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Understanding the demographic implications of climate change: A first look at localized population predictions

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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 on 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, by producing population projections at a socially and politically meaningful spatial scale (i.e., the county level), and by placing climate and population models on the same temporal scale.

Study results estimate that upwards of 20 million people will be impacted by sea level rise by 2030 in the five selected study sites. Moreover, our research shows that the impacts extend beyond the inundated counties; human populations are not isolated but are linked through migration networks. Inundation, therefore, will not only dislocate human populations, but will cause a restructuring of migration networks. Indeed, some networks, those that are regionally bound (i.e., the New Jersey case), will no longer be viable.

Building on past research linking population and environment

A major challenge facing research that links population and environment is the computational demands required to estimate future local populations. Current attention to the impacts of global environmental change has begun to focus on the vulnerability of urban areas and individuals to the negative consequences of those impacts. Research on this issue has taken one of two forms. The first includes understanding climate change and specifically sea-level rise from a geophysical perspective, where the "human impact" is estimated using static, spatially explicit population maps such as those available from Landscan (Dobson et al., 2000). While these are useful for understanding where populations are currently located, they contain no information on predicted population changes, its composition, or movement, all of which are vital for understanding the human impacts of climatic changes. The second type of research is an impressive body of regional and country-level demographic models and predictions (Lutz et al., 2004; 2008) developed at the Institute of International Applied Systems Analysis (IIASA). Here, researchers have developed probabilistic projections of total population, age and life expectancy, and total fertility rate for 2008-2100 which bracket the upper and lower bound of future population developments.

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 continental U.S. We restrict the analysis to regions affected by one climate change outcome, sea level rise, and we limit our projections to total population size given computational demands. 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 and, we conclude, demonstrate the need to invest in automating small-area population projections.

Climate change in the 21st century

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 (Meehl et al. 2007). Widespread melting of ice and snow has occurred as a result of global warming and is evident, in part, from the observed shrinking of the Artic sea ice extent (Alley et al. 2005) and increased glacial melt (Meier et al. 2007). 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. The most recent Intergovernmental Panel on Climate Change (IPCC) scenarios show that global average sea level will continue to rise, with estimates ranging from 18-38 to 26-59 cm by 2100 depending on the emissions scenario (IPCC 2007). Finally, there is observational evidence of an increase in the severity of hurricanes and typhoons that impact coastal populations, and it is likely that these storms will increase in intensity and frequency in coming decades (Webster 2005).

The anticipated climate changes have important consequences for the human population given current 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 short-term and localized impacts of climate change on population and migration patterns.

When bringing together the results of predictive numerical models and statistical models from disparate disciplines, one important consideration is the difference in the time horizon for forecasts. Climate change research is typically on the order of centuries, with 2050, 2080 and 2100 often are cited as time points for significant change and impacts. We follow current trends in demographic research that focus prediction on the order of decades, since it is critical to forecast only to the extent that past data is available (e.g., 30 years). Thus, sea-level rise predictions must be altered to reflect this time scale and to achieve synthesis with our five year time scale up to 2030. The IPCC scenario predictions for sea level rise are adjusted using simple linear interpolation (current projections follow near-linear trends for all of the emissions scenarios) for five year intervals for the period 2008-2100. The results show that it is likely that global average sea level will rise from 4.2 to 13.9 cm by 2030. Similar interpolation of recent sea level rise trends (1961-2003) also fall within this range. Although these figures may appear low, sea level rise of this magnitude is still worrisome in extremely flat, low-lying areas and especially problematic in resource-poor areas with little capacity for mitigation or adaptation. Further, these figures do not take into account known spatial variability in sea level changes, or the potential for extreme sea level changes (on the order of meters) that will result from increases in coastal storm activity, hurricane frequency and intensity due to climate change/warming.

