	Talbot	Maryland	Pasquotank	North Carolina	Jefferson Davis	Louisiana

Note: Counties in Louisiana have been grayed to denote that they were not considered during sample selection.

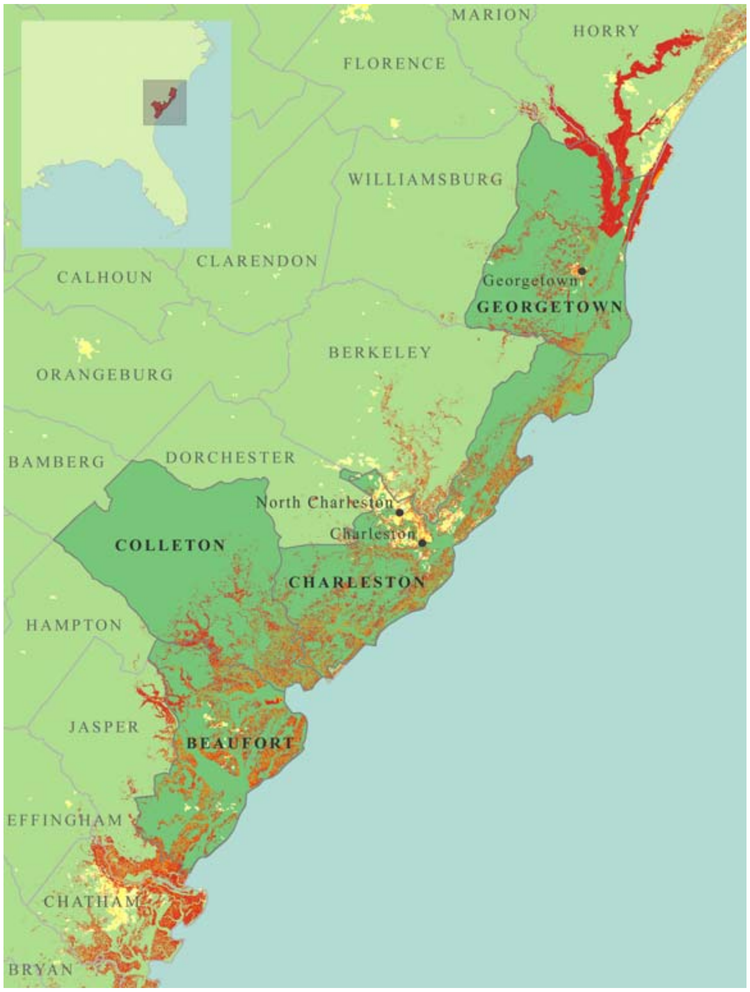

Figure 1: A map of the South Carolina coastal zone, one of the five selected study areas. The study area is shown in dark green, while inundation is shown in orange (1m sea level rise) and red (4m sea level rise). For reference, urbanized areas are shown in yellow.