ROUGH SEAS AHEAD:

NAVIGATING THE INEQUALITIES OF FUTURE SEA-LEVEL RISE

by

Robert Dean Hardy

(Under the Direction of Marguerite Madden)

ABSTRACT

With anthropogenic climate change poised to accelerate sea-level rise this century, millions of everyday lives and livelihoods are predicted be unevenly vulnerable to this social-ecological change. In this dissertation, I examine both outcome and contextual vulnerability by applying an integrative approach as my research design framework to navigate the problem of inequalities related to future sea-level rise. To apply mixed methods and plural epistemologies that move from the global to the local scale, I examined the inequalities of sea-level rise via three routes: (1) a global scale, quantitative analysis of country responsibility and risk related to multi-millennial sea-level rise; (2) a regional scale, quantitative analysis of spatiotemporal variation in risk to sea-level rise through the year 2050 for coastal Georgia; and (3) a comparative case study of two barrier island communities off the coast of Georgia, Tybee and Sapelo Islands, to show how race shapes vulnerability to sea-level rise. The are three primary findings for this dissertation: (1) our assessment of future populations' social vulnerability to sea-level rise inundation indicates that the number of people at risk to sea-level rise on Georgia's coast is more than double previous estimates that were based on 2010 population data; (2) acknowledgement and acceptance – by the professional community working on sea-level rise – of race as a process of enabling or constraining meaningful engagement, rather than as a mere demographic category, will help mitigate vulnerability for underrepresented communities; and (3) investigating the vulnerability to sea-level rise of a culture and/or place through narrative analysis of its stories and histories is strengthened by modeled projections of sea-level rise inundation and population change.

INDEX WORDS: Social-ecological vulnerability, Risk, Hazards, Sea-level rise, Climate change, Racism, Racial inequality, GIS, Coastal Georgia, Tybee Island, Sapelo Island

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DEDICATION

I dedicate this dissertation to all of Georgia's coastal residents, especially those who participated in this project through interviews and conversations, whose futures are uncertain under climate change. I could not have accomplished this project without them having shared their social and environmental knowledge of home with me. Thank you all.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The effects of anthropogenic climate change, especially human-driven sea-level rise (Slangen et al. 2016), are expected to have uneven impacts among nations (Althor, Watson, and Fuller 2016; Chapter 2), within nations (e.g., Gaillard 2012; Hauer, Evans, and Mishra 2016), and within regions and communities (e.g., Collins et al. 2013; Miller Hesed and Paolisso 2015). It is increasingly likely that Earth will experience more than one meter (and possibly two meters) of sea-level rise by the year 2100 (DeConto and Pollard 2016; Hansen et al. 2016). This could potentially directly affect as many as 13.1 million people in the US (Hauer, Evans, and Mishra 2016) projected to be living less than 1.8 m above the high tide by the year 2100. It could indirectly affect as much as 12% of the global population projected to be living in the low elevation coastal zone (the area less than 10 m above the high tide) by the year 2060 (Neumann et al. 2015). Given such projections, adaptation will be necessary for coastal populations by mid- and end-of-century time periods.

Adaptation to sea-level rise, whether it is for adaptation-in-place or relocation, will require planning for the expected (and unexpected) social and environmental changes that will occur as seas continue rising in the future. Critically, the impacts will be most uneven across social difference (Wisner, Gaillard, and Kelman 2012). To achieve socially-just adaptation planning scenarios for climate change and to fully comprehend the changes projected to occur from the social-ecological phenomenon of sea-level rise requires investigations that apply mixed methods as well as plural epistemologies (including non-scientific ways of knowing and being;

e.g., Maldonado 2014; McCreary and Milligan 2014; Miller Hesed and Paolisso 2015; Rice, Burke, and Heynen 2015). In this dissertation, I apply an integrative approach to examine the uneven effects and inequalities projected for future sea-level rise across scales, methods, epistemologies, and social difference with a primary focus on coastal Georgia.

Purpose of the Study and Major Findings

In coastal Georgia, seas have risen at an average rate of 2.6 mm yr^{-1} since 1935 (Sweet et al. 2014), 1.5 times *faster* than the average global rate (IPCC 2013). Recent studies of Georgia estimate that seas may rise another quarter meter by 2030, tripling the chance of a one-meter high flood event before 2030 to 83% (Strauss, Tebaldi, and Ziemlinski 2012). This will increase the “nuisance flooding” issues that are already occurring (Figure 1.1; Sweet et al. 2014), but more importantly, these observations suggest that coastal Georgians’ livelihoods will be increasingly exposed to sea-level rise effects well before century’s end, including the expected impacts of higher magnitude floods due to storm surge (Little et al. 2015). However, these impacts will be uneven across social difference, as hazards geographers have argued since the 1970s that natural disasters are not natural, but are instead a result of social conditions (O'Keefe, Westgate, and Wisner 1976).

Hazards scholars theorize that social vulnerability indicators include minority status, poverty, and educational attainment (Cutter, Boruff, and Shirley 2003; Wisner et al. 2004), which comprises many of Georgia’s coastal residents who live in low-income households, have limited education, and/or are racial minorities (US Census 2012). Among the more than 500,000 coastal residents, 44% are racial minorities including 34% black, 6% Hispanic or Latin@, 2% Asian, and 2% Native, other, or multiracial (US Census 2012). Many (18%) earn incomes below the poverty line, which is $23,492 for a family of four, and 39% earn less than twice the poverty threshold (US Census 2012). Of those 18 years or older, 12% did not complete high school and 32% have only a diploma or its equivalent (US Census 2012). Thus, 32-44% of Georgia's coastal residents fit the theoretical indicators of social vulnerability as minorities, low-income, or having attained only a high school education. Furthermore, approximately 23,000 livelihoods are directly dependent on Georgia's ocean economy sector (NOAA 2012b).

Despite this high proportion of socioeconomic characteristics that indicate being more socially vulnerable, Census-based model findings show that coastal Georgia has only moderate levels of social vulnerability to sea-level rise when assessed at broad scales (Emrich and Cutter 2011; Strauss et al. 2014), which corresponds with geographers findings that most residents in low-lying coastal cities of the US South are affluent white people (Ueland and Warf 2006). Yet, such models are limited in their analysis of vulnerability as they operate "from above" and equally weight vulnerability indicators, such as age and race. As a result of scale restraints and a focus on inundation and not on everyday experiences, Census-based models underplay the role of race in vulnerability's ongoing formation in Georgia. They omit the social structures and processes affecting livelihood flexibility and the everyday practices of coastal Georgia's marginalized social groups; groups that often possess limited power to access social, political, and economic resources for adaptation (Wisner et al. 2004; Gaillard et al. 2014). Through a mixed methods and plural epistemological approach, I demonstrate how an analysis that includes both model-based and qualitative investigations improves understanding of how vulnerability to sea-level rise arises and is continuously reproduced.

Broadly, in this dissertation I asked: *How can quantitative and qualitative methods be combined to produce more robust analyses of uneven vulnerability to sea-level rise*? To facilitate answering this broad question and to address the gaps between model-based and qualitative approaches in current scholarship, I asked three more specific questions:

(Q1) Who do quantitative models indicate as at risk to sea-level rise in coastal Georgia?

(Q2) What is the role of race in shaping vulnerability to sea-level rise in coastal Georgia?

(Q3) How do ethnographic modes of inquiry articulate with model-based, spatial examinations of vulnerability to sea-level rise?

To investigate these questions, I applied the methods and analyses outlined in Table 1.1 to the study site of coastal Georgia. I review the methods and analyses in more detail in the Methods and Objectives section below and provide specific answers to these questions in Chapter 6, but first I present the major findings for each question.

In examining Q1, our assessment of future populations' social vulnerability to sea-level rise inundation indicates that the number of people at risk to sea-level rise on Georgia's coast is more than double previous estimates that were based on 2010 population data. By innovatively combining techniques from demographic modeling and sea-level rise inundation modeling, we increase the robustness and utility of evaluating populations at risk to sea-level rise for adaptation planning and policy purposes.

For Q2, in order to create successful adaptation projects that lower vulnerability of marginalized groups, I contend that researchers and practitioners working on the impacts of sea-level rise need to consider the social, cultural, and political context within which environmental change is taking place. On Sapelo Island, Georgia, I found that acknowledgement and acceptance of race as a process that can enable or constrain meaningful engagement – rather than as a mere demographic category – by the professional community working on sea-level rise will help mitigate vulnerability in underrepresented communities.

Question 3 called for not only mixed methods, but an integrative approach employing a plural epistemology research design, for which I found that investigating the vulnerability to sea-level rise of a culture and/or place (Sapelo Island, in this case) through narrative analysis of its stories and histories is strengthened by modeled projections of sea-level rise inundation and population change. Conversely, ethnographic inquiry placed the modeled social characteristics back in the racialized landscape of Sapelo Island, revealing the entangled processes of how vulnerability is an ongoing process related to changing social and ecological conditions.

Study Site

My dissertation research is multi-scalar, extending from the global to the local. Chapter 2 focuses on the global scale, but Chapters 3 to 5 are based on coastal Georgia (Figure 1.2). The region of the Georgia coast extends linearly approximately 160 km from its northern section where the Savannah River flows into the sea to the south where the St. Mary's River empties the tannin-rich, tea-colored waters of the Okefenokee Swamp into the Atlantic Ocean on the border with Florida. Within this coastal zone are hundreds of kilometers of shoreline that sinuously wind around approximately 145,000 hectares of tidal wetlands; wetlands that include fresh, brackish, and salt marshes as well as tidal cypress swamps located up the numerous rivers that have names like Altamaha, Ogeechee, and Canoochee. This area's ecological significance stems, in part, from comprising nearly one-third of all the salt marsh found on the US eastern seaboard offering numerous ecosystem services to the area (Figure 1.3; Craft et al. 2009; Titus et al. 2009). The salt marshes are maintained by the large semi-diurnal tidal range of over two meters, with waters ebbing and flowing twice daily. Rising seas will likely change not only the life of the tidal wetlands, but the livelihoods and rhythm of daily life.

Methods and Objectives

In this dissertation, my main objective is to integratively navigate multiple forms of inequality that are expected to emerge due to future sea-level rise. Many geographers have called for more integrative approaches using mixed methods, arguing that qualitative case studies both broaden and deepen the understanding gained from quantitative-based modeling assessments that, by virtue of design, often merge complex phenomena into simple algorithms and indicators (O'Brien et al. 2004; Kwan and Ding 2008; Schmidtlein et al. 2008; Cope and Elwood 2009). Thus, my dissertation takes a mixed methods approach by including modeling of sea-level rise forecasts and social vulnerability, semi-structured interviews and participant observation with coastal residents, and an iterative and reflexive qualitative geographic information systems (GIS) analysis to achieve the three research objectives outlined in Table 1.1.

For Chapters 2 and 3, methods included projections of sea-level rise and populations along with the respectively associated physical inundation exposure and social vulnerability models, which allow for identifying spatial distributions of inundation as well as risk of populations over large geographic areas (e.g., Cutter, Boruff, and Shirley 2003; Emrich and Cutter 2011; Martinich et al. 2013). For our analysis in Chapter 2, we spatially modeled sea-level rise inundation exposure for countries at the global scale and compared this to each country's responsibility for global sea-level rise. Our data included a recent comprehensive assessment of greenhouse gas emissions by countries over the period 1850 to 2100 (Ward and Mahowald 2014) as well as country boundaries (Kelso and Patterson 2010), land movement (Peltier 2004), and global elevation (Jarvis et al. 2008; Amante and Eakins 2009). To forecast land exposure of countries due to multi-millennial sea-level rise, we applied a semi-empirical estimate for the relationship between global temperature and sea level (Levermann et al. 2013).

In Chapter 3, we investigated question one in Table 1.1 regarding risk to sea-level rise for coastal Georgia populations. First, we applied US Census tract data (US Census 2010; US Census 2012) to model projections of populations with the cohort change ratio and demographic metabolism methods(Swanson, Schlottmann, and Schmidt 2010; Lutz 2012). Next we spatially analyzed indicators of social vulnerability with the Social Vulnerability Index method as well as geographically-weighted principal components analysis (Cutter, Boruff, and Shirley 2003; Harris, Brunsdon, and Charlton 2011). To assess inundation exposure for coastal Georgia, we first modeled local sea-level rise out to 2050 by applying the same greenhouse gas emissions data from Chapter 2 to a semi-empirical sea-level rise projection model (Vermeer and Rahmstorf 2009) and locally-adjusting three sea-level rise forecast scenarios from the US National Climate Assessment following a previous approach (Parris et al. 2012; Tebaldi, Strauss, and Zervas 2012). We identified the coastal Georgia population at risk to sea-level rise in the year 2050 by combining the social vulnerability and physical inundation exposure assessments using a bivariate, 3-tiered classification system.

To examine the role of race in vulnerability to sea-level rise (Table 1.1, Q2) in Chapter 4, I used the methods of semi-structured interviews and participant observation on Tybee Island and Sapelo Island located along Georgia's coast. Interviews offer qualitatively rich, face-to-face opportunities for researchers to have insights and fill gaps in knowledge that other methods, such as modeling of census data, do not reveal (Dunn 2013). Participant Observation grounds the researcher in a place and adds contextual understanding and complementary evidence to more structured data collection techniques, such as interviewing (Kearns 2013). I conducted nine months of fieldwork (three on Tybee and five on and one near Sapelo) and interviewed 40 coastal residents in 34 interviews about their knowledge and understanding regarding vulnerability to sea-level rise. I also held one interactive workshop on Sapelo where I focused the discussion around sea-level rise and vulnerability of the community. I carried out nearly 100 hours of participant observation at over 30 events including, for example, church services, environmental group meetings, as well as city council and county commission meetings. Of the interview1s, I audio recorded and transcribed 26 of them while I wrote-up the remaining eight as field notes after the fact. This totals to over 30 hours of face-to-face interview time. To analyze the data collected from the interviews as well as my field notes from participant observation and the workshop, I employed narrative analysis, specifically focusing on the thematic analytic technique in order to categorize interviewee responses as well as my field notes based on participant observation data in their narrative context (Riessman 2008). Categories for thematic analysis included knowledge relating to climate change, sea-level rise, and the environment, race and racial inequality, and community vulnerability in general (i.e., vulnerability to other hazards such as storm surge).

In Chapter 5, I addressed how the previous approaches articulate with each other (Table 1.1, Q3). I applied a comparative analysis to the results from Chapters 3 and 4 to identify the strengths and limitations of not just quantitative GIS-based maps and qualitative analyses of vulnerability to sea-level rise, but moreover positivist and constructionist worldviews of GIScience and political ecology, respectively, in geography . Specifically, I reflexively compared the spatial population projection and inundation exposure data along with participant narratives of vulnerability and observations of the landscape, including my own observations. This comparison is not explicitly of the subfield of qualitative GIS, but was influenced by it, as its scholars contend that, "[d]isplaying quantitative spatial data in a variety of ways may reveal patterns, and statistical analysis may reveal correlations, but it is often the case that explanation (and thus theory building) is grounded in the experiences of real people living through specific conditions and they are in many ways the `experts', even if their explanations seem to be at odds with other sources of data" (Knigge and Cope 2006, 2028). I argue for more plural epistemology research design in geography that seeks to be integrative – focusing on the process and not attempting to transform data types – and demonstrate the effectiveness of this approach for making studies of vulnerability to sea-level rise more robust.

<u>Theoretical Framework</u>

To accomplish this mixed methods and plural epistemologies project, my dissertation was theoretically influenced by previous work on integrative approaches (Hirsch et al. 2013). Integrative research requires developing and maintaining scholarship as an "agile scientist" (Welch-Devine et al. 2014) in a number of ways. *To be integrative* means to acknowledge the importance of the historical roots and contemporary theory of established disciplines, and to be agile enough to thrive on the productive tension presented by multiple, often incommensurate, perspectives when working with a diversity of people. On the other hand, *to do integrative research*, means to actively listen and to "appreciate others' value systems" (Petriello and Wallen 2015, 1549), including the values of those outside of the academy and traditional disciplinary ways of thinking. Taken further, it means engaging with multiple methods, theories, and perhaps more importantly other epistemologies and even ontologies (e.g., McCreary and Milligan 2014; Moon and Blackman 2014). To be integrative and do integrative research simultaneously means avoiding the politics of dismissal and defensiveness, while not avoiding self-reflective critical thinking or external critique (especially other disciplinary and non-academic forms). Put simply, it means respecting other ways of thinking and being in the world.

As the overarching theoretical framework in my dissertation, I follow others' conceptual framings (O'Brien et al. 2007; Birkenholtz 2012) to examine vulnerability to sea-level rise across methodology and epistemology by applying both model-based *outcomes* (i.e., impact) and process-based *contextual* (i.e., access) approaches. While the former is typically aimed at informing policy and developing generalizable research findings, the latter emphasizes the role of local social power relations, drawing much from the fields of political ecology and nature-society studies (Birkenholtz 2012). For the outcome approach, I model risk to sea-level rise inundation at global and regional extents to identify inequalities at these scales (see literature review for further details on the relation of risk and vulnerability). For the contextual approach, I acknowledge the role that structural and colorblind forms of racism (Bonilla-Silva 1997; Omi and Winant 2014) play in vulnerability's ongoing formation. Consequently, I explicitly investigate how race affects vulnerability to sea-level rise through a case study of Georgia barrier island life. This framing with particular attention to race is meant to address the call that as human geographers, "[o]ur traditional emphasis on mapping and counting needs to be complemented by research that seeks to understand what race means to people and *how racism shapes lives and places*" (Pulido 2000, 33, emphasis added). To tie these two together, I use qualitative GIS as a conceptual framework and conduct a reflexive meta-analysis of each approach to analyzing vulnerability.

<u>Chapter Summaries</u>

The first empirical chapter (Chapter 2) serves two purposes in this dissertation. First, it positions me as a scholar of climate science, particularly sea-level rise, through requiring rigorous engagement with greenhouse gas emissions data and sea-level rise models. Rather than being a social scientist who simply reads and writes about sea-level rise, I have firsthand experience modeling the effects of anthropogenic greenhouse gas emissions on both twenty-first century and two millennium projections for sea-level rise at the country level; what are respectively called transient and committed sea-level rise. Second, and more to the point of assessing inequality related to sea-level rise, in this chapter we demonstrate country-level inequalities projected for responsibility and risk regarding inundation due to rising seas. Applying a semi-empirical model of sea-level rise (Vermeer and Rahmstorf 2009) as well as the relationship for the multi-millennial response of sea level to country-level greenhouse gas emissions data (Levermann et al. 2013; Ward and Mahowald 2014), we found that those countries who are most responsible for sea-level rise are also predicted to be the most at risk (measured as absolute area of land lost due to inundation). We concluded that this serves as an incentive in the policy arena for these countries to become the most motivated to act on climate change. The US ranks among the top two countries for responsibility and risk, which has implications for the future of the Georgia coastal region where I focus the remainder of the research in this dissertation.

In Chapter 3, we advance models of social vulnerability, specifically the Social Vulnerability Index (SoVI; Cutter, Boruff, and Shirley 2003), by applying two innovative techniques. First, we project regional populations for coastal Georgia's US Census tracts by employing a theory of socioeconomic change called demographic metabolism (Lutz 2012). Combining this with a standard method from demography, the Hamilton-Perry method (Swanson, Schlottmann, and Schmidt 2010), we are able to project population characteristics including poverty status, educational attainment status as well as race, ethnicity, and age data out to the year 2050. This allows us to compare future social vulnerability of populations with future sea-level rise forecasts. Our second innovative technique draws on the theory of spatial non-stationarity (Fotheringham, Brunsdon, and Charlton 2002) to examine how the spatial relationship of the socioeconomic indicators of social vulnerability changes using geographically-weighted principal components analysis (Harris, Brunsdon, and Charlton 2011). We find that while the total population that could be directly affected by mid-century due to sea-level rise increases significantly above assessments of the current population, the percentage of the populations living in tracts with elevated levels of social vulnerability increases significantly.

Shifting away from modeling and towards ethnographic inquiry informed by vulnerability to hazards and critical race theories, in Chapter 4 I interrogate the role that race plays in producing social-ecological vulnerability to sea-level rise through a (weighted) comparative case study of two barrier island communities off the coast of Georgia, Tybee Island and Sapelo Island. Tybee is a predominantly white population of approximately 3,000 residents, a suburb of sorts of the greater metropolitan area of Savannah, Georgia. Whereas Sapelo is 97% owned and managed by the State of Georgia's Department of Natural Resources (DNR) and has one historic community called Hog Hammock with a majority population of African Americans who call themselves Saltwater Geechee. The island's total population is approximately 69 people composed of researchers, DNR staff, and 46 Hog Hammock residents who are full or part time. Based on narrative analysis of 34 interviews and participant observation field notes, I argue that structural and colorblind forms of racism further exacerbate barriers to engagement with an underrepresented community and chances of alleviating vulnerability to sea-level rise through adaptation planning. These barriers, elaborated on in the chapter, include a colorblind problem definition, worry capital allocation, different discourses of environmental/climatic change, and strained historical relations.

In Chapter 5, I conduct a comparative analysis of Chapters 3 and 4, arguing that the different epistemological framings of outcome and contextual vulnerability studies (Chapters 3 and 4, respectively) each offer insights unavailable through the other. I make a case for a methodological framework that allows the researcher to juxtapose these seemingly incommensurate analyses, and to reveal more nuance for how and why vulnerability to sea-level rise comes about and persists. I compare and contrast the strengths and limitations of each approach for analyzing the following: (1) social-ecological spaces, (2) place-based power relations, (3) predictive power, (4) key social characteristics, and (5) replicability and normative application of results. I contend that this plural epistemology research design improves the robustness of the interpretation of vulnerability to sea-level rise along the Georgia coast. Chapter 6 concludes the dissertation with a summary of the findings as they relate to the original objectives and a reflection on the integrative approach that I took.

Literature Review

Vulnerability to Hazards

Early hazards approaches posited uneven effects from disasters as related to risk, or the statistical likelihood of exposure to physical disturbances, such as hurricanes and floods (Blaike et al. 1994). However, recognition by scholars that impacts were unevenly distributed across social difference led to a critical turn in hazards theory, which contended that it is *marginalized* social groups that are more affected by hazard events (O'Keefe, Westgate, and Wisner 1976; Hewitt 1983; Watts 1983b; Blaike et al. 1994). All of these scholars concur that there is no such thing as a “natural” disaster, agreeing with the contention that “the contours of disaster and the difference between who lives and who dies is to a greater or lesser extent a social calculus” (Smith 2006, 1). The root causes of marginalized people’s unsafe conditions are a result of dynamic pressures, including social, economic, and political forces (Wisner et al. 2004). Much of this move towards the social domain in hazards studies informed studies of environmental racism and environmental justice, which have found that marginalized social groups were placed at the fringes environmentally as well, being forced to live in the most hazardous places (e.g., Bullard 2000; Pulido 2000; a point I return to in the Climate Justice section). Despite ample field evidence identifying common proxies for social vulnerability including race, class, gender, and age (e.g., Wisner, Gaillard, and Kelman 2012; Birkmann 2014), "the dominant paradigm still ignores the underlying societal risk factors" (Gaillard et al. 2014, 14).

Scholars contest the degree to which the "social calculus" factors into social vulnerability. Some scholars contend that "social vulnerability may be viewed as one of the determinants of biophysical vulnerability" (Brooks 2003). Others suggest that natural vulnerability partially determines socioeconomic vulnerability (Klein and Nicholls 1999), while some scholars suggest a complete separation of social and biophysical vulnerability, arguing for a "social construction of vulnerability, a condition rooted in historical, cultural, social and economic processes that impinge on the individual's or the society's ability to cope with disasters and adequately respond to them" (Cutter 1996, 533). However, "[s]earching for the 'right' theory or model for vulnerability is reminiscent of the prolonged sterile debate over the 'right' political model for community politics until it finally dawned that there was in fact no single correct model" (Kasperson et al. 2005, 247).

The above differences are attributed to different epistemological commitments and worldviews of researchers, which has led to the development of multiple useful frameworks for analyzing vulnerability (O'Brien et al. 2007). For example, Füssel (2007) delimits five approaches including risk-hazard, political economy, pressure-and-release, integrated, and resilience; while Wisner (2004) delimits four approaches including demographic, taxonomic, situational, and contextual and proactive. Such diversity leads to an assortment of confusion and challenges for comparing studies (Kasperson et al. 2005; O'Brien et al. 2007). Fortunately, there are conceptual frameworks that synthesize the multitude of meanings around vulnerability.

Vulnerability studies in both environmental hazards and climate research can be generally classified in two ways. First are more normative or empiricist-driven approaches that examine “outcome vulnerability” through quantitative modeling and statistics and second are idiographic approaches that examine “contextual vulnerability,” drawing on political ecological methods such as ethnography and discourse analysis (O'Brien et al. 2007; Birkenholtz 2012). Outcome vulnerability research takes on a scientific framing and is "considered a linear result of the projected impacts of climate change on a particular exposure unit (which can be either biophysical or social), offset by adaptation measures;” whereas contextual vulnerability is "based on a processual and multidimensional view of climate-society interactions," and takes on a human security framing (O'Brien et al. 2007, 75-76). In short, outcome vulnerability is more concerned with informing policy and response to hazards while contextual vulnerability is most concerned with understanding why certain social groups are more vulnerable than others. In this dissertation, I juxtapose both types of vulnerability inquiries, arguing in Chapter 5 that this generates a more robust[1] explanation of how vulnerability occurs on the coastal landscape in relation to sea-level rise.

[1] By robust, I mean that the explanation for vulnerability is both more comprehensive and defensible, as it has the on-the-ground empirics collected during the contextual study while also having the broader regional perspective presented via the quantitative modeling approach. I expand on what I mean here more in Chapter 5.

