Sea-Level Rise and Sub-County Population Projections in Coastal Georgia

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Abstract

Sub county population projections are generally very problematic. The inputs required for a traditional cohort-component method, are rarely available at sub county geographies. There are simple workarounds, such as the Hamilton-Perry method, but these techniques require areal units that are stable between two censuses in order to generate cohort-change ratios and are oftentimes only used to project populations along short projection horizons, namely 10 years. Understanding the implications of climate change requires additional understanding of coupled human-natural systems interactions. This paper proposes a new housing unit based population projection methodology for sub-county units that will be used in conjunction with sea-level rise modeling to project populations vulnerable to inundation by 2050 in coastal Georgia.

Introduction

Population projections are an integral part of understanding the future of human populations (2013, Smith, Tayman and Swanson 2001, Lutz 2013) and are used in planning, policy making, and environmental understanding (Glover and Prideaux 2008, Hansen 2010, Jenouvrier et al. 2009, Lutz and Samir 2010, Perkins 2014). Despite the historical importance of population projections, projection methodologies for small areal units – namely sub-county units – tend to be less robust than projection methodologies at larger scales (Swanson, Schlottman and Schmidt 2010, Baker et al. 2013), tend to have serious questions regarding their accuracy for longer range projections (Smith et al. 2001), and fall victim to the modifiable areal unit problem or the MAUP (Cromley, Ebenstein and Hanink 2009) . In order to overcome these limitations on accuracy, demographers have proposed several projections methodologies for sub-county units such as the Hamilton-Perry method (Swanson et al. 2010), the Share method (Zeng et al. 2014), and various extrapolation methodologies (Swanson and Tayman 2012a). Despite the plethora of projection methodologies designed to overcome the problems listed above, the MAUP still remains (Swanson et al. 2010). This paper proposes a novel projection methodology suitable for sub-county units based on the Hammer Method (Hammer et al. 2004) and the Housing Unit Method (HU) for population estimation (Cai 2007). It also demonstrates this method's use by combining it with sea-level rise modeling in Coastal Georgia.

Projection methodologies share much in common with estimation methodologies. Many of the projection methodologies are also employed as estimation methodologies. The four main types of estimation methodologies – extrapolation, censal-ratio, component, and statistical (Siegel 2002) – also describe the main types of projection methodologies. In fact, most estimation methods are simply projections to a short time period, generally t+1, while most projections are to a longer time period. The same basic demographic accounting equation used for population estimates is also the main equation used for the cohort-component method of population projection (Swanson, Siegel and Shryock 2004). The HU method is recognized as one of the most commonly used forms for estimating small area populations (Smith 1986, Byerly 1990, Smith, Nogle and Cody 2002), having been advocated before Congress for use by the Census Bureau for sub county population estimates (Swanson 2006), and it has been in practical use by State and Local demographers since at least 1942 (Swanson 2010). Despite the known similarities between estimation and projection methodologies, the HU method has never been used in projection methodologies even with the employment of all four types of estimation methodologies in population projections. While such a method would be subject to the same bias and error as estimates (Smith and Cody 1994), it would be able to convert any projection of housing units into projections of population.

In spite of the proposed solutions to the MAUP (Norman, Rees and Boyle 2003, Martin, Dorling and Mitchell 2002), no current projection methodology can currently be used across all geographies – national, state, county, and sub-county – as a standalone methodology due to these problems. However, the Hammer Method (Hammer et al. 2004) for reverse forecasting standardized sub-county boundaries with estimates of housing units can be combined with the HU method to produce one ontologically coherent estimation and projection methodology for all geographies. This paper develops such a method and demonstrates a potential use in understanding future climate change scenarios for sea level rise in a six county area of Coastal Georgia. The methodology is considered in light of the contribution to sub-county projection methodologies and through a 3D geovisualization of sub-county Population estimates and forecasts for 1940 through 2050.