Data and analysis

Case selection

While it is often difficult to decouple 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 in terms of increased vulnerability to health risks, displacement, and migration in response to flooding. With this in mind, we use sea level rise scenarios to define 'at-risk' locations within the continental U.S. Areas of potential inundation for worst-case scenarios (1m for worst-case sea level rise and 4m for worst-case storm surges/flooding) are derived from Mulligan's (2007) analysis of 30-90m resolution 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 data derived from the NASA SRTM dataset. After compiling, mosaicking and projecting the inundation data 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 information, we produce a rank of the U.S. 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 affected by either the 1m or 4m sea level rise scenarios.

[Table 1 about here]

[Figure 1 about here]

The five study areas consist of several contiguous counties selected to represent differences in population size and composition (i.e., counties in 'high risk' areas were selected to include urban and rural populations). 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 future 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 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. It is reasonable to anticipate that the political responses to inundation would vary across the selected place types given local area variability in social and economic resources.

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) at the Applied Population Laboratory. 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. Adjustments were made by modifying the migration rate to correct for suspected over- or under-estimated population counts. The adjustments were modest, although one county was exceptional. Norfolk County, Virginia, is home to a university and a naval base, two institutions that attract a young and mobile population. The adjustment assumes that the university and navy populations persists over time, otherwise the younger 20-24 age group diminishes over the forecasted period. Specifically, we adjusted migration to reflect a higher in-migration for the 20-24 year-old age group, and higher out-migration for the 25-29 year-old and in-migration for the 30-34 year-old age groups.

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 occur. 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.

Estimated population impacts of sea level rise

Study results suggest two important findings; there is considerable spatial variability in the impacts of sea level rise, and population impacts are not isolated to inundated counties but extend to geographically nearby and distant counties connected through migration streams.

The magnitude of the estimated impact ranges from 11,821 (Posquoson County, VA) to about 3.3 million (Miami-Dade County, FL) (Table 2). In all, approximately 20 million people will be affected by sea level rise in these 24 counties. Among the selected areas, Florida is expected to experience the greatest population impacts; more than 9.7 million people are projected to be dislocated by sea level rise in 2030 (Figure 2). South Carolina is the least impacted, with “only” an estimated 715,461 effected residents.

[Table 2 about here]

[Figure 2 about here]

Certainly, the total population and land area affected by changes in sea level will be dramatically higher than the figures from the sample indicate. Of the 368 counties that line the U.S. Atlantic and Pacific coasts, 44 (12%) can expect to have more than 50 km^2 of land inundated under the 1 m sea level rise scenario. When the 4 m rise scenario is considered, this number increases to 148 counties. The bulk of these 148 (40%) counties are in Florida (28), Louisiana (25), North Carolina (16), Texas (15), California (9), and South Carolina (7). To put the current analysis in perspective, the 24 selected counties represented 4.8% of the total population in 2000 and one-sixth of the total counties expected to be impacted by significant sea level rise.

The population implications, however, are not restricted to inundated counties; counties directly impacted by sea level rise are connected to other places through migration streams. The estimated 20 million people dislocated by sea level, assuming 100% dislocation and survival, will be forced to relocate. Similarly, potential in-migrants to these counties will have to move to alternative destinations. The top five destinations (out-migration) and sending counties (in-migration) in 1990 and 2000 for a subsample of the selected counties that have the largest metropolitan area among the counties within the respective cluster are identified (Table 3). The reported counties have the following cities: Sacramento, CA; Miami, FL; Newark, NJ; Charleston, SC; and Virginia Beach, VA.

[Table 3 about here]

These data illustrate 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.

For example, Miami-Dade County sent approximately 18,860 residents to Palm Beach County in 1990 and 2000. Palm Beach also is expected to suffer significant damage from sea level rise by 2030, therefore making it an unviable migration option for residents of Miami-Dade County. The same is true for Sacramento and Yolo counties, and Charleston and Virginia Beach, among others. Similarly, potential in-migrants to Miami from New York and California will be redirected to other destinations just as potential migrants from Los Angeles to Sacramento will need to find an alternative.

To further emphasize connectedness and its implications, the strength of the in-migration and out-migration streams are illustrated for two types of migration networks: geographically dispersed (Miami-Dade, FL) and geographically localized (Essex, NJ) (Figure 3). Whether localized or dispersed, the connections show the potential magnitude of the population that will need to be redirected if faced with inundation.