As implied above, one's framing affects one's definition of vulnerability. The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability in terms of impacts as "the propensity or predisposition to be adversely affected" and continues that "[s]uch predisposition constitutes an *internal* characteristic of the affected element" (Cardona et al. 2012, 32; emphasis added). In contrast, aligned with the contextual vulnerability approach and taking a political ecology position, Oliver-Smith places vulnerability more broadly in the larger context of social forces and institutions, defining it as "the conceptual nexus that links the relationship people have with their environment to social forces and institutions and the cultural values that sustain or contest them" (2004, 10). Falling somewhere in the middle and employing a more human-environment interactions discourse, but firmly in the access vulnerability camp, Wisner et al. define vulnerability as "*the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard* (an extreme natural event or process)" (Wisner et al. 2004, 11, emphasis original). They suggest a generalized equation for understanding their proposed access model, which conceptually links risk with exposure and vulnerability:

risk [disaster] = hazard [exposure] x [social] vulnerability.

These varying definitions raise a fundamental question regarding the conceptualization of vulnerability in any study; is exposure internal to the definition of vulnerability, or is exposure external to social vulnerability? I contend that externalizing hazard exposure artificially decouples social and biophysical domains, which increases the challenge of informing policy and public understanding of why certain groups are more vulnerable to *specific* hazards. This understanding is critical for effecting change in social institutions, attitudes, and behaviors in order to mitigate vulnerability. While there are certainly generalizable and shared characteristics contributing to vulnerability across hazards and geographic space, "we can only talk meaningfully about the vulnerability *of a specified system to a specified hazard or range of hazards*" (Brooks 2003, 3, emphasis original). Below I argue that the increasing acceptance of human influences on the climate and ecosystems jibes with nature-society studies of assemblages, though with different framings. Nevertheless, this makes space for conceptualizing of sea-level rise as social-ecological.

The literature reviewed above demonstrates that in hazards geography, and hazards studies more broadly, two lines of inquiry persist that are often incommensurate regarding their epistemological commitments. However, employing one approach (e.g., the outcome assessment) and all of its requisite assumptions versus another (e.g., contextual assessment) and its assumptions does not preclude the researcher or research team from concomitant analyses, if dismissal of other ways of knowing can be suspended. In fact, in Chapter 5 I argue that a joint analysis and its associated tensions creates a more robust conceptual framework, and consequently an increased understanding of the object of inquiry.

Sea-Level Rise

Global mean sea level rose approximately 0.21 m between 1880 and 2009 (Church and White 2011). This occurred at an average rate of 1.2 ± 0.2 mm per year from 1900 to 1990 and accelerated to a mean of 3.0 ± 0.7 mm per year between 1993 and 2010 (Hay et al. 2015). The acceleration of sea-level rise has averaged about 0.01 mm per yr^2 and began over 200 years ago, rising only 0.06 m in the nineteenth century and 0.19 m in the twentieth century (Jevrejeva et al. 2008). Recent estimates have documented higher rates of sea-level rise at 4.4 ± 0.5 mm per year since 2010 due to increased rates of land ice loss and thermal expansion of ocean waters (Yi et al. 2015). Due to increased storage of water in land, these recent rates were slowed by as much as 0.71 ± 0.20 mm per year between 2002 and 2014 (Reager et al. 2016).

Sea-level rise is caused directly by multiple factors operating at different scales. At the local scale, these factors can include the effects of glacial isostatic adjustment, subsurface resource extraction, and gravity fingerprints[2] (Peltier 2004; Mitrovica, Gomez, and Clark 2009; Wang et al. 2012; Stammer et al. 2013; Dutton et al. 2015). At the global scale, there are four primary factors that influence rising seas: (1) thermal expansion of the ocean (a.k.a. steric changes), (2) melting polar ice sheets, (3) melting mountain glaciers and ice caps, and (4) changes in terrestrial storage (Domingues et al. 2008; Church et al. 2013). Since 1950, the dominant cause has been melting ice (Domingues et al. 2008), but in the past two centuries the prevailing cause for accelerated global sea-level rise was due to steric changes (Jevrejeva et al. 2014). In the long-term (multi-millennial time frame), it is ice sheets that will contribute the most to rising seas (Levermann et al. 2013). Alarmingly, two new estimates for global mean sea-level rise suggest that the Earth may experience a multi-meter rise this century if the West Antarctic Ice Shelf collapses (DeConto and Pollard 2016; Hansen et al. 2016).

How sea-level rise is forecast is typically with either process-based models such as with the IPCC approach (Church et al. 2013), or semi-empirical models that employ paleological and historical records of temperature-to-sea-level measurements to inform forecast models (Vermeer and Rahmstorf 2009). While semi-empirical models of sea-level rise are defendable in the short-

[2] Glacial isostatic adjustment refers to the movement (or settling) of land on a continental scale as a result of the released weight from the melting of glaciers from the last ice age over 10,000 years ago. Subsurface resource extraction refers to the removal of water and other mineral resources such as oil from subterranean geological environments, which leads to the subsidence of the land above the resource extraction sites. Gravity fingerprints refer to the forces exerted by the mass of the polar ice sheets on the water of the ocean basin pulling the water towards the polar regions and away from the equatorial region (see references for more details).

term (maybe 50 years; e.g., Tebaldi, Strauss, and Zervas 2012), they are perceived as less dependable for century and longer forecasts by many (Clark et al. 2016). This has resulted in a range of forecasts for sea-level rise in the twentieth century, which are dependent on both the model being applied as well as the greenhouse gas (GHG) emissions scenario that is considered. One semi-empirical modeling approach estimates that as much as 0.75 to 1.9 m of sea-level rise above 1990 global mean sea level could be expected with the highest emissions scenario from the fourth IPCC report (Vermeer and Rahmstorf 2009). The latest process-based approach of the IPCC estimates a range of 0.28 to 0.98 m above the average global eustatic[3] level between 1986 and 2005 (Church et al. 2013). The US National Oceanic and Atmospheric Administration has generated a set of four scenarios based on a combination of best estimates from process-based and semi-empirical models as part of the U.S National Climate Assessment (Parris et al. 2012). These estimates range from 0.2 to 2.0 m above 1992 global mean sea level. These models all estimate forecasts of "transient" sea-level rise, but other studies show that Earth is likely already committed to sea-level rise of greater than a meter above the mean nineteenth century level.

There is a strong relationship between global temperature and global sea level (Dutton and Lambeck 2012; Muhs et al. 2012; Raymo and Mitrovica 2012). Evidence of this relationship informs physical models that estimate an average of 2.3 m of sea-level rise per 1 °C of surface warming over the next 2,000 years (Levermann et al. 2013). This previous research on multi-millennial sea-level rise allows for the translation of observed and projected warming estimates into ranges of global sea-level rise committment, what has been referred to as "locked-in" sea-level rise (Strauss, Kulp, and Levermann 2015a). Future sea-level rise will be affected by the

[3] Eustatic sea level refers to measurements of changes in global sea level caused by volume changes; for example from the addition of water via melting ice, or via thermal expansion.

degree of sensitivity in the climate system to warming from carbon emissions, which is reported by the IPCC as the likely transient climate response to cumulative carbon emissions (TCRE) at 1.6 °C (0.8 – 2.5 °C, two-thirds probability) per trillion tonnes[4] of C emissions up to two trillion tonnes (Stocker 2013). However, Gillett et al. (2013) observed an observationally-constrained TCRE of 1.3 °C (0.7 – 2.0 °C, 90% CI).

Applying an observationally-constrained TCRE (Gillett et al. 2013) to the multi-millennial response of sea level to global warming (Levermann et al. 2013), the Earth is already estimated to be committed to 1.5 m of sea-level rise above 19th century levels (Strauss 2013). In the long-term multi-millennial range, hundreds of coastal cities around the globe could be affected by long-term "locked-in" sea-level rise if global temperatures reach above 2 °C (Strauss, Kulp, and Levermann 2015b), and many cultural heritage sites lost (Marzeion and Levermann 2014). This previous work and that in Chapter 2 both demonstrate that it is not a question of *if*, but of *when* the world (and the focal area for this dissertation, Georgia) will experience a sea-level rise of more than one meter.

In the near-term, semi-empirical models offer a defensible approach for forecasting when rising seas could potentially directly affect the everyday lives of people (Vermeer and Rahmstorf 2009; Tebaldi, Strauss, and Zervas 2012). In the United States alone, as many as 13.1 million residents could be affected with 1.8 m of sea-level rise by the year 2100 (Hauer, Evans, and Mishra 2016). To connect the global to the local in this dissertation and to assess local risk to sea-level rise, we specifically apply the mean result from the semi-empirical model (Vermeer and Rahmstorf 2009) driven by modeled data on GHG emissions estimates for global warming (Ward and Mahowald 2014) – which is presented in Chapter 2 – as the middle of three sea-level

[4] A tonne is a metric ton equal to 1,000 kg or 2,205 lbs.

rise scenarios. The upper and lower bounds for Chapter 3's risk assessment are the National Climate Assessment's intermediate low and high scenarios locally-adjusted (Parris et al. 2012). The high scenario captures the potentially catastrophic sea-level rise for this century that would occur if the West Antarctic Ice Shelf collapsed (DeConto and Pollard 2016). Analyses of the direct impacts on populations become embroiled in questions of social justice and inequality. Sea-level rise is already leading to forced displacement in the US (Anderson 2016) and is expected to continue to displace US coastal residents, even threatening some culturally distinct groups (Shearer 2012a; Maldonado et al. 2013). In Chapter 4, I specifically examine the barriers to engagement for facilitating a "climate justice" approach with one culturally distinct group, the Geechee of Sapelo Island, a community of color.

Social-ecological Vulnerability

The extent of the social domain – specifically human influence – is expanding regarding its effect on the situation of a person or group. Vulnerability does not reside only in the social domain, or the interaction of the social *and* environmental domains (e.g., Emrich and Cutter 2011; Chapter 3). The influence of the social domain is manifesting itself through driving environmental change with ecological implications (i.e., shifts in biotic-abiotic relations) at unprecedented scales (Ellis and Ramankutty 2008). It is increasingly evident that vulnerability is produced via changing social and ecological conditions (e.g., Dooling and Simon 2012). When the term *social* vulnerability to a hazard event is investigated, the analyses must now heed these social drivers of environmental and ecological change by re-conceptualizing vulnerability as *social-ecological*. Nature-society scholars have long argued for the social-ecological or socio-natural framing (e.g., Castree and Braun 2001; Heynen, Kaika, and Swyngedouw 2006b; Goldman, Nadasdy, and Turner 2011b).

Collapsing the dualism of nature-society in on itself, Castree (2001) outlines three ways that nature is social. The first is that nature can only be known through the knower. The second pertains to engaging nature, or that "the physical opportunities and constraints nature presents societies can only be defined relative to specific sets of economic, cultural, and technical relations and capacities" (Castree 2001, 13). And the third involves remaking nature through allowing that the natural has become internal to social processes, but that society is concomitantly inside the natural. Thus, social natures are patchy assemblages of a plurality of people, politics, ecologies, and objects in a dynamic web of constant interaction (Castree and Braun 2001). This perspective overcomes much of the trouble imposed by an artificial nature-society dualism and poses challenges to methods and epistemologies that necessitate the dualism (such as with many outcome vulnerability assessments).

These patchy assemblages can be examined through a site ontology of social natures perspective (Meehan and Rice 2011). I contend that as climate change and sea-level rise are poised to push the apparent stability of patchwork assemblages into new spaces, it is important to "emphasize the situated *context* within which people and objects co-constitute social life, without articulating these relations through moments of 'social' or 'natural' influence" (Meehan and Rice 2011, 57). In other words, while thinking about relationships and directional forces is important and offers insight into understanding human-environment interactions under sea-level rise, emphasizing the situated context *over* the relationships affects how vulnerability and adaptation to sea-level rise are both perceived, analyzed, and understood. In this dissertation, I use this line of argument "at a distance" as a heuristic model (Figure 1.4) for thinking critically about the contextual processes of race relations in the broader context of global assemblages (Ogden et al. 2013) and anthropogenic climate change (Crutzen and Stoermer 2000) under rising seas.

While scholars have thoroughly critiqued the usage of the phrase "natural disaster" for decades, anthropogenic climate change as well as the introduction of the "Anthropocene" concept[5] has helped further facilitate cross-disciplinary agreement for how intricately interwoven social processes are within the environment, although with radically different epistemological framings (e.g., Steffen et al. 2011; Ogden et al. 2013). Consequently, an argument can be made that, in some hazards analyses, the assumption of purely "natural" or "environmental" hazards is overly simplistic, as not only are many ecosystems altered by human modifications (Ellis and Ramankutty 2008), but as a result of global scale anthropogenic forces hazard events are increasingly shown to have an "inextricable social integument" (Castree and Braun 2001). I argue that not only are natural disasters no longer "natural," but many broad scale natural or environmental hazards (e.g., hurricanes, heat waves, droughts, and rising seas) are no longer solely "environmental." This is not to say that non-human influenced hazard events no longer occur, just that the probability that a hazard is strictly environmental is becoming less likely.

Examples of the social in the environmental are becoming more common for hazard events, particularly as the effects of anthropogenic climate change are better understood. For example, the socially- and politically-motivated process of hydraulic fracturing in the US to meet "cleaner" energy demands (Finewood and Stroup 2012) may be driving not only higher frequencies of localized earthquakes (McGarr 2016), but also global warming in the long-term (McJeon et al. 2014; Staddon and Depledge 2015). Increased rates of global warming are leading to much warmer oceans (Abraham et al. 2013), which may result in higher frequencies of intense

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[5] The Anthropocene concept was introduced by Crutzen and Stoermer (2000) and proposed as the new geological epoch to follow the Holocene and begin sometime in the late eighteenth century. They contend that is allows for acknowledging the local-to-global scale effects of human activities on geological and ecological systems.

and destructive hurricanes (Mann and Emanuel 2006; Emanuel 2013). Despite improvements in resilience, economic losses from hurricanes have been increasing for which climate change may play a role (Hallegatte 2015). These losses are largely linked to more intense hurricane winds as well as higher storm surges, which are expected to worsen with higher seas due to global warming (Lin et al. 2012), for example, Hurricane Sandy caused $2 billion more in damages due to sea-level rise (Kulp et al. 2014).

Given that it is the social, cultural, and political decisions to burn fossil fuels that cause anthropogenic global warming, which in turn leads to rising seas, sea-level rise can be said to be a social-ecological phenomenon. For example, the anthropogenic portion of twentieth century sea-level rise ranged from 7 to 17 cm (Kopp et al. 2016) with anthropogenic forcing dominating it since 1970 (Slangen et al. 2016). Moreover, the "human fingerprint" of sea-level rise has led to a 67% increase in the number of US coastal flood events since 1950 (Strauss et al. 2016). In other words, the social integument of sea-level rise is steadily expanding. This requires reframing the impacts of sea-level rise as social-ecological.

Climate Justice

How forced displacement due to sea-level rise unfolds for coastal communities is expected to take on multiple forms over the coming decades, potentially with competing discourses of global versus local knowledges (e.g., Farbotko and Lazrus 2012; Nijbroek 2014) or traditional versus scientific knowledges (e.g., Bethel et al. 2014). In particular, uneven attention historically may lead to uneven adaptation planning resulting from narratives that overemphasize some places and cultures while minimizing others (Maldonado 2014; Orlove et al. 2014). Focusing on US tribal communities, Maldonado et al. (2013, 601) illustrate how sea-level rise adaptation planning is a human rights issue, citing "[f]orced relocation and inadequate governance mechanisms" as potentially leading to loss of culture and further injustices to already marginalized peoples.

More robust empirical evidence is still needed regarding the causal factors that lead to differences in livelihood choices and life opportunities as affected by climate change, differences that directly affect a person's or social group's vulnerability status (Gaillard et al. 2014). Studies that specifically examine the role of race in relation to environmental hazards are part of environmental justice scholarship. Based on many national and case studies, environmental justice research demonstrates the ubiquity by which people of color are disproportionately affected by environmental hazards including, but not limited to, toxic substance releases, poor water quality, and extreme weather events (e.g., UCC 1987; Bullard 2000; Pulido 2000; Pastor et al. 2006; Eligon 2016). As a human rights oriented field, "[*e*]*nvironmental justice embraces the principle that all people and communities are entitled to equal protection of environmental and public health laws and regulation*" (Bullard 1996, 493, emphasis original).

Human rights focused research on indigenous communities' vulnerability to sea-level rise has touched on race (e.g., Shearer 2012b) and other work has directly engaged with African American communities (Paolisso et al. 2012; Miller Hesed and Paolisso 2015). Yet, none of this scholarship has fully engaged with critical race theory regarding the effect of race on the making of vulnerability and its continued formation in relation to rising seas, especially in US coastal communities. Consequently, the gap between critical race studies and vulnerability to sea-level rise persists even though a number of studies have recently demonstrated the increased potential for harm to people of color from climate change related events (e.g., CBCF 2004; Leiserowitz and Akerloff 2010; Shepherd and KC 2015); what Gaillard (2012) calls "the climate gap." Such analyses extend the work originating in the field of environmental justice and critical race studies that show how racism operates through much more subtle means of structural (Bonilla-Silva 1997) and hegemonic (Pulido 2000) forms of racism.

Critical race theorists contend that race is a social fact, not an essence rooted in nature or illusory and invalid; and, it is not a mask for something else, being reducible to cultural difference, national identity, or class inequality (Omi and Winant 2014). And as a social fact, it is constantly being redefined through the process of racial formation, a "sociohistorical process by which racial identities are created, lived out, transformed, and destroyed" (Omi and Winant 2014; 109). Given how structural and colorblind forms of racism facilitate the persistence of white privilege (Bonilla-Silva 2013; Omi and Winant 2014), and the effect this has on livelihood choices and life chances (Gaillard 2012), Chapter 4 focuses specifically on this gap to show how these forms of racism work to reproduce racial inequalities in sea-level rise adaptation planning.

Table 1.1. Research questions with corresponding objectives, methods, and analyses.

Research Question	Objective	Methods	Analyses
Q1: Who do quantitative models indicate as at risk to sea-level rise in coastal Georgia?	Identify and map socially vulnerable populations and their exposure to sea-level rise inundation in coastal Georgia to assess risk	Population projections using cohort change ratio with US Census tract data Modeling & mapping of current and future social vulnerability indicators Modeling & mapping of sea-level rise inundation exposure forecasts	Principal components analysis of social vulnerability indicators Spatial risk analysis of census tracts for both land inundation exposure and social vulnerability indices
Q2: What role does race play in shaping vulnerability to sea-level rise in coastal Georgia?	Determine if and how race affects vulnerability to sea-level rise in coastal Georgia	Interviews with coastal residents stratified by race Participant observation of livelihood activities and public meetings	Narrative analysis of interview transcriptions and field notes
Q3: How do ethnographic modes of inquiry articulate with model-based, spatial examinations of vulnerability to sea-level rise?	Identify strengths and limitations of quantitative census-based vulnerability maps and qualitative understandings of vulnerability	Comparative assessment of spatial population and inundation data with participant narratives	Comparative analysis of results from Q1 and Q2 Grounded visualization of coastal landscape, inundation maps, and interview data

Figure 1.1 Nuisance flooding on the Georgia coast. Nuisance floods are defined as minor flooding events that cause public inconvenience (Sweet and Park 2015). These images are of the Sapelo Island Ferry Dock and parking lot during a nuisance flooding event on October 27, 2015 at approximately 9 AM eastern daylight time (EDT). High tide was 3.178 m at 8:42 AM EDT as measured at the Fort Pulaski tidal guage. Images credited to Dontrece Smith.

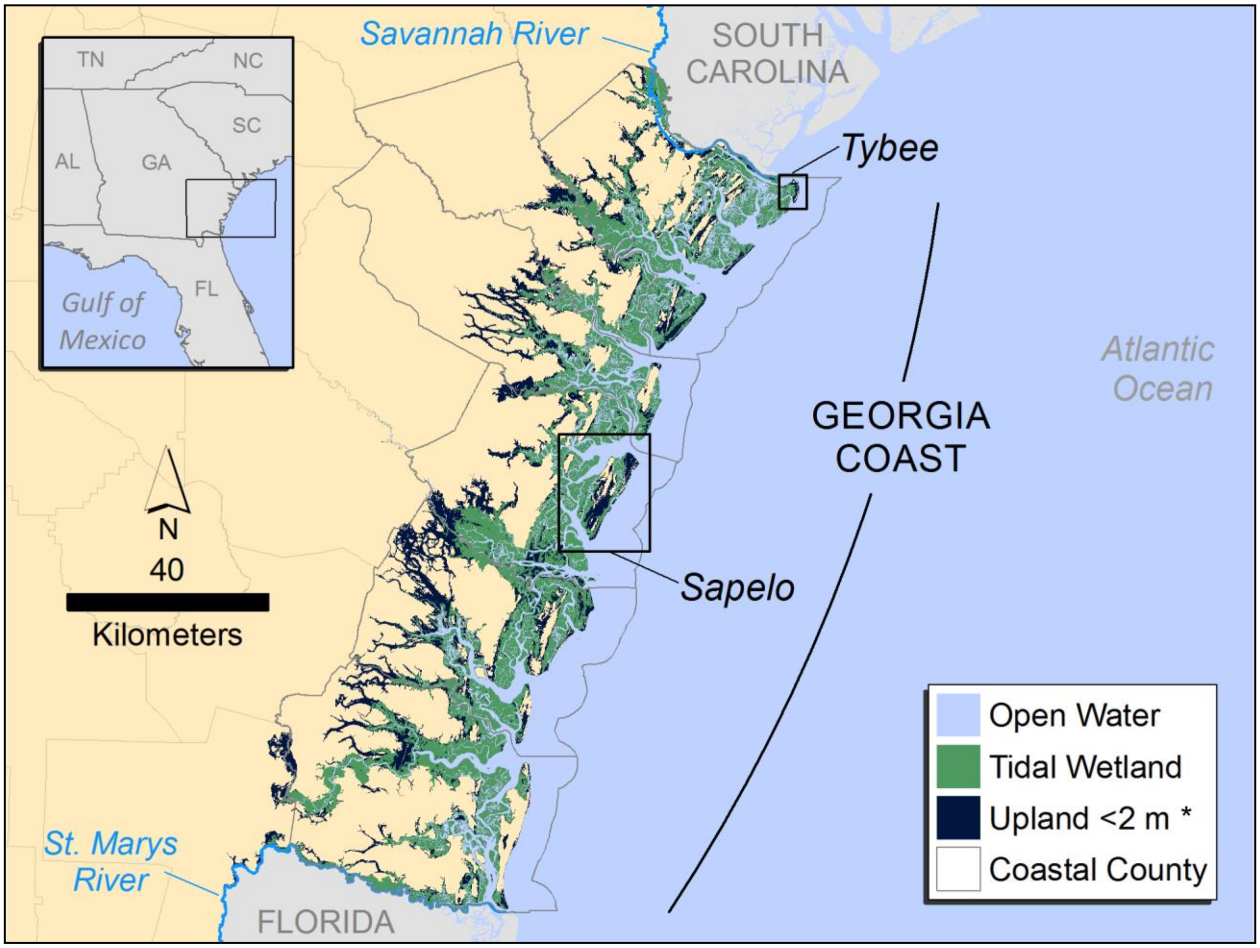

Figure 1.2 Study site of the Georgia coast showing the location of Tybee and Sapelo Islands.

*NOAA's (Parris et al. 2012) high sea-level rise scenario for 2100.

Figure 1.3 Tidal salt marsh. This image shows the more than six miles of tidal salt marsh that are between the mainland and the southern end of Sapelo Island (barely visible on the horizon, left side of image). The northern end of Hird Island is on the horizon on the right side of the image.

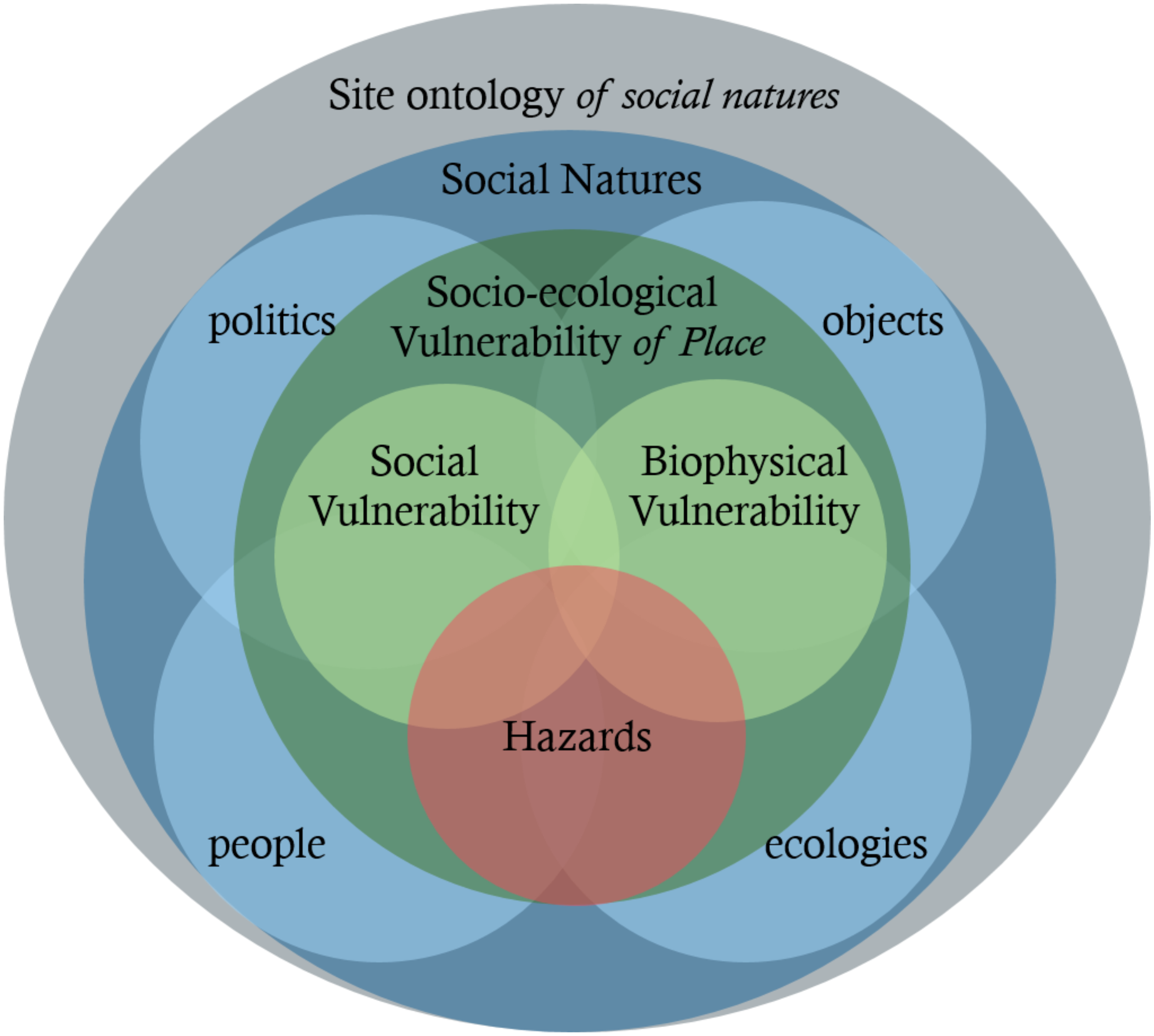

Figure 1.4 A heuristic model for conceptualizing spaces of vulnerability in the context of social natures.