Methods and Materials

The method described here relies upon the similarities between population estimates and projections. The underlying relationship between a population estimate (equation 1) and projection (equation 2) is demonstrated with demographic accounting equation (Newbold 2010) :

(1) $$P_1 = P_0 + B - D + I - E$$

(2) $$P_{t+1} = P_t + B - D + I - E$$

Where B is the Births, D is the Deaths, I is immigration, and E is the emigration. The only significant difference between the two equations is in the definition of the time period. For an estimate, it is always time 1 i.e. the present year and based on the population from t-1. For a projection, it is always time t+1 based on the population from time t. For all intents and purposes, most projection methodologies are estimation methodologies at their core, and the HU method is no different and is often referred to as a balancing equation (Swanson 2010, Smith and Cody 1994).

Equation 3 demonstrates the HU method (Swanson 2010) :

(3) $$P_t = H * \mathrm{O} * \mathrm{PPH} + \mathrm{GQ}$$

Where H is the number of housing units, O is the occupancy rate, PPH is the persons per household, and GQ is the group quarters population. Any error associated with the HU method is attributable to the quality of the inputs (Siegel and Swanson 2008). This methodology can be further simplified by combing the occupancy rate with PPH to create a PPHU or population per housing unit as the total population divided by the total housing units both occupied and unoccupied (Cai 2008). PPHU will essentially roll the group quarters population, as a component of the total population, into this variable. This leads to equation 4.

$$P_t = H * \text{PPHU} \quad (4)$$

The HU method on its own could produce a population projection if all three variables are projected on their own, but the aforementioned boundary changes at sub-county scales would lead to problems in forecasting any of the component inputs. The Hammer method, however, can provide a long range back cast of housing units for normalized boundaries in any given census geography (whether its 1990, 2000, or 2010 geographies). Based on the “year structure built” question in Census data, the method produces proportionally adjusted housing unit estimates at the smallest census geography possible – the block group. While Census designated boundaries may change, housing units typically do not move (Hammer et al. 2004).

$$H_{ij}^{\prime t} = H_{ij}^{t}\left[\left(A_j^{t+10} - \Delta_j^{t+10}\right)\frac{\hat{H}_{ij}^{t}}{\hat{H}_{j}^{t}}\right] \quad (5)$$

These estimates of housing units for each block group in each county provide the first of the two inputs needed to convert an estimate of housing units into an estimate of total population. The question then turns to producing estimates of the PPHU variable.

The two variables required to calculate the PPHU are known for each historical census at the county level – the total population and the total number of housing units. Thus, the PPHU for each county is known while the PPHU for each component block group must be estimated. Keeping in the same tradition as Hammer, we can utilize the known variability in current decade block group geography for PPHU to backcast PPHU for prior decades based on this variability. Equation 6 demonstrates the historic calculations of Population for each block group for any given time period.

(6) $$P_{ij}^{t} = \left[\frac{P_{j}^{t}}{\sum \left[\left(\frac{PPHU_{ij}^{T}}{PPHU_{j}^{T}} * PPHU_{j}^{t} \right) * H_{ij}^{\prime t} \right]} \right] * \hat{\mathrm{P}}_{ij}^{t}$$

Where the Population in time t in block group I in county j is given as the ratio of the PPHU at the block group level to the County from the ACS or most recent decennial Census multiplied by the PPHU observed PPHU from the historic census data. This initial PPHU estimate for each block group is then multiplied by the estimated number of Housing Units as estimated from the Hammer Method to create the initial estimate of population. These are then summed to the county level and proportionally adjusted based on the observed population of a county from the time period in question. This provides us with variable PPHU estimates for each block group for each time period in any given county. By simply dividing the estimated population by the estimated number of housing units we will have generated the PPHU for any given time period $\frac{P_{ij}'^{t}}{H_{ij}'^{t}}$. This makes it possible to produce a historic time series of population and housing units at the block group geography with consistent boundaries for a period of 1940-2010. Equation 7 is the fully denoted methodological approach for these historic estimates while equation 8 is the abridged formulation. Equation 8 can be utilized as a projection methodology as well through any set of extrapolation methods for the H and PPU values (Smith and Cody 1994, Bogue 1950, Starsinic and Zitter 1968, Cai 2008, Armstrong 2001).