Miami-Dade sends a substantial population to neighboring Broward County (exhibited by the large orange arrow), yet Broward County will longer be a viable receiving community for Miami-Dade migrants since it, too, is estimated to be inundated. As a result, Orange and Hillsborough counties might absorb more Miami-Dade out-migrants, or connections to new destinations might develop. Similarly, Miami-Dade in-migrants from New York state and Los Angeles will be rerouted to alternative destinations, perhaps outside of Florida state. The geographically localized migration network, exemplified by Essex County, NJ, would need to be almost entirely restructured due to inundation. The top destinations for Essex out-migrants are anticipated to no longer be viable and, similarly, the regionally-centered in-migration streams will no longer be possible.

These data suggest that existing migration networks will be dramatically restructured as a consequence of sea level rise. Indeed, some migration streams may increase as a result of sea level rise. An increase in migration will place numerous institutional and social pressures on receiving counties, including the availability and affordability of housing, seats in classrooms and job opportunities as well as social interactions between different ethnic and socioeconomic groups.

Conclusions

Researchers from the natural and social sciences have made important developments in the study of climate change and the human dimensions of climate change. Our analytical approach advances the understanding of the effects of climate change for human populations by examining spatial variability in time-correlated climate and population projections at the sub-national scale. Failure to analyze the sub-national unit and temporally correlate population and climate processes undermines the value of data generated from projection models. While computationally intensive, our research demonstrates the significant value added by directly relating climate models to population forecasts.

We view this study as the beginning of a larger research agenda that will use methodologies rooted in distinct disciplines to advance the study of environment-human interactions. Future research activities should extend the approach to different geographies, such as the entire United States and other countries with sizeable coastlines and vulnerable populations (e.g., India, Bangladesh), to gain a more global perspective on the potential impacts of sea level rise. A second aim is to decompose the population into distinct and meaningful subgroups according to, for example, age, ethnicity, and socioeconomic status. These data have important implications for understanding the social, economic, and political ramifications of population movement forced by climatic events. A third related focus is to extend the forecasts to the migration flow networks. These data will provide a more comprehensive estimate of the population implications of climate change. A fourth aim is to model coastal inundation using the increased accuracy and precision offered by new data sources and digital terrain techniques. This will allow better correlation of population forecasts to projected rates of sea level rise. Moreover, future research should aim to examine the population impacts of additional climate-change related environmental outcomes beyond simple sea level rise scenarios, including (but not limited to) desertification and soil salinization, lack of water, and increased rates of natural disasters. Researchers should articulate variation in the magnitude of the population impacts across these different types of environmental impacts, especially in terms of land suitability and the permanency of resultant population dislocation.

Finally, considerable effort should focus on automating the methodological approach articulated in the current study. Population forecasts are computationally demanding and the ability to extend the current study will require significant investment in computational resources to store and manipulate the population and sea-level rise data required to produce estimates for the different locations and geographies, population subgroups, and climate-change scenarios elaborated above and necessary to understand the full impacts of climate change on the human population.

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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.

Table 2: Estimated population impacted by sea level rise for selected counties, 2030

Area	Impacted Population
California	
Contra Costa	1,345,382
Sacramento	1,809,957
San Joaquin	1,232,698
Solano	531,716
Yolo	286,767
Sub-Total	*5,206,520*
Florida	
Broward	2,558,685
Collier	657,615
Lee	1,145,875
Miami-Dade	3,290,293
Monroe	82,980
Palm Beach	1,994,726
Sub-Total	*9,730,174*
New Jersey	
Bergen	968,174
Essex	827,851
Middlesex	959,518
Union	574,446
Sub-Total	*3,329,989*
South Carolina	
Beaufort	202,235
Charleston	380,818
Colleton	48,002
Georgetown	84,406
Sub-Total	*715,461*
Virginia	
Hampton	153,999
Norfolk	227,369
Poquoson	11,821
Portsmouth	92,877
Virginia Beach	474,533
Sub-Total	*960,598*
Total	*19,942,742*