CHAPTER 2

GLOBAL SEA-LEVEL RISE:

WEIGHING COUNTRY RESPONSIBILITY AND RISK [6]

[6] Hardy, R.D. and B.L. Nuse. 2016. *Climatic Change*. 137:333-345.
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Abstract

Accelerated sea-level rise will be one of the most significant effects of global warming. Global mean sea level has risen more than 0.2 m since 1880 and continues rising at above 4 mm yr^{-1}. Here we allocate responsibility to countries for global sea-level rise commitment (SLRC) over the period 1850 to 2100 and weigh that against their exposure to inundation from sea-level rise. We bridge two lines of climate-related research by combining assessment of countries' greenhouse gas emissions with predictions of the multi-millennial sea level response to global warming. Under the Intergovernmental Panel on Climate Change's business-as-usual scenario our findings show that the five most responsible countries for global SLRC are also the most exposed to absolute land loss. This is mostly due to their own emissions, which we call intrinsic risk. We also assess extrinsic risk, defined as a country's land exposed to inundation due to all other countries' emissions. We show that for 6 m of global SLRC, the two non-island countries with the highest extrinsic risk (Netherlands and Vietnam) are predicted to lose 27% and 15% of their own land, yet contributed less than 1.1% each to the emissions driving SLRC. We anticipate that our findings will directly inform policy discussions in international climate negotiations by identifying the relative degree of country responsibility and risk associated with sea-level rise.

Introduction

Mean global sea level has risen 0.21 m since 1880 according to global tide gage records (Church and White 2011). Recent estimates show that the rate of sea-level rise has been accelerating (Hay et al. 2015), up to 4.4 mm yr^{-1} (Yi et al. 2015). The potential impacts of global sea-level rise in this century may be enormous, displacing millions of coastal residents around the world from their homes and ways of life (Neumann et al. 2015; Hauer, Evans, and Mishra

2016). Impacts of future sea-level rise are unlikely to be confined to the 21st century, however (Jevrejeva, Moore, and Grinsted 2012).

Commitment accounting is becoming a popular method to assess the impacts that are expected to occur from anthropogenic activities in the near or distant future based on investment in coal-fired power plants (Davis and Socolow 2014), growing oil reserves (Matthews 2014), and the expected impacts that will result from the time lag between anthropogenic global warming and rising seas (Strauss 2013; Marzeion and Levermann 2014; Strauss, Kulp, and Levermann 2015a). We follow Levermann et al. (2013), using sea-level rise commitment (SLRC) to refer to the global sea-level rise that will occur over a 2,000 year period due to the climate system's response to anthropogenic greenhouse gas (GHG) emissions, particularly CO_2. This response includes ocean thermal expansion, melting mountain glaciers and ice caps, and melting of the Greenland and Antarctic Ice Sheets.

Linkages between countries' GHG emissions and global temperature have been increasingly well-studied (Hohne et al. 2011; Wei et al. 2012; den Elzen et al. 2013; Gillett et al. 2013). Two recent efforts refined previous estimates by including the direct effects of sulfate aerosols (Matthews et al. 2014), direct effects of non-sulfate aerosols, indirect effects of aerosols, ozone precursor gas emissions, and land albedo changes (Ward and Mahowald 2014). We bring this line of research together with studies that link temperature and sea-level rise.

There is a strong relationship between global temperature and global sea level (Dutton and Lambeck 2012; Muhs et al. 2012; Raymo and Mitrovica 2012). Evidence of this relationship informs physical models that estimate an average of 2.3 m of sea-level rise per 1 °C of surface warming over the next 2,000 years (Levermann et al. 2013). This research allows for the translation of observed and projected warming estimates into ranges of global SLRC, what

Strauss et al. (Strauss, Kulp, and Levermann 2015a) refer to as “locked-in” sea-level rise. Future sea-level rise will be affected by the degree of sensitivity in the climate system to warming from carbon emissions, which is reported by the IPCC as the likely transient climate response to cumulative carbon emissions (TCRE) at 1.6 °C (0.8 – 2.5 °C, two-thirds probability) per trillion tonnes of C emissions up to two trillion tonnes (Stocker 2013). However, Gillett et al. (2013) observed an observationally-constrained TCRE of 1.3 °C (0.7 – 2.0 °C, 90% CI).

Applying Gillett et al.’s (2013) observationally-constrained TCRE to Levermann et al.’s (2013) finding, Strauss (2013) estimated that the Earth is already committed to 1.5 m of sea-level rise above 19th century levels. Strauss, Kulp, and Levermann (2015b) have shown the expected exposure of land to inundation from “locked-in”, or committed, sea-level rise for a range of global warming scenarios up to 4 °C. Our focus here varies in that we investigate the *relationship* between country-level responsibility and land exposure associated with the rapidly growing commitment to multi-millennial sea-level rise that will extend beyond the 21st century (Levermann et al. 2013).

Motivated by the likely impacts that near-term and long-term global sea-level rise will have in coastal areas (Cazenave and Cozannet 2014), such as the displacement of millions of people as climate refugees (Neumann et al. 2015), the loss of cultural heritage sites (Marzeion and Levermann 2014), and the inundation of thousands of coastal cities (Strauss, Kulp, and Levermann 2015b), we first compare projected sea-level rise with SLRC up to the year 2100. We then evaluate country-level responsibility and land exposure related to Earth’s growing SLRC, considering two possible scenarios of anthropogenic climate forcing used by the IPCC. Representative Concentration Pathway (RCP) 4.5 represents a projection of intermediate mitigation of GHG emissions reaching approximately 3 °C of warming by 2100 whereas RCP

8.5 corresponds more closely to a business-as-usual scenario reaching approximately 5 °C of warming by 2100 above year 2000 temperatures (Meinshausen et al. 2011; van Vuuren et al. 2011; Stocker 2013).

<u>Methods</u>

Transient sea-level rise & SLRC

To demonstrate how much more rapidly Earth's commitment to multi-millennial sea-level rise (i.e., SLRC) is growing relative to observed and projected rates of transient sea-level rise (tSLR), we compare tSLR to SLRC. We define tSLR as the amount of global sea-level rise that has already been observed (Church and White 2011) and is forecast (IPCC 2013) to occur over a specific time period, in our case 1880 to 2100. To calculate tSLR for country groups (see the next section for how we classified country groups), we took a different approach. We calculated tSLR according to a semi-empirical model (Vermeer and Rahmstorf 2009), applying it to the comprehensive GHG emissions-driven surface warming anomalies (Ward and Mahowald 2014). We calculate modeled tSLR uncertainty by applying Ward and Mahowald's (2014) one standard deviation uncertainty estimates, derived from their partitioning of the global mean temperature into country groups using Monte Carlo simulations. We added an additional ±7% following Vermeer and Rahmstorf's (2009) approach, which represents one standard deviation of the uncertainty of their model's fit.

Transient SLR contrasts with SLRC, which is the amount of committed, or "locked-in" sea-level rise that is predicted to eventually occur over a two millennium time period (1850 – 3850) based on previous GHG emissions. For assessments of SLRC, the CO_2 portion of GHG emissions is most relevant given its extended atmospheric residence time (Archer and Brovkin 2008). We base our SLRC analyses on Ward and Mahowald's (2014) modeled CO_2 emissions data for countries derived from fossil fuel burning, cement production (Andres et al. 2011), international shipping emissions divided among countries based on the 2007 gross domestic product, and land use and land cover change estimates from 1850 to 2005, as well as projected CO2 emissions from these sources to the year 2100.

Following others (Strauss 2013; Strauss, Kulp, and Levermann 2015a), we use an observationally-constrained TCRE of 1.3 °C (0.7 – 2.0 °C, 90% CI) per trillion tonnes of C emissions (Gillett et al. 2013) and similarly apply a temperature-to-sea-level conversion factor of 2.3 m $°C^{-1}$ (Levermann et al. 2013). All reported SLRC confidence intervals are based on the 90% confidence interval of the observationally-constrained TCRE. We have removed observed sea-level rise from our SLRC estimates (details below), as we assess the *total cumulative* contribution of each country since 1850.

Country exposure and risk

For countries, we used ten-meter administrative area boundaries (Kelso and Patterson 2010). Where necessary, we merged country boundaries to align with those used by Ward and Mahowald (2014). We evaluated 166 countries for their contributions to global SLRC and 124 countries with coastal shorelines for their land exposure to global SLRC. In addition to individual country assessments, we evaluated country-groups using the political designations of Annex I and non-Annex I, which have been used in international climate negotiations via the United Nations Framework Convention on Climate Change for classifying developed and developing countries, respectively (UNFCCC 1992).

To determine heights of sea-level rise (inundation stage *x*) that would occur over a two millennium window (1850 – 3850) due to 21st century SLRC, we use the notion of zero emissions commitments (ZECs), which assumes that after commitment to a specific inundation stage *x* is reached, all GHG emissions immediately cease (Strauss 2013). That is, to consider the effects and culpability of a particular inundation stage, we assume that the SLRC curve in Figure 2.1 flattens out beyond the year when it rises to the inundation stage of interest. Responsibility for the resulting 2000-year sea-level rise is assigned according to the cumulative emissions of each country at the year when the particular inundation stage is reached.

To assess country exposure to inundation from SLRC with ZECs, we used global Shuttle Radar Topography Mission (SRTM; reference geoid WGS84 EGM96; Farr et al. 2007) data resampled to 1 km^2 resolution by Jarvis et al. (2008). For land areas north of the 60th parallel and south of the 54th parallel, we used ETOPO1 elevation data (Amante and Eakins 2009) and resampled it using bilinear interpolation from 1 arc minute to match the SRTM data. Vertical resolution of both elevation data sets was one meter, whereas the accuracy of each was less than 10 m for the SRTM data (Rodriguez, Morris, and Belz 2006) and approximately 10 meters for ETOPO1 data (NOAA 2016).

We chose to account for spatial variation in glacial isostatic adjustment (GIA) by applying a spatially explicit model of relative rates of sea-level rise (Peltier 2004). We resampled it from 1° to 1 km^2 to match the SRTM data. We assumed that the mean rate reported by Peltier (2004) for a 500-year window would persist through our 2000-year analysis window.

We adjusted the global elevation grid to be relative to mean sea level at the end of our 2000-year window, assuming no sea-level rise over this period by first subtracting the spatially explicit rate of relative sea-level rise due to GIA ($RSLR_{GIA}$) between 1996 and 3850, and second, adding the global mean for observed sea-level rise between 1850 and 1996 according to:

$$E_0 = E_{SRTM} - 1854(RSLR_{GIA}) + 0.21. \quad (1)$$

We calculated global mean for observed sea-level rise during this interval to be 0.21 m based on estimates of 0.03 m of sea-level rise from 1850 to 190 0 and 0.18 m from 1900 to 1996 as estimated previously (Jevrejeva et al. 2008).

Using E_0, for a given inundation stage x (i.e., terminal value of SLRC), we calculated the exposed area (A_E) as the area of land that would be inundated by sea-level rise (A_{SLR}) minus the area of land that was already below mean sea level (A_0) in our new elevation grid according to:

$$A_E = A_{SLR} - A_0. \qquad (2)$$

To ensure that we assessed hydrologically-connected land areas, we followed an approach similar to NOAA (2012a) and only included areas connected to the global shoreline as defined in the Global Self-consistent, Hierarchical, High-resolution Geography (GSHHG) shoreline database (Wessel and Smith 1996) for a given inundation stage *x*. The mean distance between shoreline points in the GSHHG is 178 m (Wessel and Smith 1996).

Per capita contributions

To assess country per capita contributions to SLRC, we used probabilistic population estimates out to 2100 from the United Nations (2015) based on previous work (Raftery et al. 2012; Gerland et al. 2014). We estimated countries' instantaneous SLRC per capita contributions for the years when each one-meter increment of SLRC is reached this century. All per capita results are reported as centimeters per billion people.

Comparison approaches

To facilitate comparison of countries' responsibility for and potential consequences from SLRC, we divide total inundation exposure (i.e., risk) into two components. For each country, we define *intrinsic risk* at inundation stage *x* as the proportion of its future land area that would be lost due to its own contribution to SLRC. Second, we define *extrinsic risk* at inundation stage

x as the proportion of its future land area that would be lost due to all other countries' contributions to global SLRC. For a given country, at a particular inundation stage x:

$$R_I = c\frac{A_E}{A} \tag{3}$$

and

$$R_E = (1-c)\frac{A_E}{A}, \tag{4}$$

where c is the country's proportional contribution to SLRC at inundation stage x, A is the total land area above mean sea level in the year 3850 and A_E is from equation (2).

The rationale for our application of this approach is that it allows for two ways of conceptualizing the impacts of global SLRC. The first, intrinsic risk, identifies a country's responsibility for its own losses. The second, extrinsic risk, acknowledges that while land is always a country's own, committed future sea-level rise that results from individual country emissions will be *shared*. We also compare each country's relative contributions to global SLRC to both its relative exposure (i.e., its *total* risk, A_E/A) and its absolute exposure (A_E) at each one-meter increment of SLRC under the RCP 8.5 scenario.

Results & Analysis

Global mean tSLR versus SLRC

While tSLR and multi-millennial sea-level rise due to SLRC will occur over very different time periods, we compare tSLR and SLRC from 1880 to 2100 to demonstrate how much more rapidly SLRC is growing than tSLR (Figure 2.1). Between 1900 and 2005, SLRC grew at an average rate of nearly 11 centimeters per decade nearly seven times more rapidly than observed estimates for global mean tSLR over the same period (Church and White 2011). From 2006 to 2100 the SLRC rate is projected grow at an average of 62 cm per decade under the RCP

8.5 scenario, reaching 6.9 m (3.7 – 10.7 m) by 2100; whereas for the intermediate GHG emissions scenario, RCP 4.5, SLRC would reach 3.4 m (1.8 – 5.2 m) by 2100. The RCP 8.5 SLRC grows more rapidly than does the RCP 4.5 SLRC over the 21st century due to the higher rates of GHG emissions projected for the former scenario.

Individual country and country group responsibility

The top ten contributors to global SLRC over the historically-observed emissions period 1850 to 2005 are, in descending order, the United States, China, Russia, Germany, Canada, Indonesia, the United Kingdom, Brazil, India, and Japan; their total cumulative contribution to global SLRC over this period was 0.81 m (0.44 – 1.2 m). Historical emissions from these ten countries alone represent 67% of the total 1.2 m of global SLRC that was reached by 2005. Over the same period, Annex I (i.e., developed) countries contributed more to global SLRC at 0.76 m (0.41 – 1.2 m; country group mean = 19 ± 15 mm 95% CI; n = 40) compared to non-Annex I (i.e., developing) countries at 0.46 m (0.25 – 0.71 m; country group mean = 4 ± 2 mm; n=126). Regarding projections, we found that SLRC is predicted to grow much faster than our semi-empirical model estimates for tSLR this century for both country groups (Figure 2.2).

Comparing country responsibility, exposure, and risk

There are many ways to compare countries' responsibility, exposure, and risk. We first compared percentages of total responsibility and total exposure of global land. We found that those countries most responsible for global SLRC would also have the highest percentage of global land exposed to inundation under the business-as-usual scenario, RCP 8.5, by 2089, when 6 m of SLRC would be reached (Figure 2.3a). Excluding Small Island Developing States (SIDS), this includes five countries that rank above the 95th percentile for both relative responsibility for and inundation exposure to 6 m of SLRC. In other words, 95% of assessed countries have lower values than these five countries for percentage measures of total responsibility and inundation exposure. In order of descending exposure, the countries include the United States, China, Russia, Brazil, and India. These five countries would be responsible for 52% of global SLRC at 6 m. Their exposed land area would amount to approximately 0.44 million km^2, or 44% of the more than one million square kilometers of global lands that would be inundated due to 6 m of sea-level rise over the period 1850 to 3850.

Another way of comparing SLRC contributions is by assessing the proportion of land exposed within each country due to its own emissions and due to the emissions of others; what we have defined respectively as intrinsic risk (R_I) and extrinsic risk (R_E). At 6 m of SLRC under the RCP 8.5 scenario, we find that there are seven countries that would have an intrinsic risk above the 95^{th} percentile including China, the United States, Netherlands, India, Vietnam, Japan, and Indonesia (Figure 2.3b). There are also seven countries that would have an extrinsic risk above the 95^{th} percentile excluding SIDS; in descending order, they include the Netherlands, Vietnam, Denmark, Qatar, Bangladesh, Belgium, and Kuwait. There are two countries that stand out as having relatively higher extrinsic risk in Figure 2.3b including the Netherlands and Vietnam.

In our third comparison, we assessed six selected countries' total responsibility against their total risk (i.e., $R_I + R_E$), which we defined as equal to the proportion of land exposed within the country. To highlight the relationship over time between the three nations with the highest responsibility for global SLRC and the three non-SID states with the highest total risk, we compared the total risk each country would experience from sea-level rise in one-meter increments under scenario RCP 8.5 from 1 to 6 m. We find that the high responsibility countries of the US, China, and Russia have relatively small proportions of their countries exposed compared to the Netherlands, Vietnam, and Denmark (Figure 2.4a). Each of the high total risk countries would have contributed only 1.1% combined to the CO_2 emissions driving 6 m of SLRC under RCP 8.5. Under the same scenario, however, the two most responsible countries would have contributed 37% combined to the CO_2 emissions driving global SLRC, yet are predicted to experience approximately a 0.3% loss of their future land area to each meter of multi-millennial sea-level rise.

While the proportion of country land area exposed is large for the Netherlands, Vietnam, and Denmark, their absolute exposure relative to the global total land exposed is small, at least for the Netherlands and Denmark (Figure 2.4b). In our fourth comparison of total responsibility and absolute exposure, we find that for the United States, China, and Russia, the percentage of land exposed relative to the size of their countries is small, but the absolute area is larger than for any other countries. While its proportion of land lost at 6 m of sea-level rise would be relatively small, we estimate that the United States would experience the largest absolute land loss at approximately 120,000 km^2. We estimate that China and Russia would respectively experience losses of approximately 103,000 km^2 and 102,000 km^2; these would be followed by seventh ranking Vietnam (Table A.1), which stands to lose approximately 50,000 km^2 (Figure 2.4b).

Per capita SLRC

The average country per capita SLRC contribution was 19 cm per billion people for the first meter, reached in 1995, with Canada being the highest per capita contributor. Fifty-seven of the 166 analyzed countries had above average per capita rates and are responsible for 75% of the first meter of SLRC. Among the 57 countries identified as above average rate contributors, 49% were Annex I countries. These Annex I countries were responsible for 62% of the first meter of SLRC. Of the 51% that were non-Annex I countries, they accounted for 13% of the total contribution to the first meter of global SLRC. We found an inequality regarding SLRC per capita contributions across Annex I (country mean = 53 ± 2 cm, n=28) and non-Annex I (country mean = 37 ± 9 cm, n=29) country groups for those countries with above average rates.

Under an RCP 8.5 scenario, few countries change their SLRC per capita contribution percentile ranking (Figure 2.5) between 1 m and 6 m. By the year 2089 (6 m SLRC) the mean country per capita contribution would become 87 cm per billion people. Among the largest emitters that are above the 95th percentile for SLRC responsibility (see Figure 2.3a), all would be above average per capita contributors except Brazil and India. Among the largest emitters, Canada and the United States are the highest per capita contributors through the first two meters. Russia would surpass the United States for second place at 3 m of SLRC and at 5 m, would move to first place and stay there through 6 m of SLRC.

On a per capita basis, the Annex I country group would consistently out rank the non-Annex I country group for SLRC responsibility under scenario RCP 4.5 and RCP 8.5 (Figure A.1). All country per capita contribution rates for each one-meter increment of SLRC are reported in Table A.1. Results for all countries are available in Table A.1 for scenario RCP 8.5 and in Table A.2 for scenario RCP 4.5.

Conclusion

We synthesized the latest evidence on country contributions to global warming from CO_2 emissions (Ward and Mahowald 2014) and the predicted multi-millennial response of sea level to those emissions (Levermann et al. 2013) as a first step in comparing country-level responsibility and exposure related to rising seas. However, limitations do exist. There are thresholds inherent to the sea-level rise response to global warming, such as the rapid loss of the ice sheets (Levermann et al. 2013; DeConto and Pollard 2016; Hansen et al. 2016). We do not account for these thresholds, and focus instead upon the *average* prediction for sea-level rise at the end of the next two millennia and not longer. Our study does not account for geographic variation expected for sea-level rise due to factors such as gravitational fingerprints of polar ice sheet mass losses (Mitrovica, Gomez, and Clark 2009; Dutton et al. 2015), regional differences in sea surface warming and land subsidence (Wang et al. 2012; Stammer et al. 2013), or local tide deviation from the modeled sea level of the SRTM elevation data used in our analysis (Strauss et al. 2012).

Many countries fall above the mean global SLRC contour (see Marzeion and Levermann 2014), suggesting that we have underestimated the exposure for those countries. The one-meter increments used in our analysis to assess exposure are within the statistical uncertainty of the SRTM elevation data, but they have been shown to be an overestimate of elevation (Gesch 2009), meaning our assessment is a conservative estimate of land exposed to inundation from SLRC. Finally, our assessment does not factor in a consumer-based approach to accounting for GHG emissions that relates trade and consumption of products produced elsewhere to the countries within which they are consumed (Kander et al. 2015). Such an approach would likely increase the per capita rates of many developed countries that consume products produced in developing countries.

It would be ideal to compare per capita contributions and per capita exposed in inundated areas. However, many studies have already examined the potential population impacts of future sea-level rise (e.g., Kopp et al. 2014), and one recent study estimated the potential number of current country populations that would be affected by SLRC (Strauss, Kulp, and Levermann 2015b). To move beyond this previous work and forecast population estimates over the two-millennium window expected for global SLRC was beyond the scope of this project.

A key finding shows that under the business-as-usual scenario, the largest CO_2 emitters will be the most affected regarding total global land area exposed to inundation from multi-millennial sea-level rise (see Figure 2.3a). Another important finding is that those non-SID states with the highest extrinsic risk do not bear much responsibility for global SLRC (see Figure 2.4a), especially from a per capita perspective in the case of Vietnam (Table A.1). This suggests a strong double inequality (Adger et al. 2006) for Vietnam, as it is a country that will experience significant impacts, but likely receive little of the benefit from the economic growth associated with increased CO_2 emissions (Taylor, Rezai, and Foley 2015). We note that many of the large emitter countries have a large areal extent, but do not draw conclusions about why responsibility varies. Other factors affecting GHG emissions (e.g., population size and GDP) could explain the degree of responsibility for a country, but this is beyond the scope of our work presented here.

In addition to identifying those countries most responsible and the associated impacts, the SLRC concept (Levermann et al. 2013) can inform topical debates over whether global warming should be limited to 2 °C or 1.5 °C (Tschakert 2015). What difference does 0.5 °C make? In terms of sea level, it means approximately 3.5 m of multi-millennial global sea-level rise above the 1850 level (plus the rise from natural processes; see Jevrejeva et al. 2009) compared with 4.8 m for 2 °C (Levermann et al. 2013). This would be rather crucial for countries, like Bangladesh, whose rate of land loss would increase substantially after 5 m of rise (see Table A.1). Perhaps more significantly, Levermann et al.'s (2013) work shows that the Greenland Ice Sheet destabilizes between 0.8 and 2.2 °C (90% CI) above preindustrial temperatures. Above this temperature range the Greenland Ice Sheet could eventually contribute upwards of 6 m or more to global sea level, suggesting that the losses will almost certainly be greater than those that we have estimated here if Earth exceeds 2.2 °C above preindustrial temperatures.

Preventing such a collapse would have enormous implications for the existence of SIDS such as the Solomon Islands already undergoing losses (Albert et al. 2016) as well as smaller low-lying countries like Vietnam and Bangladesh with fewer economic resources than more developed countries and, per our calculations, much greater proportions of their countries exposed to inundation. It would also have significant implications for countries like the United States, China, and Russia. These countries have been – and under both RCP 4.5 and RCP 8.5 emissions scenarios would continue to be – the most responsible for growing Earth's SLRC. They also have a great incentive to act to reduce global emissions, as they are predicted to lose a combined land area of between 138,000 km^2 and 325,000 km^2 under these scenarios (see Tables A.1 & A.2).