(7) $$P_{ij}^{t} = \left[\frac{P_{j}^{t}}{\sum \left[\left(\frac{PPHU_{ij}^{T}}{PPHU_{j}^{T}} * PPHU_{j}^{t} \right) * \left\{ H_{ij}^{t} \left[\left(A_{j}^{t+10} - \Delta_{j}^{t+10} \right) \frac{\hat{H}_{ij}^{t}}{\hat{H}_{j}^{t}} \right] \right\} \right]} \right] * \hat{P}_{ij}^{t}$$

(8) $$P_{ij}^{t} = H_{ij}'^{t} * PPHU_{ij}'^{t}$$

Given the similarities between population estimate and projection methodology (Swanson 2010, Swanson and Tayman 2012b, Smith and Cody 2012, Smith et al. 2001, Smith and Cody 1994), the ability to estimate key components of the Housing Unit Method at the sub-county scale (Cai 2008, Hammer et al. 2009, Hammer et al. 2004), and the assumption that PPHU values are variable across space and time, we will now demonstrate the proposed methodology for this six county region of Coastal Georgia.

Data

Data for conducting this population projection comes from two main sources. The first source of data comes from the American Community Survey 2008-2012 estimates. The ACS provides the "year structure built" data, and the contemporary census boundaries for block groups. The second piece of data is the actual historic count of housing units and population for each county. This data is available as digitized records from the Census Bureau's website[1]. It should be noted in the consideration of these inputs that the ACS data, though similar to decennial data, is subject to many types of error. However, all released ACS data have confidence limits above 90% (Swanson and Tayman 2012b). In lieu of ACS error, it may seem best to view the historic estimates of population and projections as projections rather than a gold-standard estimate of such populations.

For the sea-level projection, data for the Digital Elevation Model comes from the US Geological Survey's National Elevation Dataset at the 1/3 arc-second (approximately 10 meters) resolution. Inundation was assumed using the 'bathtub' model for sea-level rise (Poulter and Halpin 2008, Rogers, Saintilan and Copeland 2012) where all pixels within 1m of sea-level are assumed to become inundated. The land area of any given block group that will be inundated

[1] For 1940 to 1990, data can be found at http://www.census.gov/prod/cen1990/cph2/cph-2-1-1.pdf. Census 2000 data can be downloaded through American FactFinder.

was calculated and this percentage was then applied to the projected block group population in 2050 to assess the future populations at risk.

Evaluation

Evaluating population projections typically involves a comparing a projection launched from a historic period with population counts in more contemporary time periods (Murdock et al. 1991, Kanaroglou et al. 2009). This proves problematic, however, when looking to compare sub-county areas due to the changes in census geography that would have occurred over any evaluation period. For this reason, we have chosen to evaluate the proposed method in comparison to other projection methodologies at both the sub-county and county level. It should be noted that while this method of comparison does not utilize any of the typical demographic ex-post-facto evaluation statistics such as mean absolute percent error, mean algebraic percent error, or root mean squared error (Levinson 1947, Abraham and Ledolter 2009, Hauer, Baker and Brown 2013), this comparison is more similar to a feasibility approach (Lutz, Sanderson and Scherbov 1998, Tippett 2013) i.e. are these projections feasible compared to other projection methodologies? Absent any advanced knowledge of a future population count, this comparison merely is to determine if performance of this proposed method is comparable to similar projections across similar time periods across similar geographies. Here we summarize the similarity of the results in the proposed method to the Hamilton-Perry method and the Shift-Share Method at the sub-county scale and with the cohort-component method at the County Scale.