Table 3: Top five counties sending (out-migration) and receiving (in-migration) populations for inundated counties with large cities, 1990 and 2000

	Out-Migration				In-Migration			
	1990		2000		1990		2000	
Sacramento, CA								
	Yolo, CA	3,930	Placer, CA	22,430	Los Angeles, CA	5,027	Placer, CA	12,944
	Los Angeles, CA	3,913	El Dorado, CA	7,706	Santa Clara, CA	4,756	Los Angeles, CA	12,260
	Placer, CA	3,637	Yolo, CA	7,073	Alameda, CA	4,369	Santa Clara, CA	11,835
	San Joaquin, CA	3,070	Los Angeles, CA	6,502	San Francisco, CA	3,726	Alameda, CA	9,336
	Alameda, CA	3,050	San Diego, CA	5,747	Yolo, CA	3,624	Yolo, CA	8,961
Miami-Dade, FL								
	Broward, FL	6,159	Broward, FL	89,915	Queens, NY	4,525	Broward, FL	18,136
	Palm Beach, FL	4,232	Palm Beach, FL	14,448	Broward, FL	4,360	Queens, NY	7,467
	Los Angeles, CA	3,462	Orange, FL	10,060	Kings, NY	4,333	New York, NY	6,154
	Orange, FL	3,287	Hillsborough, FL	6,335	Los Angeles, CA	3,893	Los Angeles, CA	5,478
	Hillsborough, FL	3,054	Leon, FL	5,390	New York, NY	3,647	Kings, NY	5,340
Essex, NJ								
	Union, NJ	4,800	Union, NJ	19,831	Hudson, NJ	3,973	Hudson, NJ	10,831
	Middlesex, NJ	4,033	Morris, NJ	11,925	Union, NJ	3,595	Union, NJ	8,619
	Hudson, NJ	3,462	Middlesex, NJ	7,304	Kings, NY	3,264	Passaic, NJ	6,493
	Morris, NJ	3,300	Hudson, NJ	6,312	Passaic, NJ	3,004	Bergen, NJ	5,979
	Passaic, NJ	2,576	Ocean, NJ	5,161	Bergen, NJ	2,656	Kings, NY	5,488
Charleston, SC								
	Berkeley, SC	2,879	Berkeley, SC	9,312	Berkeley, SC	2,516	Berkeley, SC	3,997
	Dorchester, SC	2,576	Dorchester, SC	6,462	Dorchester, SC	2,111	Dorchester, SC	3,047
	Richland, SC	1,760	Richland, SC	1,859	Richland, SC	1,652	Richland, SC	2,398
	Virginia Beach, VA	1,375	Mecklenburg	1,388	San Diego, CA	1,152	Mecklenburg, NC	1,213
	Duval, FL	1,312	Greenville, SC	957	Greenville, SC	1,011	Fulton, GA	1,124
Virginia Beach, VA								
	Norfolk, VA	3,616	Chesapeake, VA	23,909	Norfolk, VA	4,324	Chesapeake, VA	21,844
	Chesapeake, VA	2,992	Duval, FL	2,618	Chesapeake, VA	2,870	San Diego, CA	3,687
	San Diego, CA	1,720	Suffolk, VA	2,394	San Diego, CA	2,159	Duval, FL	2,558
	Fairfax, VA	1,658	San Diego, CA	2,089	Portsmouth, VA	1,559	Fairfax, VA	1,787
	Portsmouth, VA	1,335	Fairfax, VA	2,029	Los Angeles, CA	1,462	Honolulu, HI	1,389

Note: Estimates are based on data from the County-to-County Migration Flow Files (US Department of Commerce, Bureau of Census 1995 and 2003)