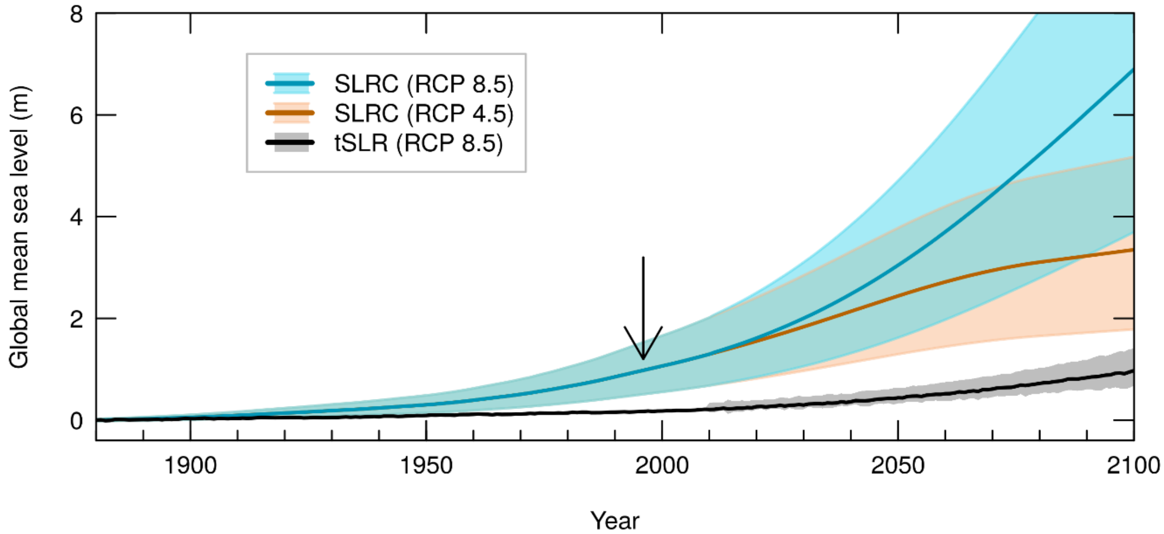

Figure 2.1 Transient sea-level rise (tSLR) versus committed sea-level rise (SLRC). The black line indicates observed global mean tSLR (1880 – 2009; data from Church and White 2011) and the IPCC RCP 8.5 mean tSLR forecast (2010 – 2100; data from IPCC 2013). The global mean SLRCs are based on modeled CO_2 emissions for two IPCC scenarios RCP 8.5 (blue line) and RCP 4.5 (orange line) (see text for details). Shading indicates 90% CI based on observationally-constrained TCRE to CO_2 emissions (Gillett et al. 2013) for the two SLRC curves and the IPCC RCP 8.5 scenario forecast for tSLR. The upper limit of the CI for the RCP 8.5 SLRC curve is 10.7 m. The arrow points to 1995, when the mean global SLRC reached 1 m.

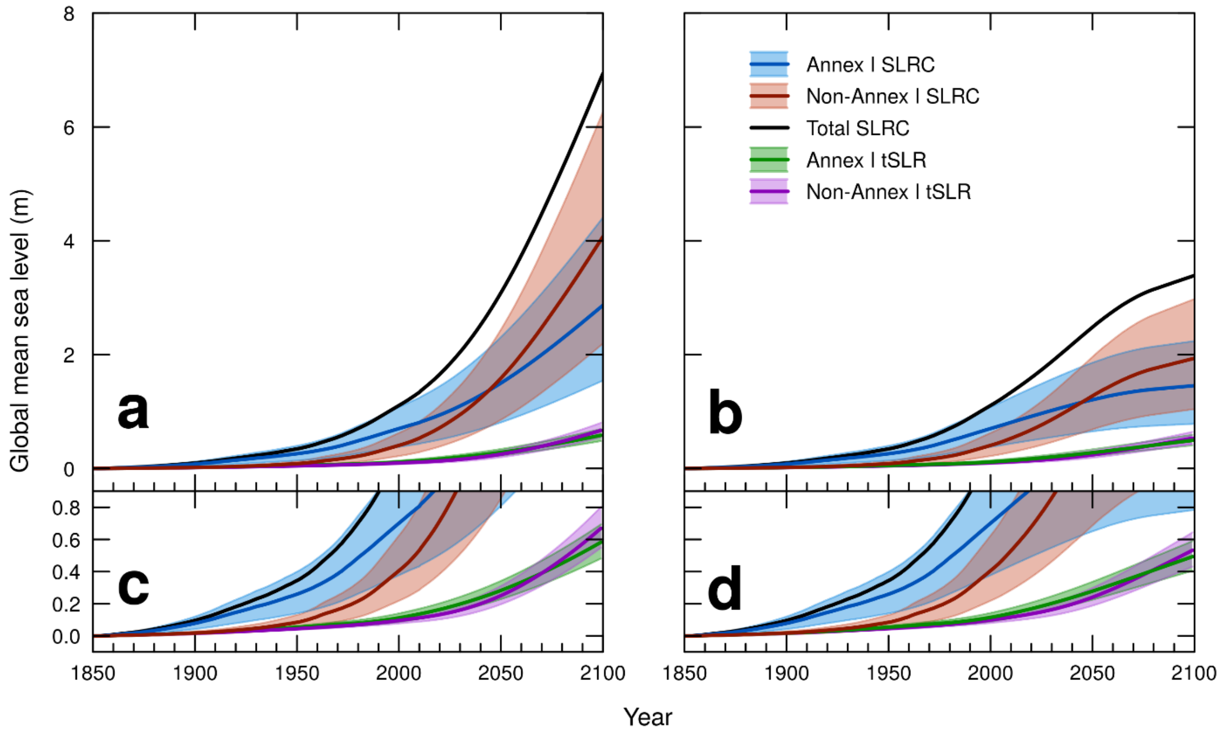

Figure 2.2 Country group contributions to SLRC and tSLR. SLRC and tSLR estimates for RCP 8.5 (a) and RCP 4.5 (b). Details of panels (a) and (b) showing tSLR prediction for RCP 8.5 (c) and RCP 4.5 (d). Shading indicates confidence intervals; see text for details on calculation of each. Solid lines indicate the global mean for each scenario. Confidence intervals for SLRC totals are in Figure 2.1.

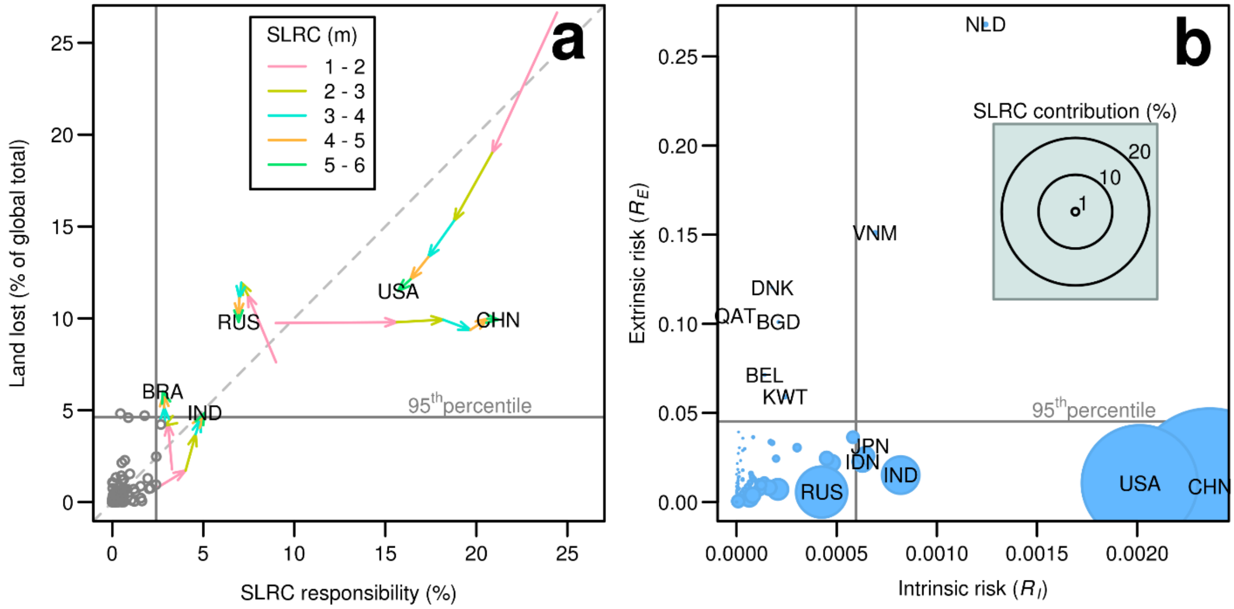

Figure 2.3 SLRC responsibility versus exposure (a) and intrinsic risk versus extrinsic risk (b) for 6 m. In panel (a), the dashed grey line shows the one-to-one relationship between the two variables and the colored lines show the movement of each country along both axes over a 1 to 6 m range for SLRC under scenario RCP 8.5. In panel (b), the size of the circle represents the SLRC contribution as a percentage of the global total. For both panels, the solid grey lines represent the 95th percentile for each variable. Bangladesh (BGD), Belgium (BEL), Canada (CAN), China (CHN), Denmark (DNK), Indonesia (IDN), India (IND), Japan (JPN), Kuwait (KWT), Netherlands (NLD), Qatar (QAT), Russia (RUS), United States (USA), and Vietnam (VNM). SIDS are removed from analysis, but are available in Table A.1.

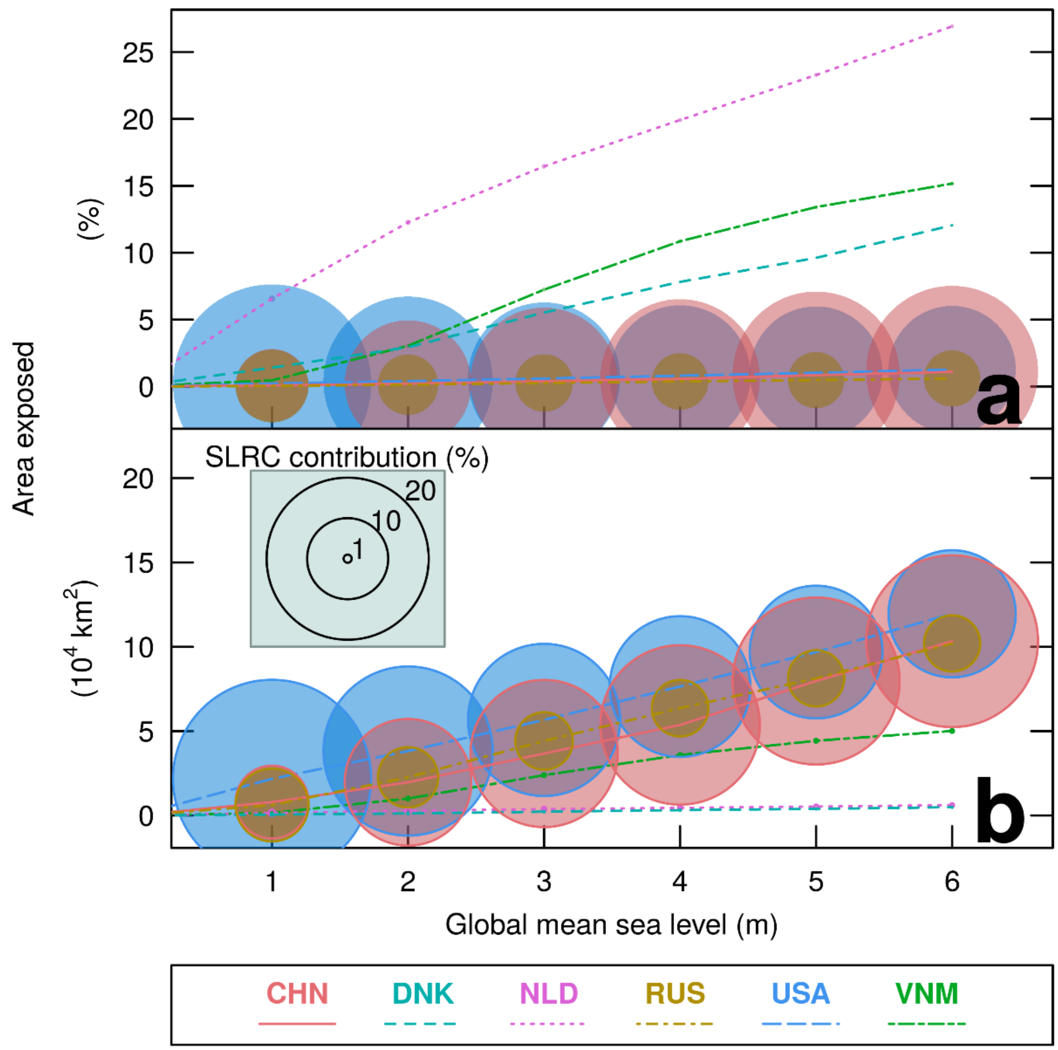

Figure 2.4 Relative and absolute area exposed for each meter increment of global SLRC under RCP 8.5 for selected countries. Panel (a) shows a country's percentage of land area exposed (i.e., total risk = $R_I + R_E = A_E/A$). Panel (b) shows the absolute area (A_E) exposed of each country. In both panels, the size of the circle represents the percentage contribution to SLRC. China (CHN), Denmark (DNK), Netherlands (NLD), Russia (RUS), United States (USA), and Vietnam (VNM).

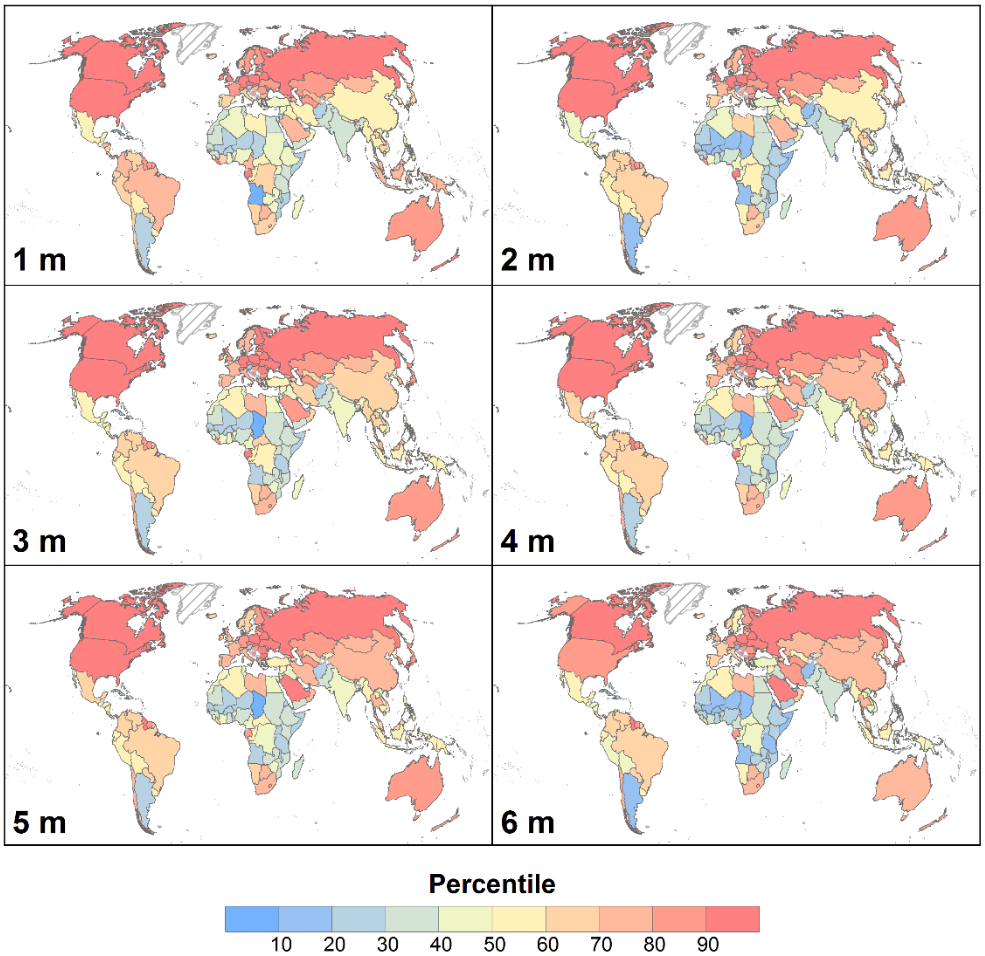

Figure 2.5 Per capita contributions to SLRC. Instantaneous per capita rates are calculated for each one-meter increment of global mean SLRC for the year when it was reached. Analysis for 166 countries is based on data from the United Nation's (2015) population estimates and observed CO_2 emissions (1850 – 2005) and IPCC projected emissions (2006 – 2100) for RCP 8.5. Cross-hatched areas in map were not assessed.

CHAPTER 3

SPATIOTEMPORAL VARIATION IN RISK TO SEA-LEVEL RISE: A CASE STUDY OF COASTAL GEORGIA [7]

[7] Hardy, R.D. and M.E. Hauer. To be submitted to the *Annals of the American Association of Geographers*.

Abstract

Assessing the potential for harm to coastal populations is becoming increasingly important as more sophisticated measurements of sea-level rise show that rates are accelerating faster than expected. The majority of studies in the US have only examined current populations' inundation exposure to future sea-level rise. Moreover, studies of social vulnerability typically do not take into account spatial variation in the relationship of the socioeconomic indicators. In this paper, our objective was to improve evaluations of risk to sea-level rise by advancing social vulnerability modeling through assessing *future* social vulnerability to *future* sea-level rise inundation exposure while acknowledging local influence. We used techniques that apply the theoretical arguments and methods associated with demographic metabolism (a theory for predicting socioeconomic change of populations) and spatial non-stationarity (a theory that the relationships of spatial variables change over space) with coastal Georgia as our case study site. Our results show that the socioeconomic indicators explaining social vulnerability in this area change between 2010 and 2050 with race and education status becoming more important. We found that the population projected to be directly exposed to mid-century sea-level rise inundation ranges from approximately 12,500 to nearly 42,000, with more than 25% of the exposed population considered to be at risk regardless of sea-level rise scenario, meaning that these populations have relatively high levels of social vulnerability and likely have limited capacity to adapt.

Introduction

When investigating social vulnerability to hazards, in particular gradual environmental changes such as sea-level rise, it is critical to examine *future* populations and their associated characteristics within the same temporal window. Few studies that have investigated vulnerability (or risk) to sea-level rise have done this (but for recent examples, see Hauer, Evans, and Alexander 2015; Hauer, Evans, and Mishra 2016). By way of the dynamics of population change including birth, death, and migration, today's population is not tomorrow's, suggesting that the size, characteristics, and location of socially vulnerable populations changes and metabolizes with demographic change over time. Analyzing environmental change concurrently with demographic change enables identifying who will be at risk to sea-level rise.

Assessing the potential for harm to coastal populations is becoming increasingly important as more sophisticated measurements of sea-level rise show that rates are accelerating faster than expected (Hay et al. 2015; Yi et al. 2015). Determining who is most at risk to future sea-level rise (i.e., who has higher social vulnerability under equal exposure levels) is important to ensure equitable allocation of adaptation funding and planning in the face of environmental change under rising seas. With few exceptions (Hauer, Evans, and Alexander 2015; Hauer, Evans, and Mishra 2016), assessments of US population exposure, vulnerability, or risk status regarding future sea-level rise have limited their analyses to examining current populations (e.g., Wu, Yarnal, and Fisher 2002; Emrich and Cutter 2011; Strauss et al. 2014). While these studies highlighted coastal communities that will be affected by rising seas, none evaluated the *future social vulnerability* of projected populations and how this affects estimates of populations identified as at risk to sea-level rise. Moreover, prior studies have not examined how the indicators of social vulnerability potentially vary within the study area, limiting interpretability of model results for identifying how the most important indicators may change throughout the study region.

One of the more popular quantitative methods for assessing social vulnerability is the Social Vulnerability Index (SoVI), which is an evolving model that applies a principal components analysis (PCA) to approximately 30 US Census variables (e.g., race, income, sex, etc.) to identify relative levels of social vulnerability to environmental hazards (Cutter and Morath 2014). SoVI-based approaches have identified spatial variation in social vulnerability across the study site via a global model PCA (e.g., Cutter, Boruff, and Shirley 2003; Emrich and Cutter 2011; Cutter et al. 2013; KC, Shepherd, and Gaither 2015), yet these assessments have not addressed the spatial heterogeneity of the socioeconomic indicators of social vulnerability *within* the study site. Such application of a global model PCA has been carried out without regard to the spatial effects that spatial theory suggests may have significant consequences on the analyst's perceived relationships of the variables being analyzed in the study area (Fotheringham, Brunsdon, and Charlton 2002).

Spatial theory and innovative techniques in computing have led to increased understanding of the spatial non-stationarity of spatial phenomena (Brunsdon, Fotheringham, and Charlton 1996). For example, Harris et al. (2011) show that the relationship between eight variables (e.g., social class, age, formal education, etc.) varies between election districts in Greater Dublin, Ireland. They demonstrate that it is necessary to apply geographically-weighted PCA (GWPCA) – as opposed to a global model PCA – to voter data in order to more clearly identify the spatial relationships between the socioeconomic characteristics of the population and voter turnout. We move social vulnerability modeling forward, specifically the SoVI model, by applying GWPCA. This approach offers insights into how the indicator variables' relative importance for explaining social vulnerability varies over space across the region of the Georgia coast, whereas current SoVI analyses are limited to examining study regions as a whole, or global model.

In addition to assuming spatial homogeneity among indicator variables, studies that have specifically examined social vulnerability to sea-level rise in the US limited the analysis to socioeconomic indicators of current populations (Wu, Yarnal, and Fisher 2002; Emrich and Cutter 2011; Martinich et al. 2013; Strauss et al. 2014). For example, one study showed that approximately 2.3 million people from the current US population would be exposed to sea-level rise of 1.26 m, and of those nearly 500,000 are among the most socially vulnerable (Martinich et al. 2013). However, this result is limited due to a temporal mismatch of comparing the *current* population to the *future* hazard of sea-level rise inundation. A more recent study overcame this temporal mismatch for population totals and showed that the future population expected to be affected by a more conservative 0.9 m estimate of sea-level rise by the year 2100 is far greater at 4.2 million (Hauer, Evans, and Mishra 2016). This larger population estimate indicates that Martinich et al.'s (2013) estimate of socially vulnerable people that will be exposed to future sea-level rise is likely an underestimate. To assess future social vulnerability, projections of not only population totals, but their associated characteristics are needed as well.

A predictive theory of socioeconomic change called demographic metabolism facilitates projecting the characteristics that typically indicate socially vulnerable populations (Lutz 2012). Theoretical indicators of social vulnerability can include race, ethnicity, age, sex, poverty status, and educational attainment (Cutter 1996; Cutter, Boruff, and Shirley 2003). To project changes in these indicators, scholars of demography have argued that, "the process of social change can be analytically captured through the process of younger cohorts replacing older ones" (Mannheim 1952; Ryder 1980; Lutz 2012, 284). Demographic metabolism is a theoretical framework that combines this argument with the cohort component model of population change into a multi-state projection model for predicting changes to socioeconomic characteristics of a population (Lutz 2012). For example, assuming age-specific poverty rates remain constant, we should expect that as the population metabolizes through the processes of birth, death, and migration the relative size and age-specific poverty exposures will shift the total population's poverty rate accordingly.

In this paper, our objective is to advance social vulnerability modeling by assessing *future* social vulnerability to *future* sea-level rise through application of techniques that apply the two theoretical arguments of demographic metabolism and spatial non-stationarity outlined above. In the following section, we briefly review our conceptual approach for relating vulnerability, exposure, and risk. Next, we give the methods of our social vulnerability and sea-level rise exposure forecasting methods as applied in a case study of the US Georgia coast. We then present the findings from our case study of how social vulnerability and risk to sea-level rise vary both spatially and temporally within the study region out to the year 2050.

Vulnerability to Hazards

Vulnerability studies in both environmental hazards research have been broadly classified in two ways (O'Brien et al. 2007). First is "contextual vulnerability," that employs ethnographic methods and tools (e.g., Adger 1999; Lazrus 2009), and second is "outcome vulnerability" that uses quantitative modeling and statistics (O'Brien et al. 2007; Birkenholtz 2012). Contextual vulnerability is "based on a processual and multidimensional view of climate-society interactions," and takes on a human security framing, whereas outcome vulnerability research takes on a scientific framing and is "considered a linear result of the projected impacts of climate change on a particular exposure unit (which can be either biophysical or social), offset by adaptation measures" (O'Brien et al. 2007, 75-76). In comparison, contextual vulnerability studies typically investigate why some social groups are more vulnerable than others and outcome vulnerability studies tend to focus more on being able to inform policy and response to hazards.

We follow the outcome vulnerability approach here and define social vulnerability as the potential for damage or loss in relation to the specific hazard of sea-level rise. We employ the theoretical framework put forward by Wisner et al. (2004) and applied by Emrich and Cutter (2011) such that:

$$\text{Risk} = \text{Social Vulnerability} * \text{Hazard Exposure}. \tag{1}$$

In this risk framework, vulnerability is always in the social space/domain and is driven by the social conditions that affect a group's potential for harm when physically exposed to an environmental hazard or change. We contend, however, that this framework allows for conceptualizing vulnerability as always social-ecological, as the vulnerability is never realized without exposure to a hazard.

Methods

Study Site

Our study site was the US Georgia coast. It is an ideal site for examining social vulnerability to sea-level rise given its diverse demographic characteristics and rural-to-urban settings. Of the greater than 500,000 people residing in the six coastal counties that comprise coastal Georgia, roughly 227,000 (44%) are racial or ethnic minorities (Figure 3.1), approximately 87,000 (17%) have experienced below poverty level incomes in the past 12 months, and of those 18 years or older, over 39,000 (12%) have less than a high school equivalent educational attainment level (US Census 2012). This indicates that coastal Georgia has relatively high numbers of people with the social characteristics that mark socially vulnerable populations according to hazards theory (Cutter, Boruff, and Shirley 2003; Wisner et al. 2004).

Recent studies have shown that current populations in coastal Georgia living on land that would be exposed to sea-level rise of 0.9 – 1.8 m by the year 2100 are estimated to be between 25,061 and 48,426, respectively; this is expected to more than triple when Georgia's coastal population living on exposed land is projected to reach between 93,056 and 178,787 by the year 2100 (Hauer, Evans, and Mishra 2016). Of the 2010 population, there are approximately 5,000 Georgia residents with high social vulnerability living within 0.9 m of the high tide line, or the mean higher high water (MHHW) mark (Strauss et al. 2014).