Results

Table 1 summarizes the comparisons of the proposed method with sub-county areas in south Fulton County, Georgia (Hauer 2013, Wm. Thomas Craig 2014) as produced for the South Fulton County Water & Sewer Authority as well as county-level comparisons in Coastal Georgia to the Georgia Governor's Office of Planning and Budget's official population projections (Budget 2013). Figure 1 also provides a spatial review in the form of a 3D geovisualization (Hauer 2012) of the six counties in Coastal Georgia for the period 1940 to 2050 at the block group level in an animated gif format. At the sub-county scale, the HU method of projection in 2060 falls within a range created by a Hamilton-Perry projection and a Shift-Share projection, though closer to Hamilton-Perry than to the Shift-Share. At the county-scale, the HU method projects county level populations that are comparable (within 10%) of a cohort-component generated projection. These results suggest that the HU method can produce similar projection results as comparable methodologies at both sub-county and county scales demonstrating the pliability of application across varying scales -- both geographic and temporal in nature. Figure 1 demonstrates the method's unique ability to standardize geographies across space and time to produce a fine-grained picture of both historic and future populations at small-scales – a remarkable strength in the face of the challenges posed by modifiable areal unit problems.

Table 1. Comparisons of the Housing Unit Method with other projection methodologies across various geographies and time scales.

		Method			
Area	Year	HU Method	Hamilton-Perry	Shift-Share	Cohort-Component
South Fulton Area	2060	121,431	118,407	128,214	
Bryan County	2030	38,424			44,465
Camden County	2030	68,078			77,516
Chatham County	2030	330,187			354,945
Glynn County	2030	97,760			98,625
Liberty County	2030	80,246			85,512
McIntosh County	2030	15,947			18,653

Figure 1. Block group population counts (color) and densities (height) for the six county region of Coastal Georgia. The Green lines traversing the coast are Interstate Highways.