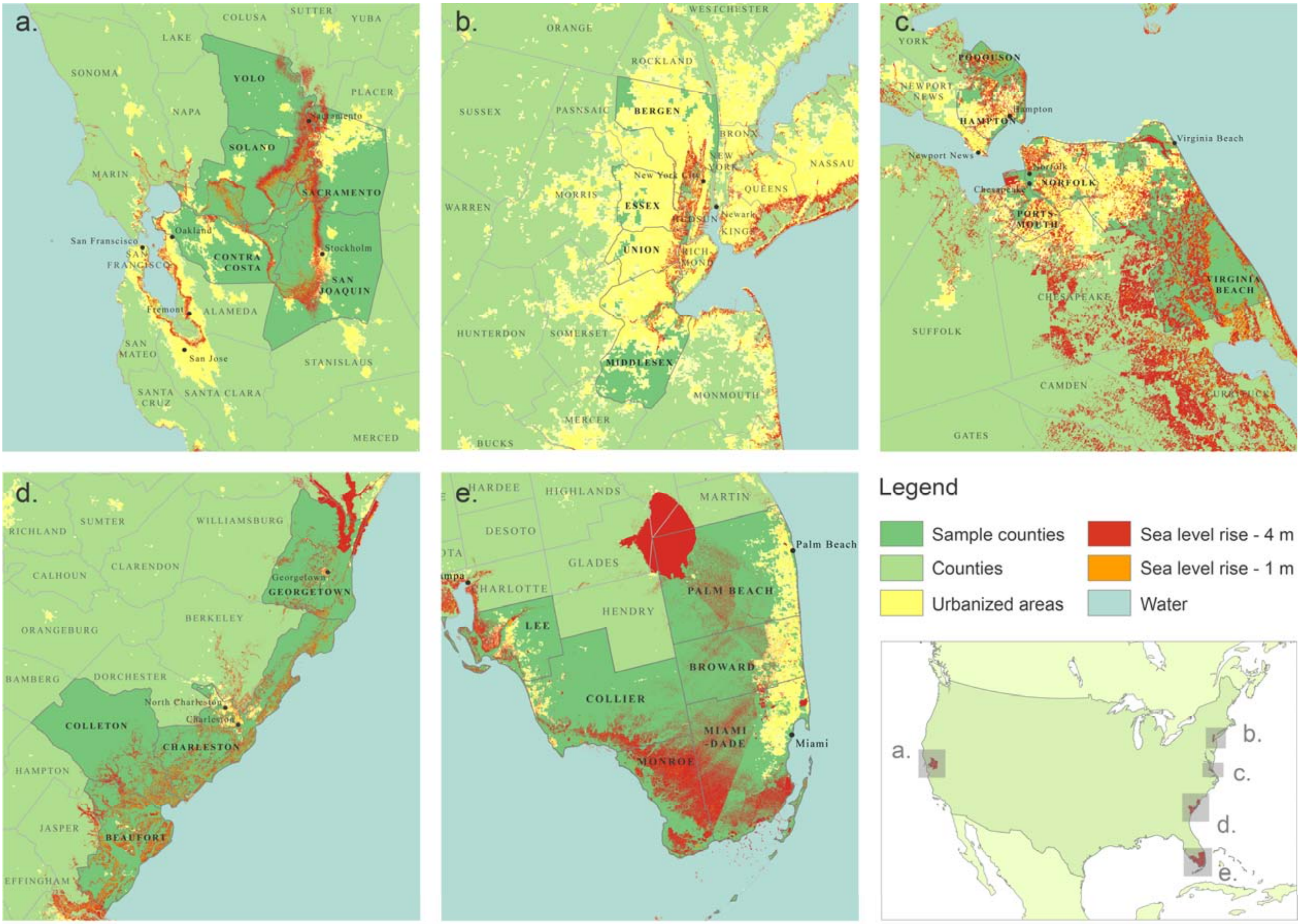

Figure 1: Maps of the five study areas highlighted in this research: (a) Northern California, (b) New Jersey, (c) Virginia, (d) South Carolina, and (e) Southern Florida. These areas were selected based on sea level rise scenarios of 1 m and 4 m rise. The counties of each sample area are shown in dark green, while potential inundation is shown in orange (1m sea level rise) and red (4m sea level rise). For reference, urbanized areas are shown in yellow.