Population Projections

Using a series of controlling factors and limits, we projected populations by age, sex, race, and ethnicity in 10-year cohorts between 2010 and 2050 at both the county and census tract levels for 23 counties including and surrounding the six coastal counties on the Georgia coast. The county level projections served as our top-down projections for controlling of the tract level projections. Details of the population projections and why we extended our analysis area to 23 counties follow.

One of the most well-accepted and popular approaches for projecting populations is the cohort-component method, which uses migration, birth, and death rates to forecast population changes within an area (Smith, Tayman, and Swanson 2001). However, given the difficulty of obtaining these data for some areas and smaller geographies such as tracts, a simpler approach was proposed that uses cohort-change ratios (CCR; Hamilton and Perry 1962; Swanson, Schlottmann, and Schmidt 2010) between the two most recent census counts to project populations by age and sex – and sometimes race or ethnicity – following:

$$ {}_{n}\mathrm{CCR}_{x} = \frac{{}_{n}P_{x+y,l}}{{}_{n}P_{x,b}}\,, \tag{2} $$

where n is the cohort interval, x is the starting age of the cohort, ${}_{n}P_{x+y,l}$ is the population aged x + y to $x + y + n$ in the most recent census (l), ${}_{n}P_{x,b}$ is the population aged x to $x + n$ in the second most recent census (b), and y is the number of years between the two censuses ($l – b$) according to Smith et al. (2001).

Given the 10 year interval of most US Census data, the age cohort of 10 – 19 is the minimum for applying the CCR. Child-woman ratios (CWR) are used to project populations of the 0 – 9 age cohort. We made two adjustments to Smith et al.'s (2001) recommendation for assessing CWRs. First, we used 10-year age cohorts instead of 5-year age cohorts as they suggest because our projection interval was 10 years. Second, we assessed the combined CWR for the population of male and female children due to low counts for some groups. We calculated CWRs for the launch year's population by calculating the ratio of children aged 0 – 9 to women aged 15 – 49 following:

$$ \text{Children aged } 0 - 9\text{: } {}_{10}P_{0,t} = \frac{{}_{10}P_{0,l}}{{}_{35}P_{15,l}}\,. \tag{3} $$

We divided this combined CWR by two before calculating the projected target population of male and female children, which assumes an equal birth rate for the sexes. As we projected in 10-year age cohorts over 10-year periods, we used half of the 10 – 19 aged female population count to ascertain the number of women 15 – 19 to be included in the 35-year window in equation (2). We only used CWRs in our county level projections. For tract level projections, we used implied total fertility rates (iTFR) following Hauer et al. (2013). We explain iTFR below where we discuss our tract projections in more detail.

We first projected age-sex cohort populations at the county scale using CCR and CWR as described in equations (2) and (3). We then projected age-sex-race-ethnicity (ASRE) cohort populations at the county scale using CCR and CWR, but also applying a single-dimensional raking to control projections for county ASRE cohorts to our county age-sex cohort projections. This requires calculating an adjustment factor equal to the county projections for age-sex specific cohorts divided by the ASRE county projections summed by age-sex cohorts and then applying this factor to the original ASRE counts. This ensures that the sum of demographic subgroups for the ASRE projections equal the independent age-sex projections within counties. Before applying the single-dimensional raking procedure, we adjusted our uncontrolled projection's CCR for the Hispanic population by dividing it by two. This concurs with US Census estimates for a significantly slowed growth rate for this subgroup over our projection period when compared to the 2000 to 2010 rates (Colby and Ortman 2015).

Two challenges emerge when projecting populations for subcounty geographies such as census tracts (e.g., Swanson, Schlottmann, and Schmidt 2010). A common challenge of population forecasting with subcounty geographies is the frequent changes that occur with boundaries between census collection years. To overcome this first challenge, we applied the Longitudinal Tract Database's conversion tool (Logan, Xu, and Stults 2014) to each 2000 Census tract data table to normalize the data to 2010 Census tract boundaries, resulting in 419 Census tracts in our population projections. Another common challenge is specific to the Hamilton-Perry method, which can lead to forecast errors and upward bias in rapidly growing areas (Smith, Tayman, and Swanson 2001). This is less of an issue with larger geographies like counties, but can significantly affect results for smaller geographies such as tracts. Consequently, projections must be controlled to independent projections or projections for larger geographies, such as counties, to overcome these errors.

For our initial projections of ASRE cohorts in tract populations, we used the Hamilton-Perry method as above, but we applied four controls to our projections. First, we limited the rate of population change for ASRE cohorts by applying the controlled ASRE county projection's race/ethnicity specific CCR. This was necessary to limit some otherwise rapidly growing or declining cohorts in some tracts with unusually high CCRs (e.g., over 200). Second, to determine the target year's 0 – 9 age cohort, we controlled this group using iTFRs (Hauer, Baker, and Brown 2013) for race/ethnicity specific groups from the controlled county projections, following:

$$ {}_{10}P_0 = 10 * \left[\frac{iTFR * {}_nW_x}{n}\right], \tag{4} $$

where subscripts are equal to those in equation (1) and ${}_nW_x$ equals the total number of women aged x to $x + n$. As with the CWR, we assumed an equal birth rate of both sexes. Third, to limit overly rapid tract population growth or decline, especially in areas that experienced rapid rates of change between 2000 and 2010 that would likely be unsustainable over a 40 year period due to build out limitations, we set an annual growth rate ceiling at 1.05 and a floor at 0.98 for *all* tract projections similar to those set in another study applying the Hamilton-Perry method to subcounty geographies (Swanson, Schlottmann, and Schmidt 2010). Lastly, we used a single-raking procedure (Smith, Tayman, and Swanson 2001) to adjust all tract population projections to county level ASRE counts to ensure tract level projections summed to county level projections.

For projecting socioeconomic characteristics including poverty status and educational attainment, we used 2008 – 2012 American Community Survey (ACS) Census data – as its middle year is 2010 – to calculate the percentage of each age-sex cohort tract population below poverty level and with less than a high school equivalent educational attainment level. We then applied these percentages to the projected age-sex cohort tract populations to assess how the total population percentages changed over our temporal analysis window of 2010 to 2050.

Social Vulnerability Model

The SoVI model is a multistep process explained in detail by Dunning and Durden (2011). First, Census variables are standardized with *z*-scores where the mean of each variable is converted to zero and $z = 1$ represents one standard deviation. Second, a PCA is conducted on the variables' *z*-scores using varimax rotation and the Kaiser criterion for component selection (i.e., selecting eigenvalues >1). Third, the components of the PCA are then interpreted, named, and given a cardinality in relation to their theoretically understood influence on social vulnerability. Fourth, all component scores are summed by the unit of analysis to determine a unit's score. Fifth, scores are then mapped as quantiles to show relative levels of social vulnerability over the study area.

We followed the same approach outlined in Dunning and Durden (2011) with a few modifications. The SoVI 2006-2010 model includes 27 variables that are available at the subcounty geography, however we include only nine of the original variables due to the constraints of projecting many of the original variables. Our socioeconomic variables include race (Asian, black, and all other races), ethnicity (Hispanic/Latin@), age dependence (≥65 or <5), sex (female), poverty status, and less than 12th grade educational attainment level. Based on the Kaiser criterion, we identified two principal components that explained 61% of the variance in the data for the years 2010 (Table 3.1) and three components that explained 67% for the year 2050 (Table 3.2).

We rank social vulnerability of tracts into a three-tiered classification system of limited, moderate, and elevated levels based on standard deviations of SoVI scores (Emrich and Cutter 2011). Tracts with scores within half a standard deviation are classified as moderate social vulnerability. Tracts that scored less than half a standard deviation below the mean score are classified as limited. Tracts that scored more than half a standard deviation above the mean score are classified as elevated.

Geographically-Weighted Principal Components Analysis

Before running the GWPCA model, and to limit edge effects associated with geographically-weighted approaches (Fotheringham, Brunsdon, and Charlton 2002), we determined a “region of socioeconomic influence” surrounding our six county area of interest along the Georgia coast (Figure 3.2). We created a buffer zone around this region based on the average travel time to work (~ 25 minutes) reported in the 2008 – 2012 ACS Census for counties within a subjectively chosen 100-km distance of our six coastal counties. Applying the average travel time to work for the region to a subjectively chosen average driving speed of 72 kilometers per hour (45 miles per hour), we determined the distance traveled by the population of interest to be 31 km, which indicated 217 tracts for analysis. We applied this distance as our neighborhood for the “region of socioeconomic influence” used in our GWPCA model. We used a Gaussian curve, so influence declined over the neighborhood as distance from the local tract increased. We recognize that our choice of using average driving time and 45 miles per hours to determine the region of socioeconomic influence is subjective, but such decisions about neighborhood selection in geographically-weighted analysis are common (Fotheringham, Brunsdon, and Charlton 2002).

To perform the GWPCA, we applied the R statistical program and associated package called GWmodel (Lu et al. 2014; Gollini et al. 2015; R Core Team 2015). Proportion of the total variance (PTV) explained by principal components 1 and 2 ranged from approximately 50% to 75% in the GWPCA model for year 2010 and 61% to 89 % for the year 2050 (Figure 3.2). To examine the strength and directionality of variable loading for each tract, we created a glyph plot, which shows relative loading of the eight variables and the direction (positive or negative) for each of the principal components in the GW PCA used in our social vulnerability assessment (Figure 3.3). This is essentially an exploratory sensitivity analysis, as the relative length of the line in the glyph plot indicates the relative strength each of variable's loading on the principal component.

Risk to Sea-Level Rise

By mid-century, the time frame for our analysis, Strauss et al. (2014) estimate a range of 0.1 – 0.5 m of sea-level rise above the 1992 level for the Georgia coast based on locally-adapted scenarios of the National Climate Assessment intermediate low, intermediate high, and high scenarios (Parris et al. 2012). We follow Strauss et al.'s (2014) approach and model the same locally-adjusted curves with the intermediate low (0.5 m by 2100) and high (2.0 m by 2100) estimates (what we call slow and fast scenarios for simplicity) to assess sea-level rise inundation for the year 2050. As our medium scenario, we use a locally-adjusted estimate for global mean transient sea-level rise (Chapter 2). This model is based on comprehensively modeled greenhouse gas emissions' effect on global warming (Ward and Mahowald 2014) under the Intergovernmental Panel on Climate Change high emissions scenario (Representative Concentration Pathway 8.5). Transient sea-level rise was projected follwing a semi-empirical model (Vermeer and Rahmstorf 2009). We do not use Parris et al.'s (2012) lowest estimate as there is an incredibly low likelihood of a linear rate of sea-level rise for the 21st century based on semi-empirical models of the relationship between global temperature and sea-level rise, as well as recently observed rates of acceleration (Vermeer and Rahmstorf 2009; Hay et al. 2015; Yi et al. 2015).

To model inundation exposure on dryland, we used LiDAR-based elevation data with a 3-m horizontal resolution and 15 cm vertical accuracy (RMSE). We tidally-adjusted the elevation data to the local mean higher high water (MHHW) datum with data available from the National Oceanic and Atmospheric Administration (Strauss et al. 2012; NOAA OCM 2015). Following a similar approach to Strauss et al. (2014), we employed a conservative three-fold approach to create a land/ocean layer. First, the area had to be above the MHHW mark in the elevation data to be considered land. Second, we marked all areas indicated as marine habitat in the US National Wetlands Inventory as ocean. Third, to ensure hydrologic connectivity between low-lying areas that are often overlooked in such assessments due to buried culverts not captured in elevation data, we classified streams or canals from the USGS National Hydrography Dataset high resolution data as "ocean." To ensure connectivity to the shoreline, we only included areas that are connected to the National Shoreline (NOAA OCM 2016).

We assessed inundation exposure and risk for tracts in Georgia's six coastal counties at the year 2050 using the slow, medium and fast sea-level rise scenarios described above. To rank relative exposure, we applied the same three-tier classification system as for SoVI results, but to the percentage area inundated for each tract. We report absolute area exposed to inundation, but ranking facilitates comparison with the SoVI results. We assessed relative levels of at-risk populations (eq. (1)) where highest risk is equal to the tracts with the highest inundation exposure and the highest social vulnerability in a three-tiered bivariate comparison (Emrich and Cutter 2011).

In a similar but separate assessment of the population, we examined the total population exposed as well as the socially vulnerable population considered to be at-risk to sea-level rise. For the total population, we assumed the population within a tract was evenly distributed, such that the proportion of the tract exposed to inundation was used to determine the proportion of its total population affected. This meant multiplying the projected population density (assessed based on available land) by the area forecast to be inundated under each sea-level rise scenario as done in other studies (e.g., Hauer, Evans, and Alexander 2015). To examine the population at-risk, we followed a similar approach, but based these estimates on only the populations living in tracts with elevated levels of social vulnerability.

Results

Population Projections

The population of the socioeconomic region around and including Georgia's coast is projected to increase to approximately 2.9 million people (745,000 for Georgia's six coastal counties) by the year 2050, becoming a majority-minority population (Figure 3.4). The minority population is projected to increase from approximately 44% to 60% between 2010 and 2050 for the six counties of the Georgia coast. The percentage of the population in these same counties with below poverty level incomes is projected to increase from 17.3% to 18.5%, and with educational attainment levels below high school from 9.7% to 10.2%.

Social Vulnerability

For the global model PCA of 2010, the variables age, along with All Other Races and Hispanic/Latin@, explain 35% of the variance in the data, all loading highly on the first component (Table 3.1). The variables black, poverty status, and educational attainment explain 26% of the variance in this region for 2010. The more urbanized areas in parts of Chatham, Glynn, and Liberty Counties including the cities of Savannah, Brunswick, and Hinesville, respectively, are where the majority of tracts with elevated levels of relative social vulnerability are located (for elevated tracts, n=34; Figure 3.5a).

The highest loading variables from the GW PCA results for principal component one only partially support the global model findings with both indicating the All Other Races variable as important (Figure 3.5b). For a few tracts in the six county region, the locally-weighted analysis shows that the variables black, educational attainment, and female explain more of the variance in some tracts' locally-weighted areas than the global model would suggest. While the global model results identify relative social vulnerability of tracts for certain variables, it cannot show which variables were the most important. The locally-weighted results demonstrate that the relative importance of the variables for explaining the variance in the indicators of social vulnerability changes spatially over the study region.

Moving to the year 2050, our results show that social vulnerability changes temporally too. The key areas identified as having elevated levels of social vulnerability are projected to still include tracts in urban areas of Savannah, Hinesville, and Brunswick, and although some shifts have occurred, only one more tract is indicated as having an elevated level of social vulnerability compared to 2010 (n=34; Figure 3.5c). According to the global model PCA, the variables educational attainment and black are projected to become more important indicators of social vulnerability in this region by mid-century, explaining 34% of the variance compared to Hispanic/Latin@ and female explaining 18% and 14%, respectively (Table 3.2). The locally-weighted model results support these findings with educational attainment and black becoming more important variables for explaining social vulnerability in most tracts (Figure 3.5d).

Risk to Sea-Level Rise

The total population that is projected to be directly exposed to sea-level rise, as well as at risk, depends on the scenario. We found that locally-adjusted estimates of sea-level rise for the Georgia coast range from 0.24 to 0.67 m above the 1992 level; the semi-empirically based medium projection is estimated at 0.34 m (Figure 3.6). The area of land that would be inundated by the year 2050 under the three sea-level rise scenarios ranges from 82 to 285 km^2. Under all scenarios, this would affect land in 83 tracts (+1 for the fast scenario) along Georgia's tidal coastline. Under the three sea-level rise scenarios, we estimated that 12,488 to 41,972 people could be directly exposed (Table 3.3). Of those, 3,545 to 11,009 are projected to be at risk to sea-level rise, as they would be exposed to inundation and living in tracts with elevated levels of social vulnerability. This indicates that from approximately 26% to 28% of the directly exposed population in 2050 could be at risk and have a relatively limited capacity to cope with the stresses of inundation from sea-level rise. For the fast sea-level rise scenario, eight census tracts have elevated levels of inundation exposure *and* social vulnerability. In other words, these census tracts are projected to have 6,563 people that are the *most* at-risk to sea-level rise for the Georgia coast in the year 2050 (Figure 3.7d; Table 3.3).

When we compared 2010 population counts to 2050 projections, our results showed an increase in the total population projected to be exposed to sea-level rise; under the fast scenario the increase was from 27,171 to 41, 972 people, a 55% increase. Moreover, we see a much higher increase in the population that is projected to be at risk (i.e., living in a tract identified as having elevated social vulnerability and exposed to inundation) from <1% when based on 2010 census tracts with elevated social vulnerability to approximately 26% in 2050 census tracts with elevated social vulnerability; the total count increases from 1,951 in 2010 to 11,009 in 2050, an increase of over 400%. We suspect that this significant increase is partially due to the relatively higher mean growth rate in tract populations located along the shore (0.87% annual growth) and projected to have elevated levels of social vulnerability in 2050 (0.89% annual growth) compared with the mean growth in all tracts (0.78% annual growth). This indicates that the future population at risk to sea-level rise of 0.64 m by 2050 on Georgia's coast is projected to be more than double the amount of one previous estimate of approximately 5,000 residents, which was based on 2010 social vulnerability and 0.9 m (Strauss et al. 2014).

Discussion and Conclusions

We applied demographic metabolism (Lutz 2012) and geographically-weighted PCA to show how social vulnerability and risk to sea-level rise change over space and time. With the population projected to become majority minority by the year 2050 with higher rates of people in poverty and with low educational attainment levels, we found an increase in the population at risk to sea-level rise.

Our findings regarding the total population projected to be exposed match reasonably well with other studies for this region. For example, in an analysis of Census block groups for the Georgia coast, Hauer et al. (2015) reported similar magnitudes for the total population that is projected to be exposed to inundation due to sea-level rise by mid-century; their projected mean estimates ranged from 7,318 to 41,392 people for two sea-level rise scenarios including curves for one meter by 2100 and two meters by 2100. Our larger estimates could be partially attributable to different sea-level rise forecast curves that end at the same point in 2100. However, we applied locally-adjusted upper and lower bounds following the quadratic equation reported in Parris et al. (2012), which forecasts lower rates of rise by 2050 than the curves used by Hauer et al. (2015; Clough, Park, and Fuller 2010) suggesting that our estimates are higher for another reason. We believe that this could be due to two factors. First, we increased our area via implementing hydrologic connectivity using USGS streams and canals to connect seemingly disconnected low-lying areas in the elevation grid that may not have been included in Hauer et al.'s (2015) inundation assessment. Second, our approach used the Hamilton-Perry method, which is known to have an upward bias for areas undergoing rapid growth (Swanson, Schlottmann, and Schmidt 2010). We also did not apply tract-specific limitations on growth, which would take into consideration "build-out" scenarios where there was no more space to add more houses, nor did we account for potential technological innovations that would improve capability of coastal populations to adapt to sea-level rise.

We found that the locally-weighted results offered more interpretive power when combined with the global model PCA. The global model results indicate that race (black specifically) and low educational attainment are predicted to become more important indicators of social vulnerability over for the Georgia coast as a whole (Table 3.2). The locally-weighted results convey spatial variation in the importance of each, however, showing that black is more important in the northern region, whereas educational attainment is more important in the southern region (Figure 5d). However, in the locally-weighted assessment, poverty is revealed as the most important variable in some northern tracts, which is completely missed by the global model PCA approach.

This reveals an important contribution of GWPCA, which is the exploratory spatial data analysis that is made possible. What is of particular importance regarding interpretive power is the ability to visualize the highest loading variable (Figure 5d) for the tracts with *elevated* levels of social vulnerability (Figure 5c) as well as the relative loading of those variables for different components (Figure 3c-e). As one intent of the SoVI model is to target hazard mitigation at areas with relatively high levels of socially vulnerable populations, the knowledge from a combined SoVI plus GWPCA approach allows for more specific targeting of the subgroup most at-risk. This offers a mechanism for not only planning and funding allocation to areas with elevated social vulnerability in the region, but a more informed understanding of why these areas are indicated this way.

Through our application of a locally-weighted analysis in conjunction with a population projection, our results show that the theoretical indicators of social vulnerability change over space as well as through time. This approach reveals some of the important details about why certain areas are indicated as more vulnerable than others, details that previously were masked in non-locally-weighted assessments of social vulnerability. By our approach recovering this critical information on vulnerability to hazards, local and state governments will be able to develop more appropriately-oriented hazard mitigation plans, targeting those with low educational attainment in specific areas while specifying needs for those in poverty in others. Specifically in our case, more informed sea-level rise adaptation plans could be drafted by coastal governments and agencies working to mitigate long-term impacts to these populations. We imagine that our spatiotemporal risk assessment could be extended to other hazards such as storm surges and heat waves in future studies.

Table 3.1 Model variables and components of global model PCA along with variance explained and variable loadings for year 2010 analysis.

Component	Cardinality	Component Name	Variance Explained (%)	Dominant Variables	Component Loading
1	‖	Age & Race/Ethnicity	35	Age	0.525
				All Other Races	-0.525
				Hispanic/Latin@	-0.516
2	-	Race & Poverty	26	Black	-0.552
				Poverty	-0.542
				Education	-0.537

Table 3.2 Model variables and components of global model PCA along with variance explained and variable loadings for year 2050 analysis.

Component	Cardinality	Component Name	Variance Explained (%)	Dominant Variables	Component Loading
1	-	Education & Race	35	Education	-0.510
				Black	-0.505
2	‖	Ethnicity	18	Hispanic/Latin@	-0.835
3	‖	Sex	14	Female	0.760

Table 3.3 Projected total exposed, total at-risk, and most at-risk populations for the year 2050 that would be directly affected under a given sea-level rise scenario. Total at-risk populations are the proportion of the exposed population in tracts with elevated social vulnerability. Most at-risk populations are the proportion of the exposed population in tracts with elevated social vulnerability and elevated exposure (see Figures 3.7b-d).

Scenario	County						Total
	Bryan	Camden	Chatham	Glynn	Liberty	McIntosh	
Slow 0.21 m in 2050							
Total exposed	631	1,346	5,729	2,619	170	1,993	12,488
Total at-risk	0	54	1,258	224	15	1,993	3,545
Most at-risk	0	48	0	0	15	1,934	1,997
Medium 0.37 m in 2050							
Total exposed	1,535	1,957	12,194	5,033	455	2,970	24,145
Total at-risk	0	143	2,665	826	44	2,970	6,648
Most at-risk	0	116	0	0	44	2,804	2,963
Fast 0.64 m in 2050							
Total exposed	2,599	2,654	23,154	8,476	823	4,167	41,972
Total at-risk	0	287	5,033	1,430	96	4,167	11,009
Most at-risk	0	206	2,665	0	94	3,597	6,563

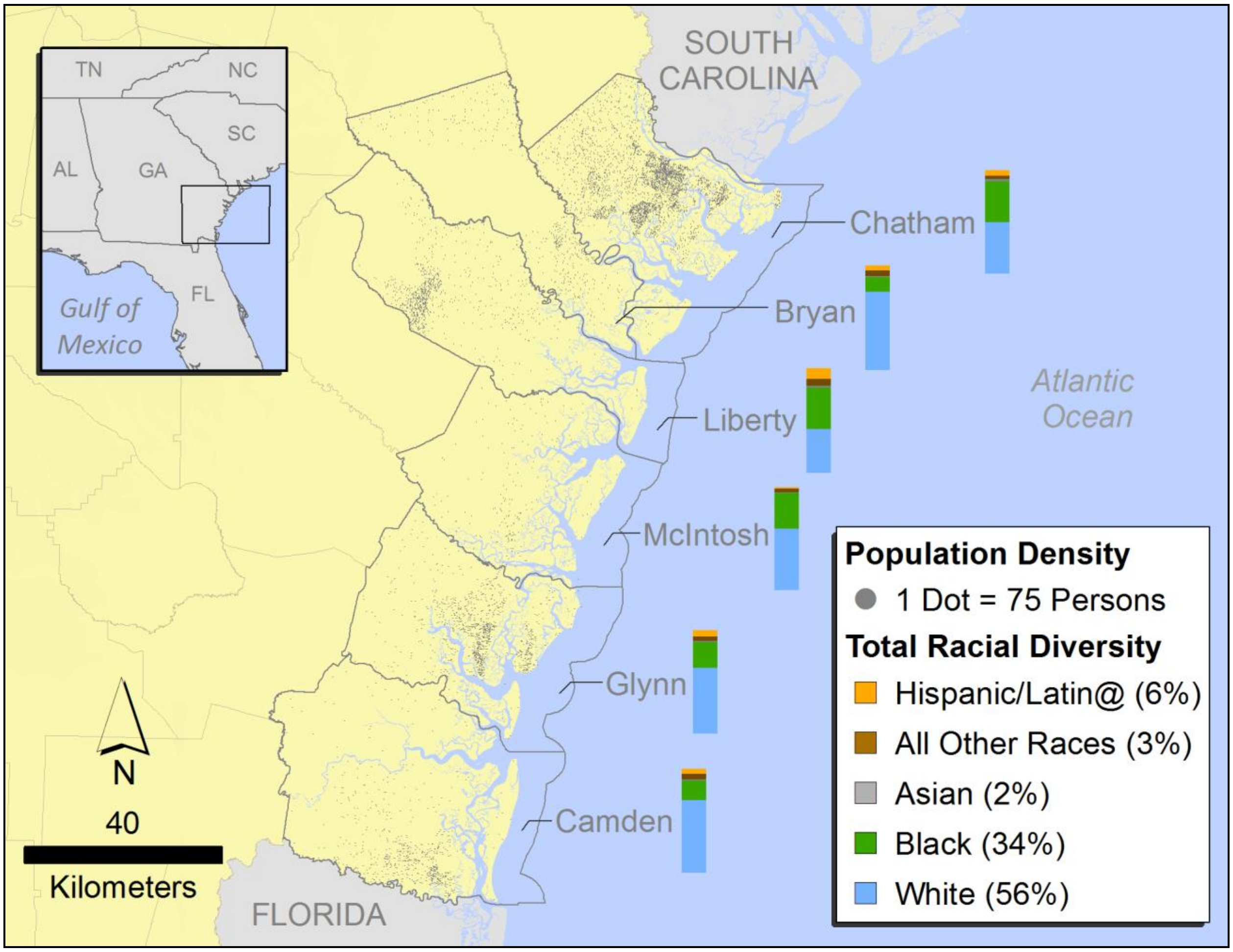

Figure 3.1 Study site of the Georgia coast. Racial diversity by county and population density by 2008 – 2012 ACS Census block groups. Block group outlines are not shown for clarity. Dots are restricted to land only. Stacked bars show racial diversity as proportion of each county.