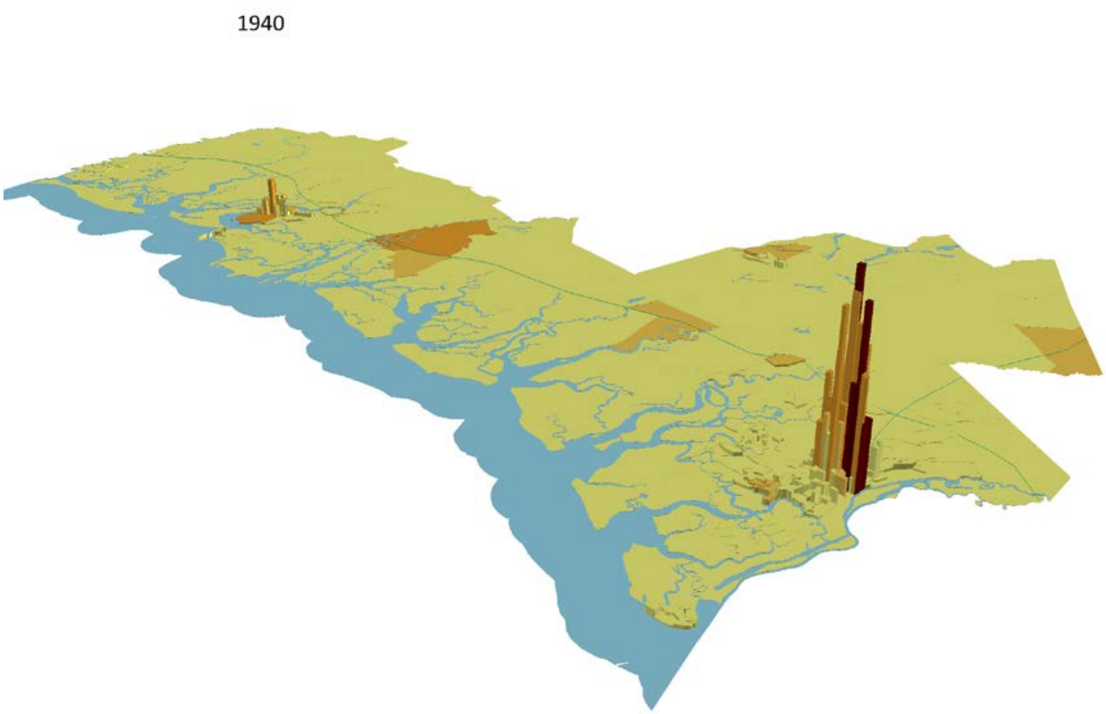

Figure 1 is displayed such that population density within each block group is represented vertically while the number of total population is represented by the color – the taller the block group, the higher the density, and the darker the block group, the more total population within the block group. The city of Savannah anchors the map in the forefront in the bottom right while the city of St. Mary's in Camden County anchors the map on the top left[2]. As can be seen in Figure 1, several classic demographic phenomena are readily apparent in the historic period of 1940-2010. The historic population growth at the sub-county level for Coastal Georgia has been quite uneven, as should be expected (Bongaarts 2009, Meyer and Turner 1992, Bourne and Rose 2001), the decline of the central city of Savannah into the classic donut shape of modern urban development (Soja 1996, Deal and Schunk 2004), and the rise of surburan enclaves or edge cities (Garreau 2011, Bingham, Bowen and Amara 2013) are all readily apparent in an easy to understand visual manner. In terms of the projected geographic distribution of future populations along the coast, several troubling hot spots can also be seen. While Tybee Island, Georgia, west of the city of Savannah, and a typical beach community, should not experience much growth over the next forty years, Wilmington Island, located several miles inland from Tybee is projected to continue to grow quite rapidly. All in all, the six county coastal Georgia region is projected to grow from 503,000 people in 2010 to around 816,000 people in 2050 – a 62% increase the population.

[2] Who said North was up?

Table 2. Current Populations, Projected populations in 2050, and the populations at risk for Six Coastal Counties in Georgia, 2010-2050.

Area	2010 Population	2050 Population	Projected Populations at risk of 1m of Sea level Rise	% of Total Population at Risk in 2050
Bryan County	30,391	49,863	6,369	12.8%
Camden County	50,693	92,825	10,986	11.8%
Chatham County	265,695	427,144	60,652	14.2%
Glynn County	79,821	123,524	28,038	22.7%
Liberty County	62,746	104,733	690	0.7%
McIntosh County	14,289	18,291	5,410	29.6%
Total	503,635	816,380	112,145	13.7%

Figure 3. Populations at Risk for Sea Level Rise in Coastal Georgia in 2050 at the Block Group Level.