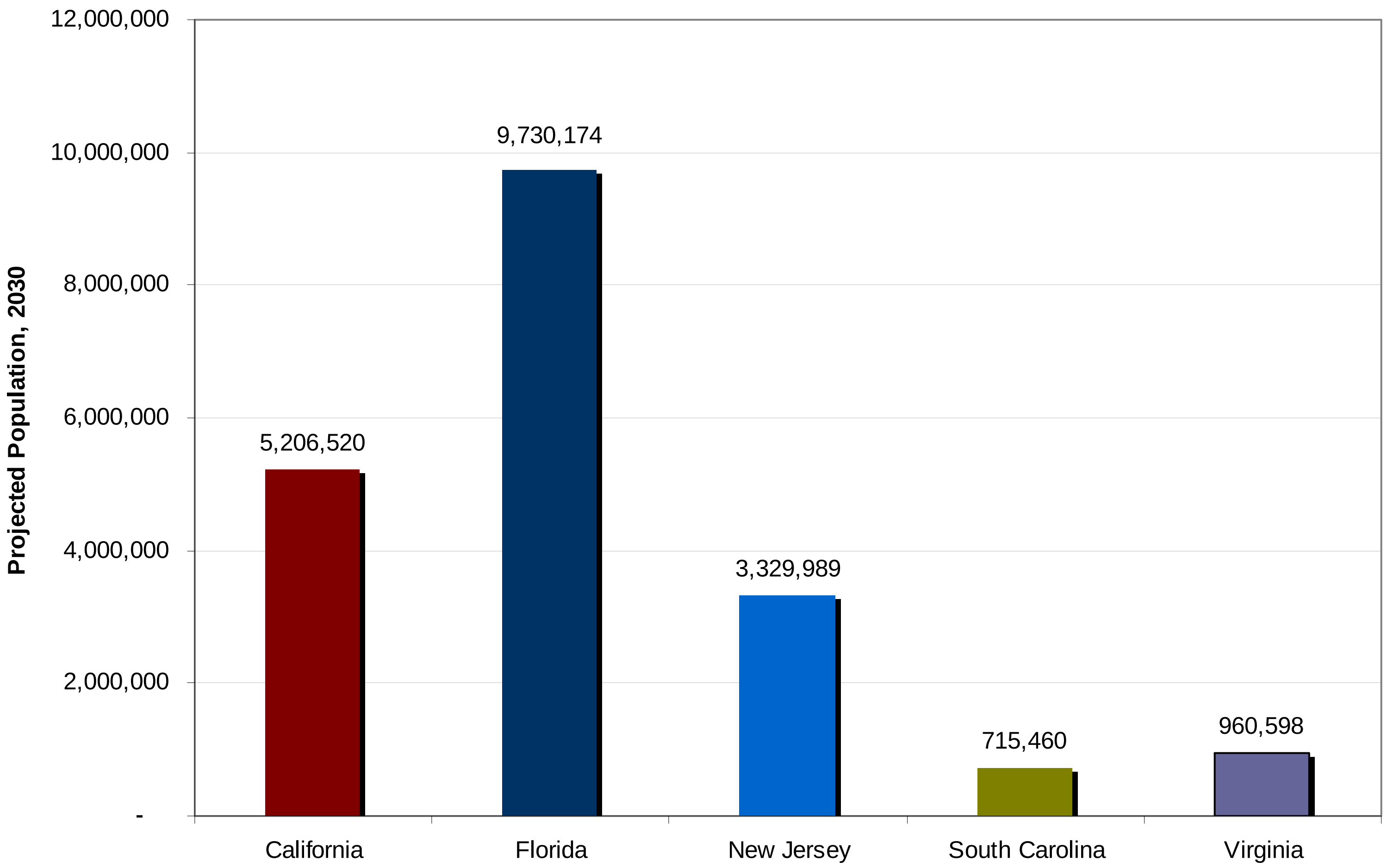

Figure 2: Estimated population impacted by sea level rise in 2030 for the five study areas.