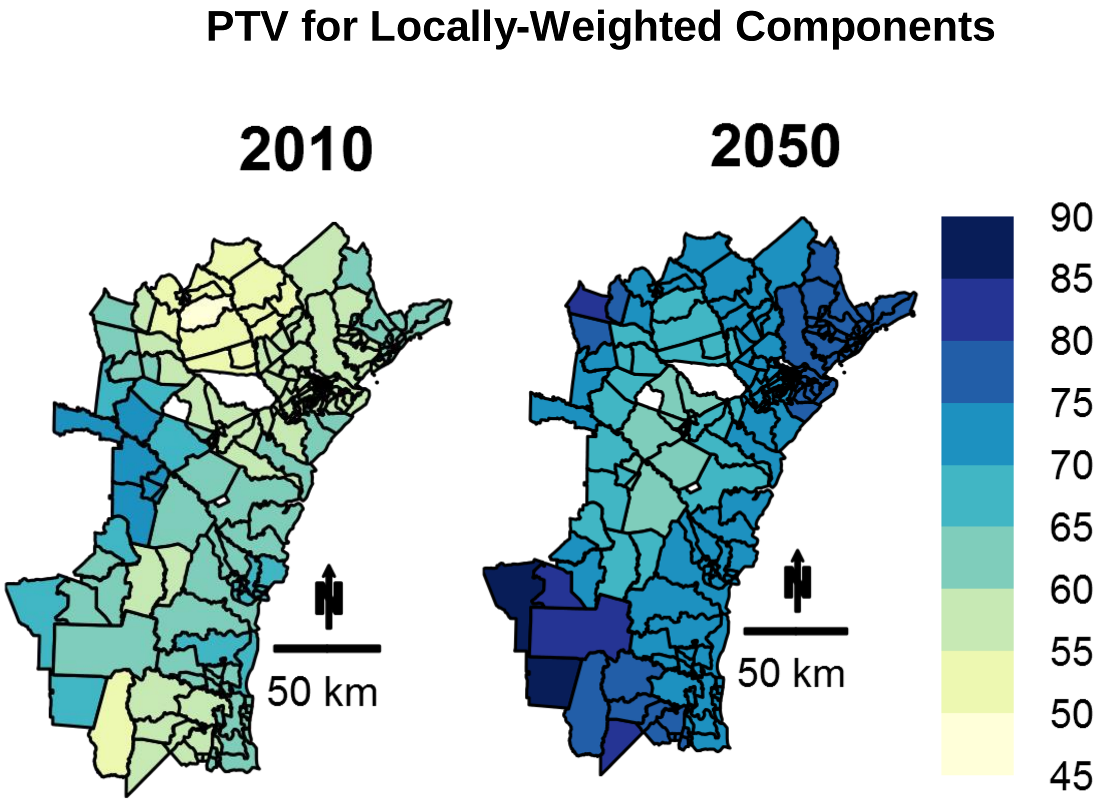

Figure 3.2 Proportion of the variance (PTV) explained for locally-weighted principal components (PC) 1 and 2 for year 2010 and PC 1-3 for year 2050. Figure shows the "region of socioeconomic influence" defined in the methods section as 217 Census tracts within a 31 km radius of the six coastal counties on the Georgia coast.

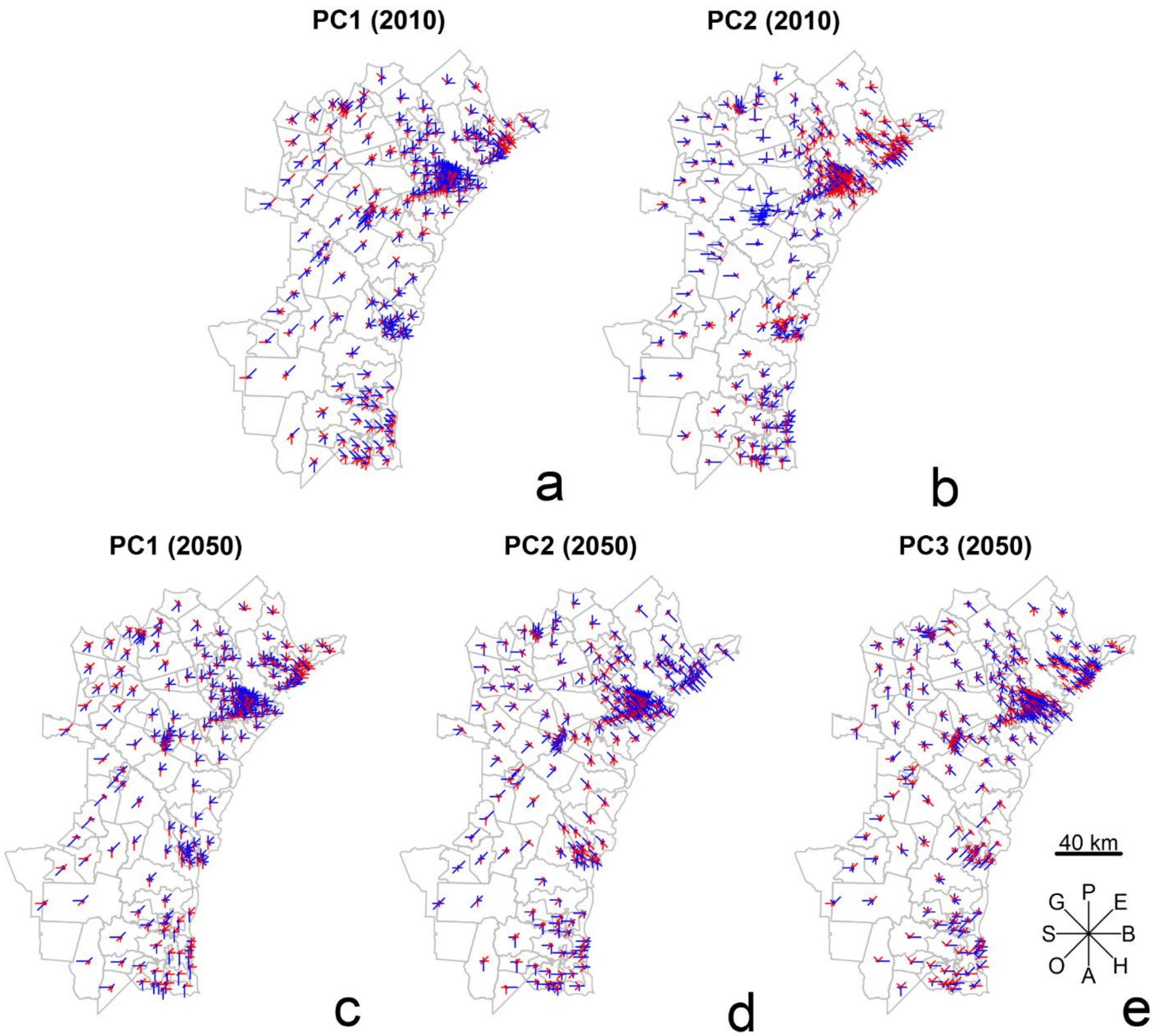

Figure 3.3 Glyph plot showing relative loading of model variables for principal components (PC) 1 (a) and 2 (b) for the year 2010 and 1-3 (c-e) for the year 2050. Blue indicates positive loading and red indicates negative loading. Length of line represents relative loading compared to the other variables. P=poverty; E=low educational attainment; B=black; H=Hispanic/Latin@; A=Asian; O=All Other Races; S=sex; G=age.

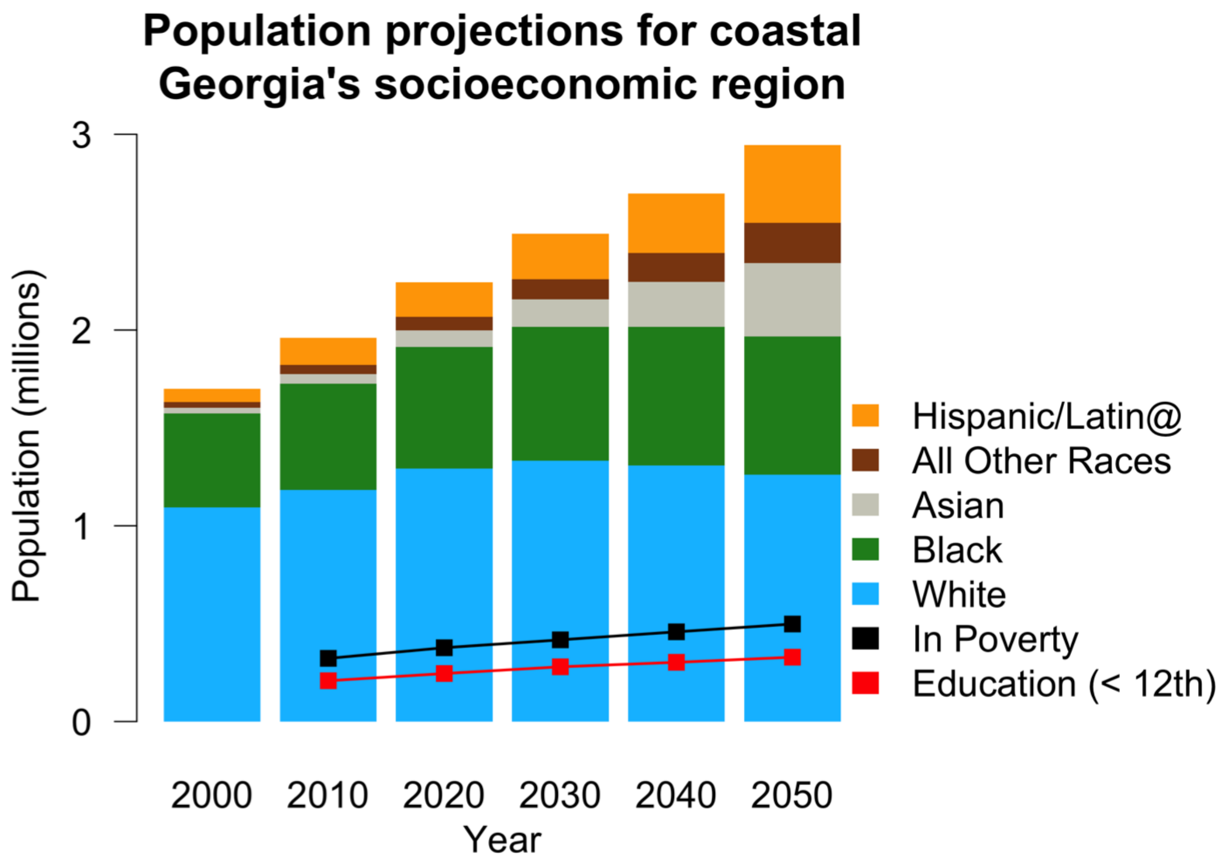

Figure 3.4 Population projections for the socioeconomic region of the Georgia coast including 23 counties. Data for 2000 and 2010 for race and ethnicity are from the full count US Census and the 2008 – 2012 ACS Census for the number in poverty and with an education less than 12th grade. All characteristics and counts for 2020 to 2050 are from our projected populations.

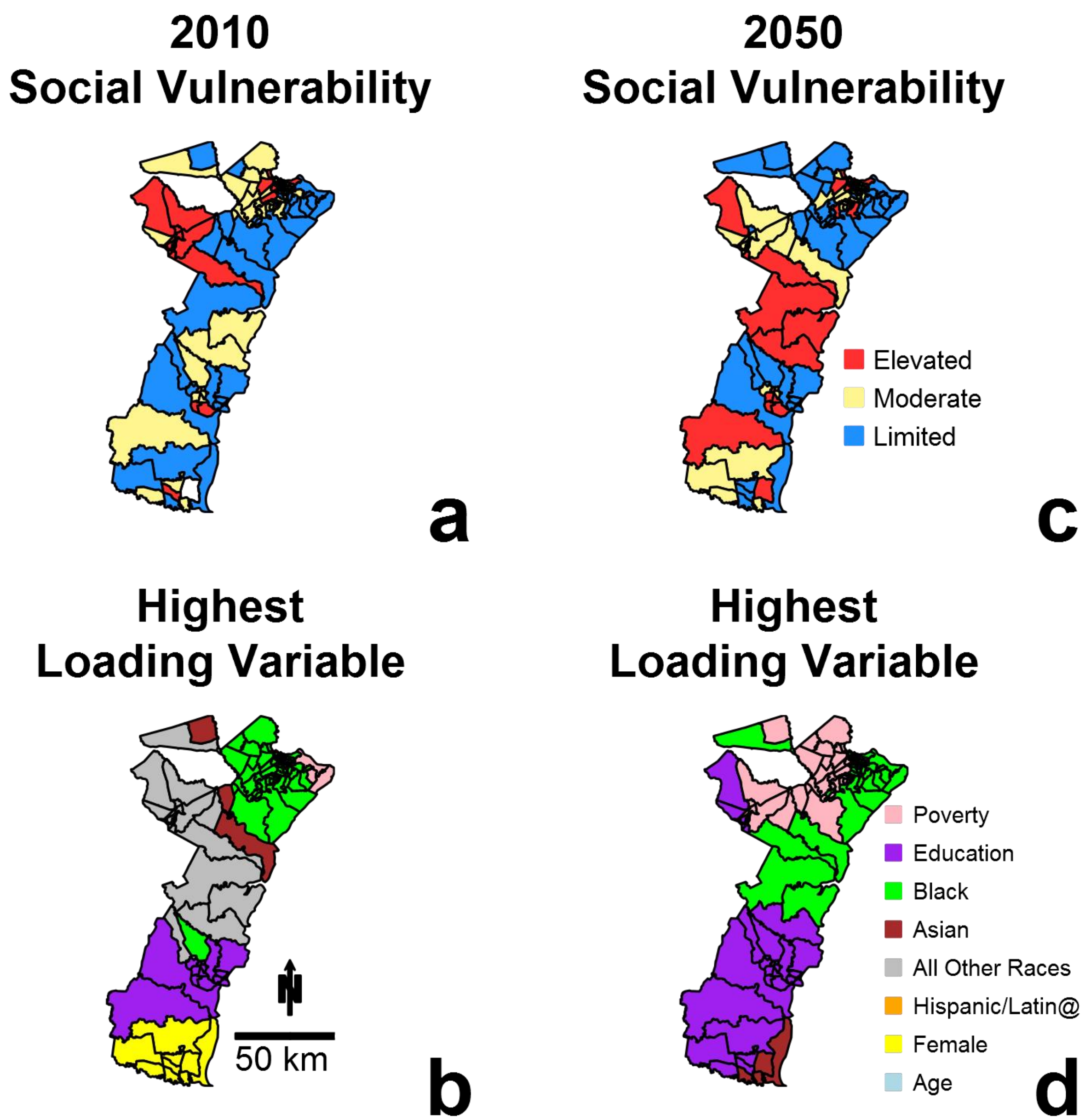

Figure 3.5 Social vulnerability for US Census tracts on the Georgia coast. Global model PCA results for social vulnerability for the years 2010 (a) and 2050 (c) along with the highest loading variable for the first principal component in the locally-weighted analysis for 2010 (b) and 2050 (d).

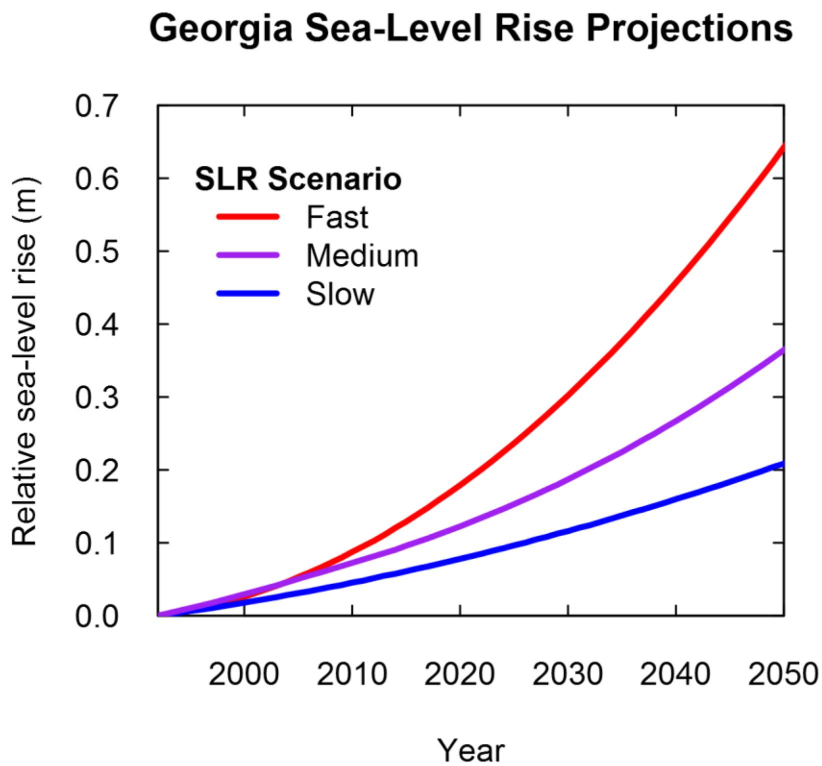

Figure 3.6 Locally-adjusted mean sea-level rise projections for Georgia's coast. The fast and slow scenarios are based on the National Climate Assessment's high and intermediate low scenarios (Parris et al. 2012) and the medium scenario is based on a semi-empirical model (Chapter 2).

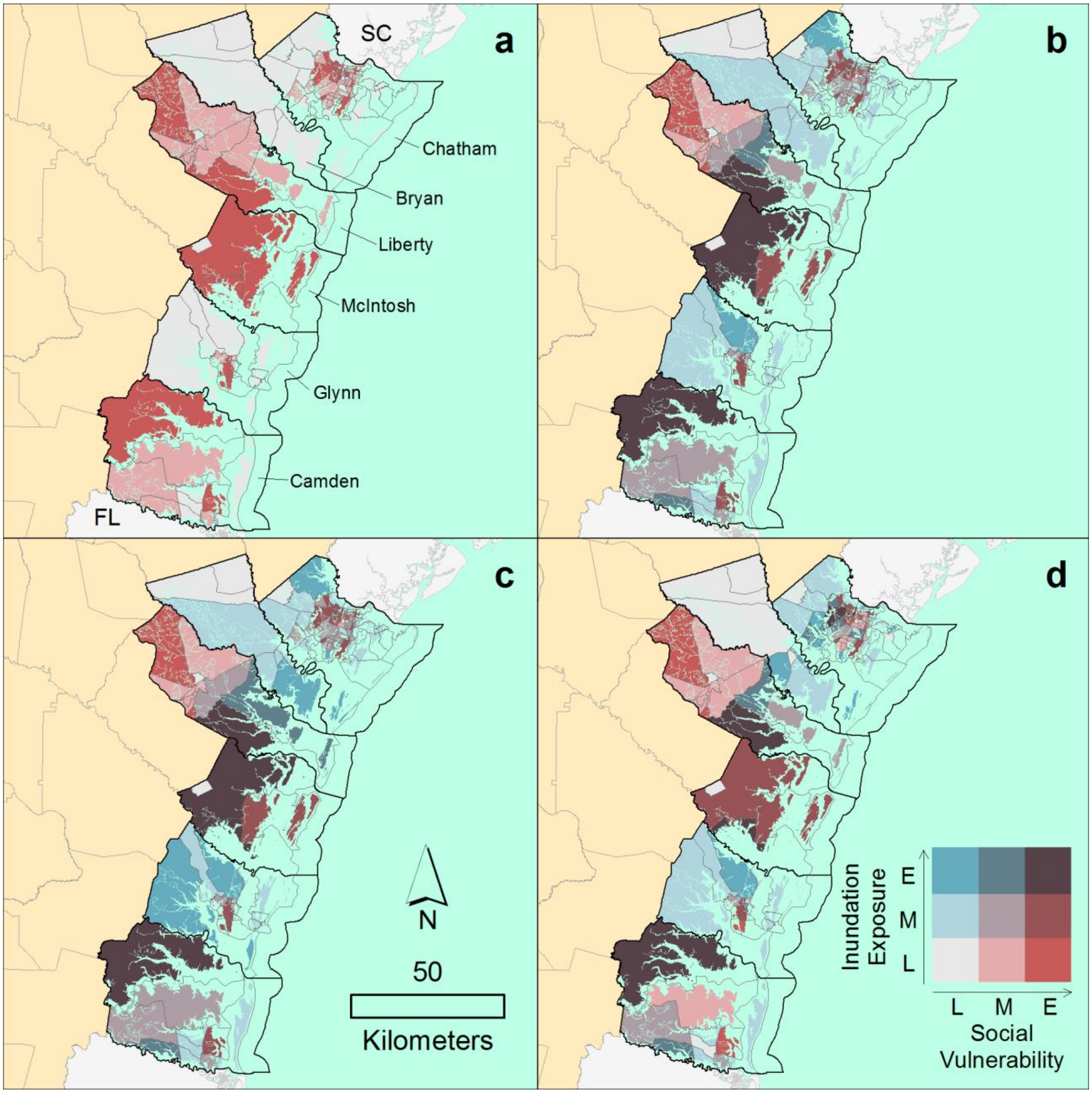

Figure 3.7 US Census tracts on the Georgia coast showing future social vulnerability (a) and risk (social vulnerability *x* exposure) for three scenarios of sea-level rise slow (b), medium (c), and fast (d) for the year 2050. In the legend, risk increases in the "northeast" direction. E = elevated; M = moderate; L = limited.

CHAPTER 4

PLACING RACE IN THE MAKING OF SOCIAL-ECOLOGICAL VULNERABILITY TO SEA-LEVEL RISE [8]

[8] Hardy, R.D. To be submitted to *Geoforum*.

Abstract

Global sea-level rise has accelerated over the past century and is predicted to continue, increasing the likelihood of disruptions to the everyday lives – and even displacement – of millions of coastal residents worldwide in the coming decades. These impacts are expected to occur unevenly, disproportionately affecting people who are more vulnerable due to having limited access to the resources needed to adapt to or migrate away from rising seas and associated increases in storm surges. In the US, and especially the US South, the history of racial violence has resulted in an ongoing racial inequality that limits many scholars' and others' potential for collaboration with underrepresented communities via multiple barriers to engagement. In this article, I examine how systemic racism, realized through structural and colorblind forms, affects vulnerability to sea-level rise. My analysis is based on the results from a comparative case study of barrier island life on two coastal Georgia islands that have incredibly different socio-political, cultural, and ecological histories, Tybee Island and Sapelo Island. Specifically, I show how most sea-level rise studies in coastal Georgia have a colorblind problem by defining vulnerability through the lens of contemporary scientific discourse on climate change. Moreover, I demonstrate how divergent knowledge discourses between the predominantly white scientific community and local African American residents allows for the persistence of strained relations as well as the allocation of worry capital by African Americans to other more important issues. I argue that a shift in the prevailing scientific discourse on sea-level rise would permit calls for climate justice to reverberate through the discursive practices of sea-level rise science by making space for a color-*aware* problem definition; one that encourages discussions at the onset of project formation to include issues of power and racial inequalities,

how race relations influence worry capital, as well as the inclusivity of multiple forms of knowledge.

Introduction

Social-Ecological Vulnerability to Sea-Level Rise

The field of hazard studies was profoundly redefined when investigations moved away from analyzing just the differential physical exposure to a hazard event (i.e., away from thinking that disasters are physical in origin) towards inclusion of the social domain and socioeconomic characteristics to explain uneven outcomes across social groups (O'Keefe, Westgate, and Wisner 1976; Hewitt 1983; Watts 1983a) (Wisner et al. 2004). Nature-society studies have further pushed scholarly understandings of human/non-human relations and the politics of knowledge production (e.g., Castree and Braun 2001; Heynen, Kaika, and Swyngedouw 2006a; Goldman, Nadasdy, and Turner 2011b; Meehan and Rice 2011), requiring yet another major paradigm shift in hazards studies, one that acknowledges vulnerability as *social-ecological*[9] (Oliver-Smith 2004; Dooling and Simon 2012), especially in an era of anthropogenic climate change driving sea-level rise (e.g., Ogden et al. 2013; Castree et al. 2014; Slangen et al. 2016). Such a shift opens up the potential for climate change research to be a transformative moment, especially if democratized and inclusive of multiple forms of knowledge (Rice, Burke, and Heynen 2015; Stehr 2015). As Mark Pelling has written, "[c]limate change adaptation is an opportunity for

[9] What I am referring to as social-ecological vulnerability is distinct from what others in the literature have defined as risk, or the product of social vulnerability and physical hazard exposure (e.g., Wisner et al. 2004). I am arguing that with climate change, the evidence for the entanglement of the social and ecological is so ubiquitous and overwhelming that climate change related hazards must be thought of as more than physical events. Social inequalities are now working their way through physical and ecological processes to create uneven vulnerability.

social reform, for the questioning of values that drive inequalities in development and our unsustainable relationship with the environment" (Pelling 2011, 3).

Rising seas could potentially affect the everyday lives of millions of people worldwide. As much as 12% of the global population is projected to live in the low elevation coastal zone (the area less than 10 m above sea level) by the year 2060 (Neumann et al. 2015), suggesting that sea-level rise could have indirect effects on numerous livelihoods globally, especially if the economic damages and losses outpace the rising sea as has been suggested could happen in some places (Boettle, Rybski, and Kropp 2016). In the US, as many as 13.1 million residents could be affected with 1.8 m of sea-level rise by the year 2100 (Hauer, Evans, and Mishra 2016). Moreover, sea-level rise is already leading to forced displacement in the US (Sabella 2016b) and is expected to continue to displace US coastal residents, threatening some culturally-distinct groups (Shearer 2012a; Maldonado et al. 2013; Sabella 2016a).