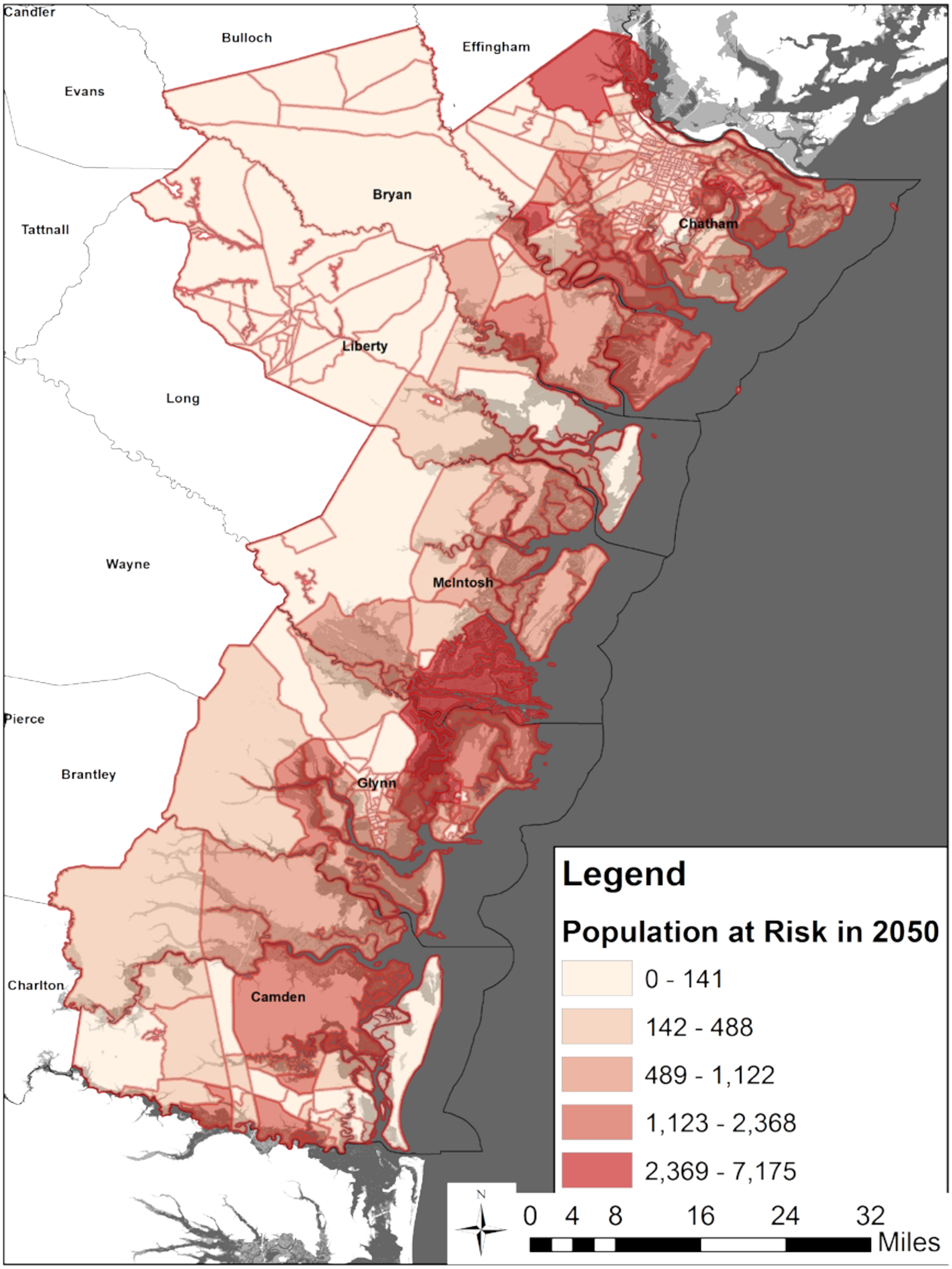

Table 2 shows the 2050 projected populations and populations at risk for inundation for the six counties in Georgia. In total, we find approximately 112,000 will be at risk for 1m of sea level rise in 2050 in Coastal Georgia representing 13.7% of the coastal population. Chatham and Glynn counties are poised to see the greatest numbers of population at risk, accounting for nearly 79% of the total populations at risk for sea level rise. Figure 3 shows the total populations at risk for sea level rise by block group and Figures 4 and 5 show more detailed maps of Chatham and Glynn counties. The areas of these counties with the greatest concentration of block groups, indicative of downtown areas and also the old city cores, show the least risk of inundation. It seems that Coastal Cities are founded at some of the highest elevations within a county. This is true for the county seats of Camden, Chatham, Glynn, and McIntosh counties. The populations at risk also do not follow a natural progression of risk inland i.e. an area that is 5 miles inland could be at less risk than area that is 20 miles inland.

Discussion

Human-natural systems interfaces are important for understanding a host of ecological processes including wildfires (Syphard et al. 2007), forests and public land use (Hammer et al. 2009), and of course sea-level rise (Grubler and al 2007). Additionally, there is a growing need to understand the population dynamics associated with climate change(Hugo 2011) with local communities increasingly burdened with creating adaptation and mitigation policies (Lutsey and Sperling 2008, Titus et al. 2009) for sea-level rise. Oftentimes, research to aid these local areas focuses on the locales at risk of sea-level rise (Craft et al. 2009, Wu, Yarnal and Fisher 2002, Gesch 2009) or combine current population estimates with future scenarios (Lutz et al. 2007, Plyer, Bonaguro and Hodges 2010, Rowley et al. 2007). Most of this work also focuses on geographic scales that are far outside the bounds of sea-level rise risks, choosing to focus on National, regional, and even county scales, assuming all populations in those geographies are at equal risk. Lacking adequate methodologies for projecting small areas, scholars are often left with projections of sea-level rise at the scale of 10 meter by 10 meter pixels and population projections at the county level. Curtis and Schneider (Curtis and Schneider 2011), utilizing a county level cohort-component projection, project that 20 million people will be affected by sea-level rise in parts of Florida, California, New Jersey, and South Carolina by 2030, for instance.