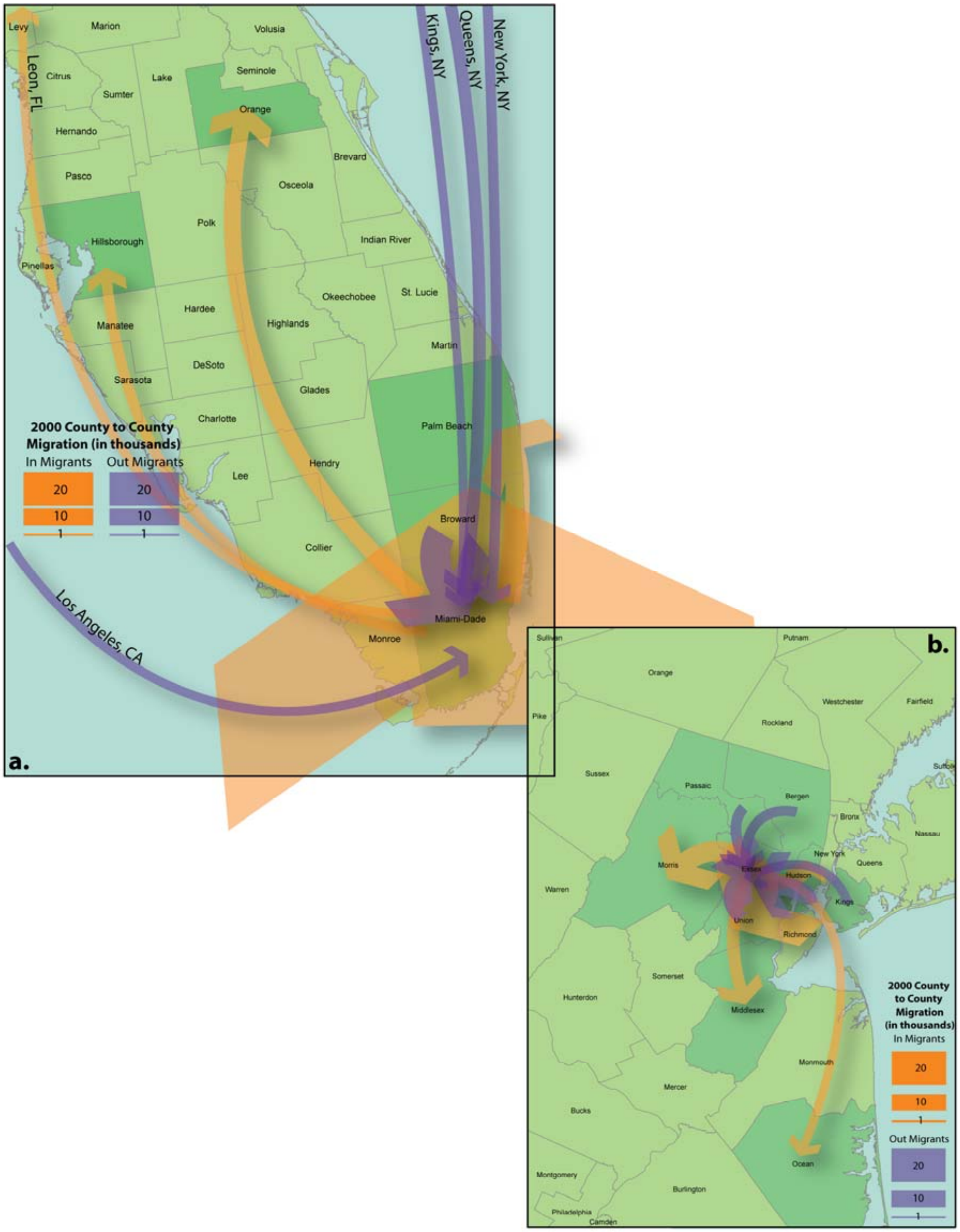

Figure 3. Flow map illustrating the strength of observed in-migration and out-migration streams in 2000 for (a) Miami-Dade County, Florida and (b) Essex County, New Jersey.