The likelihood that sea-level rise will affect coastal populations this century is increasing rapidly. Over the period 2010 to 2014, global mean sea level rose at an average rate of 3.5 times the rate observed from 1900 to 1990 (4.4 ± 0.5 vs. 1.2 ± 0.2 mm per year, respectively) due to increased rates of land ice loss and thermal expansion of ocean waters (Hay et al. 2015; Yi et al. 2015). Alarmingly, two new estimates for global mean sea-level rise suggest that the Earth may experience a multi-meter rise this century if the West Antarctic Ice Shelf collapses (DeConto and Pollard 2016; Hansen et al. 2016).

Given that it is the social, cultural, and political decisions to burn fossil fuels that cause anthropogenic global warming, which in turn leads to rising seas, I argue that sea-level rise is a social-ecological phenomenon. The anthropogenic portion of twentieth century sea-level rise ranged from 7 to 17 cm (Kopp et al. 2016) with anthropogenic forcing dominating it since 1970

(Slangen et al. 2016). Moreover, the "human fingerprint" of sea-level rise has led to a 67% increase in the number of US coastal flood events since 1950 (Strauss et al. 2016). In other words, the "inextricable social integument" (Castree and Braun 2001) of sea-level rise has become the prevailing explanatory factor. I contend that this fact should affect the conceptual framings and the empirical analytical arguments of studies on vulnerability to sea-level rise, including how adaptation planning occurs. Without anthropogenic climate change being the main driver of rising seas, the specific question of vulnerability to sea-level rise would become negligible. Assessing uneven potential for harm to this primarily human-driven hazard (Slangen et al. 2016) across racially different groups would be nearly, if not entirely, irrelevant.

Knowledges of Sea-Level Rise

The hegemonic paradigm of climate change action rests on the discourses of science, climate science in particular, which leads to calls for technocratic solutions defined via objective "upstream" science informing "downstream" policy decisions (Demeritt 2001; Rice, Burke, and Heynen 2015). This is the model of the Intergovernmental Panel on Climate Change that translates scientific findings into policy recommendations, but with an explicit effort towards separation of these two "groups," scientists and policy-makers (Miller 2001; Hulme and Mahony 2010). Scholars examining the politics of science studies have presented strong arguments that these purportedly separate groups have a "pattern of reciprocal influence" where the policy questions drive the scientific practice as much as the scientific results influence the policy (Demeritt 2001, 308; Forsyth 2003). Consequently, the politics of knowledge on climate change, or the discursive framing of climate change as a global technocratic problem, influences the "production, application, and circulation of environmental knowledge" around how to adapt to climatic change (Goldman, Nadasdy, and Turner 2011a, 2). To disrupt these flows of knowledge and democratize climate change adaptation planning, more openness to and engagement with experiential forms of knowledge is warranted.

Sea-level rise adaptation planning with underrepresented communities calls for explicit inclusion of multiple forms of knowledge (Maldonado 2014; Miller Hesed and Paolisso 2015). The value of incorporating experiential knowledge into climate change discourse is three-fold: "[i]t enables and legitimates more diverse communities of action, it resists the extraction of climate change from its complex socionatural entanglements that have place-based meaning, and it provides culturally specific understandings of what is at stake with climate justice" (Rice, Burke, and Heynen 2015, 2). Yet this can be challenging as "*knowledge is embodied* within and imperfectly translated across *power-laden social networks*" (Goldman, Nadasdy, and Turner 2011a, 16, emphasis in original). Consequently, scholars must attend to how existing power inequalities (e.g., across racial difference) affect the collection, translation, mediation, and representation of various knowledges as rising seas continue to increasingly affect everyday lives.

How forced displacement due to sea-level rise unfolds for coastal communities will take on multiple forms over the coming decades, potentially with competing discourses (e.g., local vs. scientific knowledges). Sea-level rise adaptation planning is a human rights issue, and not having an agency appointed to specifically deal with adaptation, displacement, and/or relocation associated with climate change may potentially lead to the loss of culture and further injustices to already marginalized peoples via "[f]orced relocation and inadequate governance mechanisms" (Maldonado et al. 2013, 601). As a human rights issue, facilitating a more inclusive, collaborative, and democratic approach is likely to have more success than a top-down managerial form of governance (Stehr 2015).

Including multiple knowledges in sea-level rise adaptation planning is fundamental to achieving equitable and just adaptation (or relocation) outcomes (Maldonado 2014; Nijbroek 2014). This argument is supported by work on "embodying climate praxis" and embracing local forms of knowledge to not only undermine the hegemony of science in climate discourses, but also the "[silencing of] vulnerable communities and [reinforcement of] historical patterns of cultural and political marginalization" (Rice, Burke, and Heynen 2015, 1). Treating local knowledge simply as alternative discourse can be dangerous and counter-productive (Bankoff 2004; Lazrus 2009). As has been shown for forms of environmental governance (McCreary and Milligan 2014), perhaps more critically what is needed is attention to the ontological politics at work when including traditional or local knowledge in sea-level rise adaptation governance. Furthermore, the challenges of representation and mediation of knowledge through scholarship must be considered as well, as scholars working on climate change "must never conflate data provided by those who work at a local level with local voices themselves. We [scholars] can offer our translations, our mediated accounts, and these can be very valuable, but we must never presume that we actually ever speak *for* the local" (Brosius 2006, 133, emphasis in original). However, the most socially vulnerable people are often "excluded from the decision-making, power, and resources involved in governance of risk and disaster" (Lazrus 2009, 247), which I contend can be partially attributed to choices over allocation of "worry capital" by marginalized groups.

Not only are the discursive practices of climate change science impermeable for many non-scientists, for most African Americans there are greater barriers. African Americans involvement in science and the environment is relatively limited (National Science Foundation 2015). Although increasing, African Americans inclusion in the science, technology, engineering, and math (a.k.a. STEM) fields in the US is relatively low and increasing more slowly when compared to other racial and ethnic minority groups (National Science Foundation 2015). This has repercussions for scientific practice in climate change as well as adaptation planning, specifically regarding what types of questions are considered to be important and worth funding and investigating as well as how adaptation planning includes/excludes climate justice initiatives. Moreover, action on climate change is part of the environmental movement more broadly, which suffers from a significant lack of diversity and inclusion of African Americans (Finney 2014). This further exacerbates the problem of including the experiential knowledge of underrepresented communities.

Scaled Climate Justice and Race

Scale matters in climate change studies. Many studies of climate change inequalities have focused on the nation as the unit of analysis (Althor, Watson, and Fuller 2016; Chapter 2). This creates space for oversight where intra-national inequalities could be overlooked during resource allocation for climate change adaptation planning, including relocation efforts (Shearer 2011; Shearer 2012a). This would be a particularly significant oversight for the US as it is predicted to have the greatest land losses due to future sea-level rise (Chapter 2), suggesting that a targeted effort is necessary to highlight marginalized groups living along US shorelines. Moreover, extending this notion, cities and urban settings are likely to experience the largest economic impacts and subsequent migration, thus attracting the most attention for funding and mitigation of the effects. This could create an oversight of rural communities, particularly communities that are both rural and underrepresented.

More robust empirical evidence is still needed regarding the causal factors that lead to differences in livelihood choices and life chances of underrepresented groups, differences that directly affect vulnerability (Gaillard et al. 2014). Environmental justice scholarship has taken on much of this work through examining the role of race in relation to environmental hazards. Based on many national level and local case studies, environmental justice research has demonstrated the ubiquity by which people of color have been disproportionately affected by environmental hazards including, but not limited to, toxic substance releases, poor water quality, and extreme weather events (e.g., UCC 1987; Bullard 2000; Pulido 2000; Pastor et al. 2006; Eligon 2016). As a human rights oriented field, "[*e*]*nvironmental justice embraces the principle that all people and communities are entitled to equal protection of environmental and public health laws and regulation*" (Bullard 1996, 493, emphasis in original).

Human rights focused research on indigenous communities' vulnerability to sea-level rise has touched on race (e.g., Shearer 2012b) and other work has directly engaged with African American communities (e.g., Paolisso et al. 2012; Miller Hesed and Paolisso 2015). Yet, none of this scholarship has fully engaged with critical race theory regarding the effect of race on the making of vulnerability and its continued formation in relation to rising seas, especially in US coastal communities. Consequently, the gap between critical race studies and vulnerability to sea-level rise persists even though a number of studies have recently demonstrated the increased potential for harm to people of color from climate change related hazards (e.g., CBCF 2004; Leiserowitz and Akerloff 2010; Shepherd and KC 2015); what has been called "the climate gap" (Gaillard 2012). Such analyses extend the work originating in the field of environmental justice and critical race studies, investigations that have demonstrated how racism operates through not only overt acts of violence, but much more subtle means of hegemonic, structural, and colorblind forms (Bonilla-Silva 1997; Pulido 2000; Bonilla-Silva 2013; Omi and Winant 2014; Pulido 2015).

Critical race theorists contend that race is a social fact, not an essence rooted in nature or illusory and invalid; and, it is not a mask for something else, being reducible to cultural difference, national identity, or class inequality (Omi and Winant 2014). As a social fact, it is constantly being redefined through the process of racial formation, a "sociohistorical process by which racial identities are created, lived out, transformed, and destroyed" (Omi and Winant 2014, 109). Given how structural and colorblind forms of racism facilitate the persistence of white privilege (Bonilla-Silva 2013; Omi and Winant 2014), and the effect this has on livelihood choices and life chances (Bonilla-Silva 1997; Gaillard 2012), in this article, I focus specifically on this gap to show how these forms of racism work to reproduce racial inequalities in vulnerability to sea-level rise by limiting opportunities for adaptation planning.

Through affecting social networks that appropriate access to power and resources, structural and colorblind forms of racism affect everyday lives and opportunities of racial and ethnic minorities, but especially black people in the US South due to its history of racial violence and legacy of slavery (Greene 2006; O'Connell 2012). For example, there is an inequality in poverty across black-white lines that correlates with the 1860 slavery concentration, independent of economic and social status today (O'Connell 2012). Spatially, however, most residents living in low-lying *coastal* cities of the US South are affluent white people (Ueland and Warf 2006). This finding is supported by empirical evidence that historically traces the social and political processes along the US southern coast that facilitated disenfranchisement of racial minorities through land grabbing practices (Kahrl 2012). Many communities along the US East Coast and Gulf Coast regions were historically predominantly black-owned, but through processes of "coastal capitalism" these coastal properties were bought cheaply and black community access to investment opportunities and amenities limited through coercive and corrupt business practices (Kahrl 2012).

Although migration of affluent white people to the coasts since the 1920s has facilitated the loss of many waterfront properties by people of color (Kahrl 2012), the population of US coastal counties is still 47.5% who are identified as minorities (i.e., not white alone) and 14.2% as African Americans (US Census 2010). In the US South specifically, African Americans make up 19.8% of the population in coastal counties, which is considerably higher than the national percentage of 13.6% (US Census 2010). This suggests a definitive potential for racial minorities to be affected by rising seas in the coming decades, even if not directly through ownership of waterfront properties but indirectly through impacts on their daily use spaces. White privilege upheld by a racialized social system is why the US South's coasts are not populated with larger numbers of theoretically vulnerable social groups (Kahrl 2012), but for those urban and rural spaces that remain majority-minority communities in low-lying coastal areas, it becomes important to highlight these marginalized groups and facilitate "community-led and government-supported" adaptation planning (Maldonado et al. 2013, 602). When these efforts are targeted towards marginalized and underrepresented communities, barriers to engagement can persist and block meaningful and productive dialogue.

Worry Capital

In studies of climate change risk perceptions, climate scientists and social psychologists have shown that people have a "finite pool of worry" (Hansen, Marx, and Weber 2004; Weber 2006; Weber 2010). Hansen et al. (2004) tested this hypothesis with farmers by comparing ranking of concerns regarding national level politics versus crop yields via two scenarios. In one scenario, information was shared about unfavorable seasonal climate conditions for the upcoming growing season. Farmers in this scenario rated climate as of greater concern than national politics compared to farmers presented with a favorable seasonal climate forecast. This study and similar ones suggest that when one issue of concern or risk becomes more pressing, concern for other issues tends to decrease due to limited emotional resources (Linville and Fischer 1991; Hansen, Marx, and Weber 2004). I refer to this concept more generally as worry capital and situate it within a political ecology of livelihoods framework. As my argument is situated in the context of how worry capital affects local livelihood decisions and strategies – particularly, decisions about where to allocate limited worry capital in the context of the ongoing formation of social-ecological relations under climate change (i.e., what to worry about right now) – I briefly review the concept of capitals in livelihoods studies.

The original sustainable livelihoods framework called for evaluating livelihood strategies via resources, or assets including natural, economic, human, and social capitals (Scoones 1998). Yet, despite its promise this approach was critiqued for failure to take seriously the notions of politics and power due in part to an overemphasis on instrumental economic analyses (Scoones 2009). As an effort to make explicit the engagement with politics and power, Carr (2015) has called for a merger of political ecological examinations of power within a livelihood approach's place-based, analytic context in order to generate more robust explanations for livelihood decisions-making in the context of purportedly external forces. Drawing on these theoretical frameworks, I define worry capital as not a quantifiable asset, but as an analytical concept for considering how locally marginalized groups of people necessarily navigate and manage hegemonic structural relations of power. Specifically, I investigate how systemic racism and race relations affect vulnerability to sea-level rise due to their affects on allocation of worry capital in the case study that I present below.

Using a comparative case study of barrier island life off the coast of Georgia, in this article I argue that a racialized social system plays a critical role in the production of vulnerability to sea-level rise. In the last two sections, I describe my case study research site, coastal Georgia including Tybee and Sapelo Islands, and I illustrate the role of race in the making of social-ecological vulnerability to sea-level rise by discussing barriers to engagement with an underrepresented island community.

Georgia Barrier Island Communities

Coastal Georgia

The daily rhythm of all human and non-human life on Georgia's coast is defined by the large tidal ebb and flow, having tides with a range of two plus meters that move in and out twice daily, what is called a semi-diurnal tide. Tourists sometimes think the region is in a drought if they arrive at low tide, as the creeks look like mud sloughs with only traces of the millions of gallons of water that was there just hours before. Yet, this daily rhythm is being disrupted by rising seas leading to increased levels of nuisance flooding (Sweet et al. 2014). Given twenty-first century local sea-level rise projections for as high as two meters by the year 2100 (Parris et al. 2012; DeConto and Pollard 2016), "extreme flooding" is only expected to increasingly affect daily life (Strauss et al. 2014).

The region of the Georgia coast extends linearly approximately 160 km from its northern section where the Savannah River flows into the sea to the south where the St. Marys River empties the tannin-rich, tea-colored waters of the Okefenokee Swamp into the Atlantic Ocean on the border with Florida (Figure 4.1a). Within this coastal zone are hundreds of kilometers of shoreline that sinuously wind around approximately 145,000 hectares of tidal wetlands; wetlands that include fresh, brackish, and salt marshes as well as tidal cypress swamps located up the numerous rivers with names like Altamaha and Ogeechee. This area's ecological significance stems, in part, from comprising nearly one-third of all the salt marsh found on the US eastern seaboard offering numerous ecosystem services to the area (Craft et al. 2009; Titus et al. 2009).

Evidence from ecological studies support the notion that these coastal systems may be intensely social natures (Castree and Braun 2001; Meehan and Rice 2011). The tidal marsh systems are formed and transformed via land and sea through rapid local population growth and development practices as well as by rising seas and increased storm surge intensity that affect wetland processes and ecosystem resilience (Kirwan et al. 2011; Kirwan and Megonigal 2013; Little et al. 2015). For example, nineteenth century New England area farming practices triggered large amounts of erosion, resulting in large sediment loads flowing down rivers to the coastal marshes of the Plum Island, MA area (Kirwan et al. 2011). This, in turn, built the existing marshes upward and outward, potentially making them more resilient to rising seas (Kirwan et al. 2016). It is undetermined if this is the case for Georgia's salt marshes; regardless, with the effect of the social-ecological phenomenon of rising seas and the marshes response to it, all marshes are becoming human modified social natures.

Tybee Island

Tybee Island is situated as the most eastern point in Georgia and just south of the mouth of the Savannah River and just east of the city of Savannah (Figure 4.1b); Georgia's earliest colony and a city that has served as a strategic port for Georgia and the US since the eighteenth century(Sullivan 2003). The northern end of Tybee Island served as a military post in many wars from the American Revolutionary War through World War II (Ciucevich 2005). In its earlier days, Tybee was initially accessible by steamboat, with its first hotel constructed in 1876 followed by numerous boarding houses. It was promoted heavily as a beach resort destination for the city of Savannah; railroad access came in 1887 and could bring as many as 80,000 visitors in a four month period (Ciucevich 2005).

The causeway was completed in 1923, facilitating an entirely new boom era for Tybee of beach-seeking automobile owners, which specifically targeted white people as captured in this circa 1930 brochure, " '[t]wo million white population can reach Savannah Beach by automobile in far less time and with far greater comfort than a few thousand could not many years ago' " (Ciucevich 2005, 110). Despite the development of the road, the closure of railroad access in 1933 limited the target audience to the local automobile-owning population, and prevented a regional or national scope for attracting tourists. Beach tourism began waning in the 1930s as a consequence and the resort life gave way to more of a fulltime residential population of a few thousand people. After World War II through the 1990s, Tybee became primarily a small residential community of blue collar workers who labored in Savannah.

According to Ciucevich (2005), the 1996 Olympic Games turned the economy around, however, and since this time Tybee has become a popular retirement destination with property values increasing nearly ten-fold in some cases according to study participants. I was informed that Tybee is becoming a community of amenity migrants, consisting of retirees and second homeowners seeking access to beaches, marshes, and a "quiet" life at the edge of the city. A similar process is occurring on Sapelo Island, though at a much lower magnitude. The current City of Tybee Island is a barrier island community with an area of about 830 hectares and approximately 3,000 fulltime residents and is accessible via the approximately 10 km US Highway 80 causeway from the city of Savannah, Georgia.

Sapelo Island

Sapelo Island came to be exclusively owned by the plantation owner Thomas Spalding and his relatives or heirs throughout most of the nineteenth century (Sullivan 2001). The Spalding family's primary activity on the island was operating a slave plantation growing long-staple (i.e., Sea Island) cotton and rice through 1865. The Civil War ended most large scale industrial activity until automobile industrialist Howard Coffin purchased most of the island in 1912 for agricultural and recreational purposes (Sullivan 2001).

During the interval between 1865 and 1912, at least 15 small communities around the island were purchased and settled by former island slaves and their descendants (Walker Bailey and Bledsoe 2001; Sullivan and Gaddis 2014). Today's descendants call themselves Saltwater Geechee, having identities that are tied to the rhythm of the surrounding tidal salt marsh (Walker Bailey and Bledsoe 2001). They are part of the greater Gullah/Geechee Nation, a culturally-distinct group of African American West African slave descendants that live along the US Southeast's Sea Islands and Lowcountry, a region that extends from northern Florida into southern North Carolina (Goodwine 1998; Walker Bailey and Bledsoe 2001; Crook et al. 2003; Goodwine 2015; Derickson 2016). A notable piece of history for this place is that it is home to the earliest known Islamic text in the Americas, a 13-page document of Muslim law and prayers written in the early nineteenth century by a native West African named Bilali who was enslaved on Sapelo from approximately 1802 until 1855 when he moved to the mainland due to ill health (Martin 1994). A few of the people that I interviewed and spoke with during my fieldwork have traced their heritage directly to Bilali.

In 1934, tobacco industry magnate R.J. Reynolds Jr. purchased the majority of the island from Coffin, except for seven privately held Geechee communities (Figure 4.2c). Throughout his

30-year tenure as primary land owner on Sapelo, Reynolds relocated all but one of these communities, consolidating the hundreds of Sapelo's Geechee people from the remaining seven communities into one community (Sullivan and Gaddis 2014).

The State of Georgia purchased the northern end of the island in 1969 followed by the southern end in 1976 from Reynolds' widow, Anne Marie Reynolds. The Georgia Department of Natural Resources (GA DNR) has since managed 97% of the island, mostly as the R.J. Reynolds Wildlife Management Area. Prior to these purchases and during Reynolds time, the University of Georgia (UGA) began conducting ecological research on Sapelo in 1947, facilitated by the relationship between ecologist Eugene P. Odum and R. J. Reynolds (Sullivan 2008). This relationship led to the establishment of the UGA Marine Institute in 1953, being housed in Reynolds' former guest residence and dairy farm areas. In 2000, the UGA Marine Institute became the host of one of the National Science Foundation's Long-Term Ecological Research (LTER) programs (currently there are 25); Sapelo's is called the Georgia Coastal Ecosystems LTER, which focuses on the long-term effects of climate change, sea-level rise, and human perturbations on estuaries and marshes. In 1976, the National Oceanic and Atmospheric Administration created the Sapelo Island National Estuarine Research Reserve (SINERR), which is focused on the four goals of stewardship, research, training, and education and part of DNR.

Hog Hammock is the only privately held community remaining on Sapelo Island; an area of about 166 hectares with approximately 46 part and fulltime residents. Unlike Tybee Island that has a US highway running to it, Sapelo Island is only accessible by a State-run ferry, the Katie Underwood, which is named after the last mid-wife to have lived on the island. The ferry runs two or three times per day each way, depending on the day of the week.

In comparison, these are two barrier island communities with significantly different histories of racial politics. Racial difference is prominent between these areas today as indicated in the 2010 US Census tract data (US Census 2010), which shows that Tybee Island residents are 94% white and that the residents of the Sapelo Island area (this includes a portion of the mainland) are 47% African American (49% non-white); of Sapelo residents specifically, based on my fieldwork I estimate that approximately 64% are African American.

Both of these communities are significantly exposed to physical inundation of land from sea-level rise (Figure 4.1b-c). Assessing the area of land currently above the mean higher high water (MHHW) mark, at 1.2 m, approximately 80% of Hog Hammock and 60% of the City of Tybee Island would be inundated on a regular basis. While these statistics highlight the impact to the community as a whole – and if applied to parcels, property owners – such numbers may unintentionally limit discussion around the potential effects that near daily inundation will have on the everyday practices and experiences of residents. Alternatively, they can be used to facilitate discussion, though special attention and sensitivity must be paid to the potentially dire messages about future community losses that are presented during such meeting spaces.

Methods

In a (weighted) comparative case study, I examined how vulnerability to sea-level rise in these two barrier island communities varies across social groups, especially racial difference. I should mention here that while this is a comparative case study between an urban community with predominantly white residents (City of Tybee Island) and a rural community with primarily African American residents (Hog Hammock of Sapelo Island), I dedicate more analytical attention to the empirics and race relations on Sapelo Island. I use data from Tybee to draw a contrasting view of a similarly situated physical geography (i.e., a low-lying barrier island) that possesses a distinctively different set of socio-demographic characteristics.

The fieldwork for this project consisted of a total of nine months on the Georgia coast, three months on Tybee Island (one in 2013 and two in 2015), one in McIntosh County where Sapelo Island is located (2015), and five on Sapelo Island (all in 2015) with one preliminary visit the month before and two follow-up visits after the main period. I conducted participant observation in these communities and the greater area of the Georgia coast by attending or participating in 39 events such as church services and functions, city council and county commission meetings, environmental group meetings, public and private presentations on sea-level rise to county and city governments and residents along the Georgia coast.

Some of the meetings and presentations regarding sea-level rise date back to 2008 (some for which I was an active presenter), and although many years ago, they still inform my understanding and analytical interpretation of vulnerability to sea-level rise. I paid explicit attention to racial diversity regarding presence and mention at all of these public and private meetings about sea-level rise as well those of environmental group meetings. This, in part, informs my understanding of the lack of racially diverse involvement in these meetings and sea-level rise adaptation planning efforts on Georgia's coast. Specific quotes from all of these meetings are not included due to confidentiality and rights of those present not being sought for this specific project.

To familiarize myself with and immerse myself in these landscapes at an efficient, but observable pace, I spent a period of time exploring both islands via foot, bicycle, and automobile with a computer tablet that had an app loaded on it, which allowed me to see my location overlaid with predictions of areas that would be inundated by different levels of sea-level rise. I conducted semi-structured interviews (n=34) with local residents (n=40) and with people in management or government positions with state, county, and city entities (though all but four were residents of these islands) in which I inquired of the interviewee's awareness and knowledge regarding each community's challenges, including climate change, environmental hazards, and sea-level rise (Appendix B). Tybee included 24 interviewees and Sapelo included 16 interviewees; interview times ranged from approximately 30 to 90 minutes and total over 30 hours. For government or management interviewees (eight for Tybee and four for Sapelo), in addition to the questions I asked of all interviewees, I explicitly probed about sea-level rise adaptation planning as either an ongoing process (Tybee; e.g., see Evans et al. 2016) or as a future endeavor (Sapelo). Of those people that I officially interviewed, 10 identified as African American.

On Tybee Island, I employed snowball sampling, beginning with my own professional network of contacts within the local government. I attended and/or observed (on television or the internet) many city council meetings and citizen-based, government appointed committees, two Martin Luther King Jr. Day parades (Tybee's and nearby Savannah, Georgia's), as well as a few other festival type events including Sapelo's Culture Day hosted by a local non-profit organization called the Sapelo Island Cultural and Revitalization Society (SICARS).

All audio-recorded interviews (n=26) were transcribed for analysis by either myself, an undergraduate assistant, or a professional transcription service. I analyzed the interview transcriptions as well as field notes from the remaining eight interviews with no audio recording and participant observation at events and of daily life using narrative analysis. Specifically, I read the transcripts and field notes while analyzing them for narratives on themes related to race, vulnerability, and sea-level rise, with particular attention to references to racial inequality and environmental knowledge. Narrative analysis enables the research analyst to examine "how a speaker or writer assembles and sequences events and uses language and/or visual images to communicate meaning, that is to make points to a particular audience (Riessman 2008, 11). As I experienced in early interviews on both Tybee and Sapelo Islands, participants often expressed lacking substantial knowledge about sea-level rise or their community's or their own vulnerability to it. This came with concern that they would have anything to offer me during the interview. Consequently, I shifted my interview style from a questioner/respondent format to one that elicits narration and storytelling and an interplay between two participants. "Encouraging participants to speak in their own ways can, at times, shift the power in interviews, although the relations of power are never equal, the disparity can be diminished" (Riessman 2008, 24). This was a particularly effective approach with Sapelo Island participants due to the "research fatigue" that has occurred there.