This type of approach to modeling future population scenarios is quite problematic. The assumption that the total population in any given coastal county is at equal risk of sea level rise inundation renders the point of utilizing sea-level rise modeling rather moot. Determining the areas at risk is rather redundant since it doesn't matter if 20% of a county is at risk or 80% of a county is at risk when the total projected county level population is considered at risk regardless of the encroachment of the sea. If that is our working assumption, than a simple county level population projection of coastal counties will suffice in estimating the populations at risk of sea level rise inundation – no coastal modeling is required. Currently, 39% of the United States' population resides in Coastal areas. With just the working assumption that all coastal populations share equal risk of sea level rise, we can easily deduce that 121 million people in the United States are currently at risk of sea level rise. However, we know that inundation risk is *not* equally shared across coastal populations. While inundation risk can be highly localized, other hazards that are the byproduct of sea level rise are potentially county wide. These include flood plains, storm surges, and changes in highest-high high tides, amongst others (Nicholls and Cazenave 2010, Burton 2012).

Coastal Georgia and Coastal South Carolina share many geophysical and population characteristics. The respective major cities in both states, Savannah and Charleston, are oftentimes lumped together in travel guides (Sullivan 2007), both coastal areas are home to Gullah populations (Pollitzer 2005), the system of barrier islands are both called sea islands (Jones-Jackson 2011), and both states share similar salt marsh estuaries (Odum 1988). Future projections also show similar population sizes with coastal South Carolina projected at 722,000 people by 2030 (Curtis and Schneider 2011) and Georgia with 816,000 people by 2050. Yet the total projected populations at risk, despite these similarities, are markedly different. Previous projections for South Carolina find all 722,000 people at risk for inundation while we find 112,000 people at risk in Georgia. Scale seems to play a decisive factor in these differences (Herod 2011), and specifically the scale at which population projections are undertaken. By better approximating the scale of sea level rise with population projections, we are better able to project the future populations at risk for inundation.

The method presented represents a methodological step forward for small area population projections by crafting a projection methodology that unifies geographies across space and time and projection and estimation methodologies. Given the strong assumptions regarding the PPHU variable and the variability of ACS estimates, the similarities between the proposed method and conventional projection methodologies speaks to the strength and value of a method that can be employed across census designated scales for both forecasting and backcasting. Despite these results, there are important limitations with this method regarding the components of projected populations. It is clear that this methodology can project total populations, but the ability to project components (age/sex/race) is left unexplored. Further refinements of this method to project the components of a population would be a fruitful endeavor in future demographic research. Previous scholars have questioned whether projected populations will remain in inundated areas (Curtis and Schneider 2011) and whether adaptation and mitigation policies will be employed thus shaping future population scenarios along unknown future public policies (Wilson and Piper 2010, Gifford 2011). We share the same questions but recognize the need for baseline scenarios to both help shape these public policy decisions and to craft ever better demographic scenarios. Much work is still to be done in understanding the demographic implications to environmental phenomena; this is but one piece in the puzzle.

It should also be noted that the analysis contained herein utilizes the basic bathtub model for sea level rise, the accuracy of which has been questioned by ecologists and systems modelers (Murdukhayeva et al. 2013, Parkinson and McCue 2011) and has been critiqued as being too simplistic. The authors of this paper share this critique and welcome future projections that can be utilized alongside a more comprehensive set of sea level scenarios. However, with regards to population projections, more complicated methodologies do not always yield more accurate results (Smith et al. 2001, Swanson and Tayman 2012b). The results contained herein should not necessarily be dismissed due to the simplified approach to sea-level rise modeling.

Despite these limitations, the successful application of this project method is quite promising for a number of areas for scholarly inquiry – not just for sea-level rise. Future populations residing in flood plains, hurricane tracks, tornado or earthquake prone areas, and so on have the potential to be modeled and understood. Additionally, past population trends of sub-county areas are now possible to be understood at a level of detail that has been unheard of in the demographic literature. The leap from housing units to population should not be underestimated and through the combination of this method with a whole host of other processes appears near limitless.

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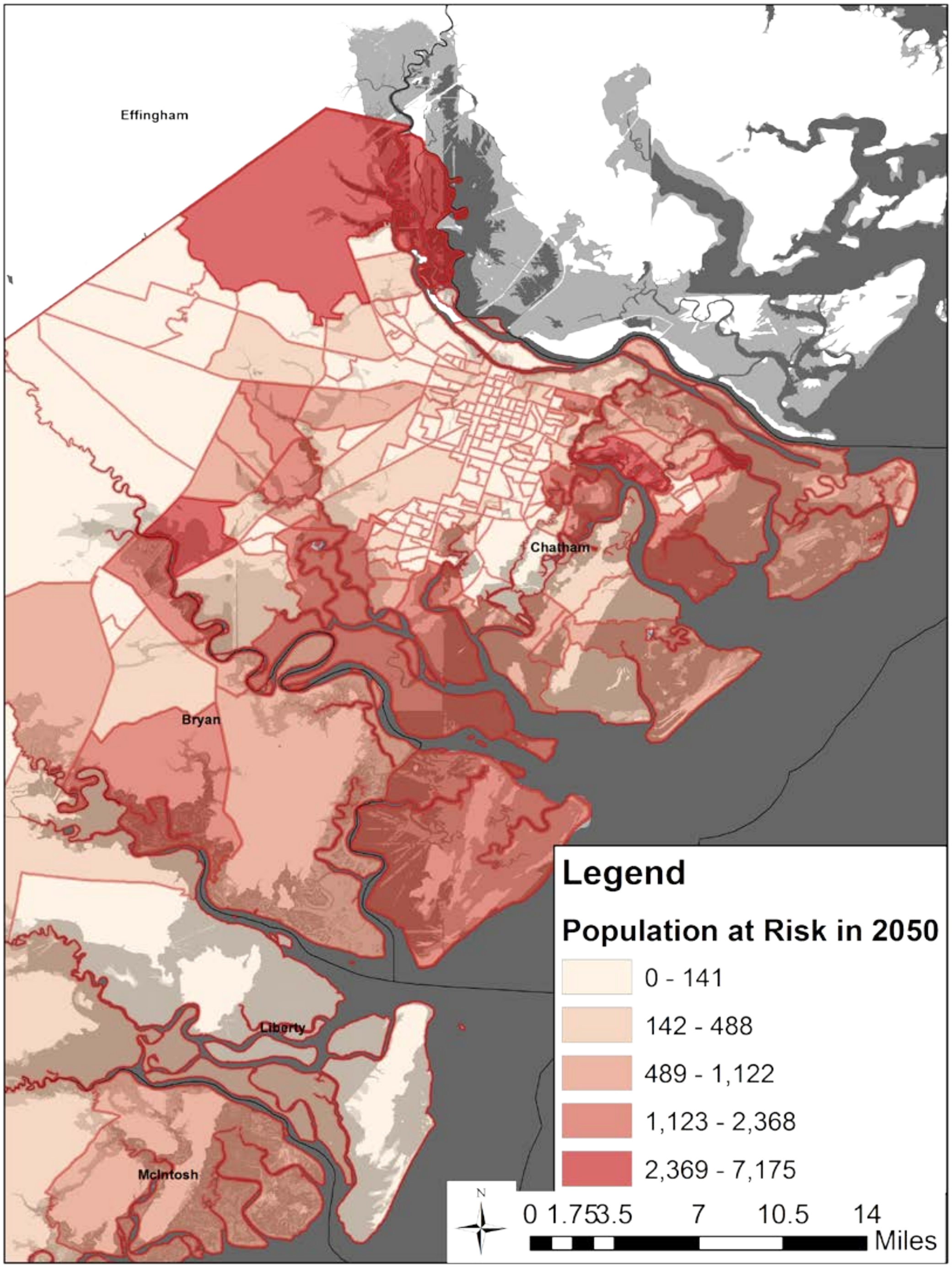
Tables and Figures

Figure 4. Chatham County and surrounding area's projected populations at risk. Notice the large number of block groups in down town Savannah that are spared from sea level



rise.

Figure 5. Glynn County and surrounding area's projected populations at risk. The densest block groups are also the ones with the least number of future populations at risk.