Journalists, historians, and social science researchers have extensively interviewed and documented the culture of the Geechee residents of Hog Hammock over the past century (e.g., Granger 1940; Crook et al. 2003). Very reasonably, this has led to "research fatigue" with many Geechee residents, some having been asked the same questions repeatedly for decades. To develop rapport with Hog Hammock residents, I did not ask research related questions or request interviews during the first two months of my five month stay on the island. Instead I developed relationships with island residents and donated a limited amount of time to planting peas, part of the Geechee Red Peas Project, an initiative to create jobs and income for Geechee residents. I also offered my website design skills to SICARS, and worked with the organization's president and vice-president to redevelop their website on a free hosting service to help them save on organizational overhead costs.

After this two month period, as a precursor to requesting interviews and to further establish the reason for my presence as well as to facilitate engagement with Hog Hammock community residents, I held one interactive presentation at the public library. It was attended by approximately 37 adults that included island visitors, non-traditional residents, and ecological researchers. It was interactive in the sense that I presented my knowledge about sea-level rise with the attendees, but also requested theirs via a short survey and focused group discussion throughout the presentation.

During the entire five month period, I spent many days dragging seine nets along the beach sloughs and surf to catch fish and nights playing cards at the local bar with Geechee residents. I attempted to make it clear that my research involved interviewing coastal residents about sea-level rise, a point I made an explicit effort to convey when first meeting anyone. I intended for the interactive presentation at the library to help make this point, but also to open up the possibility of an informal dialogue developing between me and all Sapelo residents around stories of flooding, observations of environmental change, and the potential impacts of climate change and rising seas. While only 25% of my official interviewees identified as African American, I had substantive interactions with many African American coastal residents, no less than 22 outside of my interviewees.

As an elicitation tool and qualitative GIS technique (Cope and Elwood 2009), I measured elevation with a Real Time Kinematic Global Positioning System (RTK GPS) on Sapelo Island (Figure 4.2). While this allowed me to collect ground control points (n = 30) for a rudimentary accuracy assessment of the laser-based (LiDAR, or light detection and ranging) elevation data I used in my estimation of sea-level rise inundation, it more importantly worked as a boundary object around which conversation regarding knowledge about sea-level rise and relative height of land to high tide could be facilitated with Sapelo residents. This led to six such conversations, which aided in me working through the barriers to engagement that I elaborate upon below.

Barriers to Engagement

The City of Tybee Island has recently concluded a multi-year sea-level rise adaptation project in partnership with the Georgia Sea Grant of the University of Georgia (Evans et al. 2016); Hog Hammock has no sea-level rise planning in place. Before I move on, I want to first clarify that I am not making the claim that Tybee Island has an adaptation project whereas Hog Hammock does not because of racial difference, and especially not because of intentional acts of racism. Second, I recognize that there is a higher likelihood for the larger community of Tybee Island to have planning in place both as a more populated and incorporated entity, just purely from the greater chance of there being someone living on the island and/or in the government that would exert such efforts. Despite these caveats, what I am claiming is that the City of Tybee Island is *more likely* to have a sea-level rise adaptation project due to racial difference, not just because of differences in population size, class, education, or access to the right social networks. The higher likelihood is facilitated by race as a "master category" (Omi and Winant 2014), one that prevails in producing these different socioeconomic characteristics due to structural and colorblind racisms, which in turn, I contend, generate many barriers to engagement regarding climate change adaptation planning aimed at mitigating vulnerability of coastal communities.

Generally speaking on directionality of engagement, I explicitly do not want to suggest a need for a unidirectional, top-down style engagement by scientific researchers presenting to underrepresented communities. This would assume limited agency for the members within the underrepresented community. Instead, I contend that structural and colorblind racisms produce semi-permeable barriers to *co*-engagement with Sapelo's African American, Geechee community, and perhaps other minority communities as well. In other words, these barriers limit collaborative engagement opportunities, which must occur to facilitate working across social differences that include race, class, education, and ways of knowing. In coastal Georgia, and perhaps beyond in many instances, I argue that these barriers include at least a colorblind problem definition in much of the professional community working on the potential effects of sea-level rise, strategic allocation of limited worry capital in underrepresented communities, and divergent discourses of environmental/climatic change between the scientific and non-scientific communities. Below, I elaborate on each of these three in turn, but first I want to briefly articulate how each of these is specifically related to race while acknowledging that the latter two barriers can be found in many non-racialized contexts (e.g., see Hansen, Marx, and Weber 2004 for an example on worry; see Rice, Burke, and Heynen 2015 for an example on knowledge).

Placing Race

As I outlined in the section on Sapelo Island's history, since the importation of West Africans as slaves in 1802 by the white plantation owner, Thomas Spalding, Sapelo has had a racialized landscape (Schein 2006). The intersectionality of race and landscape is partially revealed through Sapelo's slave descendants self-identification as *Saltwater Geechee* (Walker Bailey and Bledsoe 2001). It is very possible that the descendants of Sapelo slaves came to be called Geechee through their West African heritage (Gomez 1998) and that their identity as a saltwater people is linked to their livelihoods being tied to the salt marsh that surrounds Sapelo (Walker Bailey and Bledsoe 2001). This necessarily entangles race and culture in the landscape, as well as the ecology in the identity of the Saltwater Geechee people living on Sapelo.

This process of racialization of the landscape continued through the twentieth century, demonstrated in part by what Geechee people living on Sapelo told me during my fieldwork, which is that the relocations and closing of six Geechee communities by a white man, R.J. Reynolds (majority island-owner 1934 to 1964) occurred through acre-for-acre swaps, coercion, threats, and broken promises of new homes with electricity and tin roofs. Perhaps some people willingly relocated, but the relocations were, at least in part, a result of the unequal power relations between Reynolds and the island's Geechee people. Reynolds was the only employer on the island and also controlled access to the mainland (approximately 10 km away by boat). If a Sapelo Geechee person lost his/her job, finding other sources of income would become extremely challenging, often necessitating being on the mainland away from friends and family during the work week. Reynolds also controlled access to electricity on the island, another mechanism of influence and control over Sapelo's Geechee people, until Georgia Power connected it in 1953 (Walker Bailey and Bledsoe 2001).

This process continues even today in "how the landscape ... *work*[s] in reproducing everyday life and all of its social relations" (Schein 2006, 10). For example, a number of Geechee residents of Hog Hammock are employed by the DNR Parks and Recreation Division as service staff at the only mansion on the island, originally built by Thomas Spalding in the early 1800s, and restored by both of his wealthy white successors, Howard Coffin and R.J. Reynolds, as majority-owners of the island. Local Geechee referred to the mansion as "the Big House" in conversation and interviews, citing examples of disagreement when white tourists staying at the house would sometimes reminisce of the "good ol' days" and how pleasurable they must have been. The landscape, through continued presence of its ante-bellum structures and current labor relations, has an inscription of slavery that resonates in the everyday lives of local Geechee residents, which I contend permeates all of the barriers to engagement (outlined below) between Georgia's professional community of practice working on sea-level rise and Sapelo's Geechee population, and likely extends to Georgia's greater population of Gullah/Geechee coastal residents in other venues.

Colorblind Problem Definition

Seeing sea-level rise vulnerability as only a physical inundation problem encourages pursuing solutions that are engineering and technological in nature. It also frames the problem as solely spatial and not cultural or socio-spatial. This focus has led to beneficial and significant advances in quantitative modeling assessments of projected inundation areas (e.g., Strauss et al. 2012; Strauss et al. 2014; Strauss et al. 2016), potential impacts on future populations (Hauer, Evans, and Alexander 2015; Hauer, Evans, and Mishra 2016), and when vulnerability is included, as indices indicating relative levels of vulnerability among populations (e.g., Emrich and Cutter 2011; Evans et al. 2014a; Chapter 3). In my eight years of participation in sea-level rise projects and fieldwork-based participant observation in Georgia, I have observed that regional sea-level rise research is skewed towards assessing the impacts of inundation (and on ecological systems in many cases) as opposed to how sea-level rise may affect livelihoods and everyday experiences.

If a research or adaptation planning project's focus is on people (and not ecosystems), the flows of funding are more often towards adaptation projects that unevenly benefit urbanized landscapes of typically middle and upper class white people who, in the US South, are more commonly the coastal residents with low-lying property along the exposed shorelines (Ueland and Warf 2006; Kahrl 2012). White people were disproportionately represented in the many scientific and public meetings I attended along the coast. The benefits from the public funding supporting these meetings and projects are aimed at alleviating impacts of sea-level rise through local government adaptation projects such as beach re-nourishment, stormwater drainage retrofitting, and potential shoreline armoring (e.g., Evans et al. 2016).

While such assessments are definitely needed and beneficial for these communities, seeing sea-level rise as only an inundation problem calls for engineering or technical solutions through assessing potential inundation impacts to private property and economies. Given the whiteness of the coastal population, and especially shoreline area urban environments, this process reproduces the system of racial inequality by facilitating flows of funding as well as research attention away from alleviating the vulnerability of marginalized social groups who no longer occupy the majority of waterfront properties in Georgia, but also in many places around the US In Georgia, the number of non-Hispanic white residents in communities along the shoreline (defined as US Census block groups intersecting the shoreline and in one of the six Georgia coastal counties, n=142) is a higher proportional average at 65.8% than the coastal region at 55.5% (defined as Georgia coastal counties intersecting the shoreline, n=6) (US Census 2013; NOAA OCM 2016).

This focus on predominantly white communities in Georgia is very likely unintentional, yet is perpetuated by a racialized social system that creates inequalities in class and educational status across racial groups. I argue that it is more than class, educational status, facilitation of funding flows, or limited access to resources that minimize minority participation in these meetings and projects. However, an attribution to class was commonly stated as more deterministic than race in my interviews and discussions with white residents and government officials, evidencing how colorblind racism perpetuates this racial inequality.

Studies are increasingly examining the expected daily disruptions that would occur from roadway flooding (e.g., Evans et al. 2016), yet more studies are needed that examine how identities and livelihoods may be altered, especially marginalized and/or underrepresented identities such as that of the Saltwater Geechee. Recognizing the substantial investment many amenity migrant retirees have made, I contend that the lost asset of a physical home or property (especially for second home owners) will likely not intimately affect their identity. At least not nearly as much as that of a Saltwater Geechee, for example, whose identity and cultural capital is tied to the landscape and has been since his/her ancestors were forcibly brought to the Sea Islands some 200 years ago (Goodwine 1998; Walker Bailey and Bledsoe 2001; Goodwine 2015).

Nearly every day of the five months that I was living on Sapelo, I observed and/or participated with a Geechee resident who was either line fishing off the island's bridges and docks, casting a net into the tidal creeks, pulling a seine along the beaches, or crabbing and clamming in the creeks and on the mudflats. If seining, the day's catch was split evenly among all involved, and sometimes, a portion of the catch was distributed to community elders; the same for crab hauls. While this subsistence fishing may not be as necessary as in the past due to easier access to off-island resources, it still supplements local diets and continues to define the identity of Saltwater Geechee. A disruption to these identity-based activities due to sea-level rise possibly triggering salt marsh habitat decline (e.g., Craft et al. 2009; though see Kirwan et al. 2016) and/or estuarine species declines (e.g., Hunter et al. 2015; Nuse, Cooper, and Hunter 2015) would potentially be significant for the longevity of Sapelo's Saltwater Geechee culture. Yet concerns that resonated in my interviews and conversations with Geechee residents did not reflect sea-level rise or climate change as a threat as much as more pressing matters of employment and land ownership. Moreover, most studies of vulnerability to sea-level rise in coastal Georgia overlook these activities as the studies are focused on inundation and economic benefit-cost analyses, not cultural identity or race relations (but for examples of studies of this kind in the U.S. see Paolisso et al. 2012; Maldonado et al. 2013; Moore 2015).

Worry Capital Allocation

I observed and documented via interviews limited worry among Geechee residents on Sapelo Island regarding the potential impacts of sea-level rise to their community or way of life. In an interview with a Sapelo resident, this was described to me in the context of Geechee residents allocating their "worry capital" to other issues rather than rising seas, at least for the moment. It became evident rather quickly during my fieldwork that many of Hog Hammock's Geechee people (including residents and those who had moved off-island but wanted to return) had other more pressing challenges to navigate including access to decent paying employment and keeping the title to Hog Hammock land in Geechee hands. One of my participants captured this succinctly when I asked what the major challenges were facing the community by replying:

> *"Land, selling, taxes going up, and pretty much turning into St. Simon's [a developed neighboring island]. A lot of people feel like given the next 10 to 15 years, taxes are going to go up to the point that a lot of people cannot afford it. I mean, it ain't nothing but a bunch of elderly people over here, anyway, getting a Social Security check and that's not enough to even live on plus pay bills and taxes, like over $2,000, that's not enough."*

This quote captures many of the same issues expressed to me by Geechee descendants regarding what they were most worried about for their community. These issues include land, taxes, and jobs as conveyed in the quote above, but also concerns of cultural longevity and racial identity. For example, in response to me asking about what the community would be like in 50 years, one participant replied, "*it'll be all white people*."

The worry by Geechee residents of Hog Hammock that the community will transition to being majority (or as in the instance quoted above, *all*) white residents is based on recent land sales and delinquent property tax auctions (Darien News 2015b; Darien News 2015a). Worry over land losses is in part due to amenity migrants seeking low cost coastal properties in the US South, which is displacing Gullah/Geechee people from the region, as is happening to Gullah/Geechee people in Bluffton, South Carolina (Finewood 2012). With the increased interest of low cost coastal property, demand in Hog Hammock has increased and consequently the sale of property to non-descendants. In addition to legal land sales by descendant residents, land sales are facilitated by heirs' properties, or property that has passed down to multiple family members after the title holder dies without a will. Heirs' properties are vulnerable to dispossession, especially in Gullah/Geechee communities (Grabbatin 2016). Accordingly, I was informed by two interview participants that land is where the value is at in Hog Hammock and that heirs' property holders have little interest in keeping the land when the value is high. These participants also said that some heirs' property holders, many not having grown up on the island, have less personal investment in the place or island life and consequently have limited sentimental value for the community. Consequently, these land sales and auctions are leading to a shifting demographic for the community.

As of the summer of 2015, I found that the status of ownership within the community is moving towards outsiders, which is based on participatory mapping exercise that included two separate in-depth conversations with two island residents and a poster-sized paper map of parcels in Hog Hammock. Of the 292 property parcels within the community, 180 are owned by families who are Gullah/Geechee, 69 by non-descendant property owners (or "outsiders" as Geechee residents often refer to them), and the remaining 45 are held by the Sapelo Island Heritage

Authority (Figure 4.3). The Heritage Authority properties are overseen by four official board members, the State's Governor, the Sapelo Island Manager, and two Geechee representatives. The majority of land (87 hectares[10], 52%) is still owned by Geechee people, though a few of these properties were auctioned to non-traditional (i.e., non-Geechee) parties due to delinquent property taxes in the spring of 2015. In the participatory mapping exercise, the informants and I attempted to account for any changes due to these auctions, but we were not entirely sure of the outcome (i.e., who held title) for all of them. Also, some of the auctions were won by partnerships that included Geechee descendants and outsiders, complicating our classification system.

At the front of the McIntosh County Courthouse, the county in which Sapelo Island and Hog Hammock are located, I observed one of these two delinquent property tax auctions and the emotional toll experienced from losing land that had been in a family for generations; nine generations as one Geechee descendant informed me weeks after having the land lost at auction for over $60,000 for a delinquent tax of approximately $6000. If the property owner is unable to pay the tax owed as well as the auction price to the bidder within one year of the auction, then the property is turned over to the bidder for the price paid at auction.

According to the county government, in 2012 the State of Georgia mandated that McIntosh County reassess all county property values, stating that the reassessment was long overdue. County Tax Assessor records show that many Hog Hammock properties have recently (in the past 10 to 15 years) sold for as much as $150,000 per acre or more, significantly increasing the "neighborhood" property values. Even though McIntosh County did not raise tax

[10] This area calculation is based on an analysis of polygons of parcels in a GIS database obtained from the McIntosh County Tax Assessor's Office in May 2015 and are not based on legal titles or land surveys.

rates, the mandatory reassessment of properties increased values to as much as 300% of their previous value, which in turn raised annual property taxes substantially. This property value reassessment has subsequently been nullified through court action by a group of Hog Hammock residents. Yet, many Geechee residents told me that it was just a matter of time before the annual taxes owed would increase significantly again. While a state mandated action, a few of Hog Hammock's Geechee residents expressed sentiments of racism, telling me that the increased tax values were a racially motivated action to run all black people out of Hog Hammock.

Georgia has a Homestead Exemption law for primary resident homeowners that allows for a tax deduction, but this rate is based on the assessed value, which can go up if neighboring properties are sold for higher amounts. On Tybee Island (and the greater Chatham County area where Tybee is located), this exemption was expanded in 2001 under the Stephens-Day law, which allows the local county government to raise the exemption value as property reassessment values occur, with the intent of shielding homeowner residents from being taxed off of their property due to neighborhood value increases from nearby sales (Day 2000). McIntosh County and Hog Hammock homeowners have no such protection. I contend that the lack of such legal protections from increasing taxes consumes much of the worry capital for Hog Hammock residents.

Another major allocation of worry capital goes towards jobs and developing employment opportunities. In an interview, one Geechee resident asked, "*Without jobs, what good's the land?*" As the only major employers on the island are the University of Georgia's Marine Institute and the Georgia DNR, which manages the R.J. Reynolds Wildlife Management Area, the Sapelo Island National Estuarine Research Reserve, the R.J. Reynolds Mansion, and the ferry, on-island employment opportunities are limited. Geechee people work for the DNR, but the number of positions is limited. Most of the University staff live in state housing or ride the ferry daily. Currently no Geechee person works for the University, a situation that to some Geechee residents is clearly a result of racism in hiring practices.

Irrespective of whether any of these issues could be “proven” to be a result of colorblind or structural racism that maintains racial inequality, some of Hog Hammock’s Geechee residents see these issues (land and employment) through a lens of racial inequality. Since many of the white people that I spoke with who are affiliated with Hog Hammock either in official governing capacities or new property owners do not see these issues in this way, I argue that this inconsistent reading of the sociopolitical landscape as one that is racialized functions as a barrier to engagement with Geechee residents pertaining to sea-level rise adaptation planning, which could partially alleviate their vulnerability to it.

The issues that Geechee descendants allocate their worry capital towards illustrate the dynamic state of the social and cultural landscape within which a rising sea is taking place. Vulnerability to sea-level rise becomes lower ranking as issues that are more imminent threats to cultural longevity and racial identity are addressed. While allocation of worry capital to other more pressing issues presents a barrier to engagement for proposing and conducting sea-level rise adaptation planning, it does not necessarily indicate a lack of knowledge or awareness regarding ongoing environmental changes and the greater context of global climate change.

Divergent Discourses of Climatic/Environmental Change and Strained Historical Relations

In the case of Hog Hammock’s Geechee people, despite the fact that many of Sapelo’s Geechee descendants have achieved higher education degrees, none are scientists. This lack of Sapelo Geechee scientists was pointed out to me during an interview as quite ironic since there has been ongoing academic research on the island since 1947. Having no Geechee scientists affiliated with the research on and around Sapelo maintains the distance of Sapelo's Geechee descendants from the scientific social network, which is linked to broader racial inequalities in the US context regarding a lack of diversity in science more generally. This further exacerbates the problem of including the experiential knowledge of underrepresented communities such as Hog Hammock's Geechee people, who have their own language and discourse for environmental change rooted in place-based narratives and histories collected through everyday experiences.

During all of my interviews and conversations with Geechee descendants, knowledge about environmental or climate change was situated within personal memories, observations, and stories. Yet, with white participants on Sapelo and Tybee Islands, these discussions largely resonated around the science of climate change (its anthropogenic origins or not) and the potential for technocratic solutions to the global problem (i.e., mitigation). Moreover, when the discussion topic turned to the local scale, it concerned engineering to prevent inundation of property or policy-based measures for when buy-outs would be appropriate. However, for African Americans living on Sapelo, climate change was viewed as a global problem that one could do little about, one Hog Hammock Geechee resident responding, "*climate change, I don't worry about it because there's nothing that I can do about it*." I argue that such views are the result of both the discursive distancing of climate change as a global and scientific problem, one that has limited value for many African Americans outside of the practice of climate science or environmental movements (Finney 2014; National Science Foundation 2015), but also a temporal mismatch between local and scientific understandings of translating past observations into distant futures (Fincher, Barnett, and Graham 2015).

During the interactive presentation that I held at the Hog Hammock Public Library I presented a map of Sapelo Island and Hog Hammock inundation that would occur under various levels of sea-level rise (1 to 4 feet). Upon seeing this map, a white audience member suggested bulkheading or damming of the creek where most of the inundation would seem to originate for the community. In response, a Geechee resident stated:

> *"Action in a salt creek keeps it open; no action, tends to close up. It's gonna overflow somewhere. We know because we live here. We don't need no one to tell us, because we know. We don't have science, but we know because we've been here. We see it with our eyes."*

This quote captures a number of significant points regarding local environmental knowledge as well as the relationship of local Geechee with outsiders, including white people, and outsider knowledge and expertise. The first part conveys an experiential knowledge related to witnessing the dynamic nature of how tidal creeks and ditches shrink (and expand) over a lifetime of living on the island. Moreover, it conveys a rather sophisticated understanding of hydrology both in the sense of flow being necessary to maintain a stream, but also that bulkheading would lead to sedimentation and just displace the water to another low point of entry (Titus 1988; Michener et al. 1997). The second part alludes to the relationship with outsiders generally, but specifically science, and the strained historical relations between Hog Hammock's Geechee people and outsiders including people prospecting for land, journalists, and social and scientific researchers. The historical relations create even more of a barrier to engagement as they influence knowledge flows related to scientific research generally, as well as climate change and sea-level rise vulnerability and adaptation planning more specifically.

While all of Sapelo's (black and white) residents and second homeowners appear genuinely congenial and friendly with one another, there is a tension for some of the Geechee descendants regarding "outsiders." This tension resonates around sentiments of racial inequality and concerns over cultural longevity of Saltwater Geechee ways of life, which are threatened by the land sales and few opportunities for employment that exist in the area, as I reviewed above. The racial tension was evident in numerous conversations I had during my fieldwork, with more optimistic statements revealing this issue including sentiments such as hoping the relationship with white people would hold. Moreover, referencing an interaction with an island newcomer, one Geechee resident alluded to class and racial inequality by referencing wealth differences between newcomers and descendants, but also the former days of being told what to do being gone.

This tension with outsiders was also evident in comments regarding property rights and trespassing, specifically about closing of “roadways.” There is an extensive network of roads that cut through the Hog Hammock Community. However, of all of these roads, few of them have associated public right-of-ways meaning that the majority cut across private property parcels. As non-traditional residents have moved into the community, some Geechee descendants have suggested blocking these “cut-through” roads to prevent people they do not know well from driving on their land.

During interviews and informal conversations, I probed about ways to adapt to rising seas, asking what might be done, if anything. A few individuals, some descendants and some non-descendants, talked about moving to higher ground. One of the higher areas on Sapelo Island is the former community of Raccoon Bluff. Moving to higher ground (now owned by the State and managed by DNR) via acre-for-acre swaps emerged as a solution in a few of these conversations, but past historical relations of acre-for-acre swaps carry sentiments of betrayal for many Geechee, as these previously occurred via coercion, threats, and broken promises from the island’s previous majority landowner, R.J. Reynolds, according to many Geechee residents. The idea of the State, seen as representing the interests of white people, offering acre-for-acre swaps again was suspect for many of the Geechee who I discussed this with in interviews and informal conversations.

The legacy of slavery and continued racial inequality and the effects of these are very real for many of Sapelo's Geechee people. Some of the currently living community elders are old enough to have known people who were born into slavery and still alive when they were children. This is the lens through which daily experiences are filtered for some Geechee residents as evidenced in statements made in interviews and conversations regarding the poor government services being because of racism and job opportunities on the island being given to non-descendant off-islanders too readily. Of course, this is not the case for every descendant, as a few participants either said race had little to do with the current challenges or downplayed its significance in relation to current struggles regarding land and employment. I contend that without a sensitivity to these specific place-based historical relations on the island, particularly the race-based relations, and how their legacy is facilitated through structural and colorblind forms of racisms, planning for climate change and sea-level rise adaptation will become fraught with misunderstandings and miscommunications.

Conclusion

Thinking about sea-level rise as a social-ecological phenomenon – and not just as a physical or ecological problem – has the potential to shift the scientific discourse around planning for, coping with, and adapting to the impending impacts expected to occur from major changes to the socionatural systems of coastlines. A conceptual shift of this magnitude in mainstream climate change and sea-level rise science would improve the chances for overcoming the barriers to engagement with underrepresented communities, such as the one on Sapelo Island outlined in this article. More importantly, it would permit calls for climate justice to reverberate through the discursive practices of sea-level rise science by making space for a color-*aware* problem definition; one that encourages discussions at the onset of project formation to include issues of power and racial inequalities, how race relations influence worry capital, as well as the inclusivity of multiple forms of knowledge. It has the potential to change the conversation to one of human rights by shifting the emphasis from inundation exposure and economic impacts to evaluating how livelihoods (including cultural and racial identity), as well as the everyday lives of coastal residents, will be affected by rising seas in the coming decades.

A focus on livelihoods and everyday lives would necessitate a more complex policy process whereby investigations on the historical conditions that led to uneven vulnerability across social difference would not only be taken into consideration, but treated as of equal importance to proposals for inundation exposure assessment or economic impacts. The prevailing modes of inquiry into sea-level rise vulnerability research in Georgia (and more broadly) are valuable, but miss out on the human rights issue by avoiding the history of racial violence in the US South and the ramifications that continue to result from that legacy. Specifically, projects that partner with organizations from underrepresented communities and groups and bring local knowledge into the research design and planning phases may reveal new and insightful adaptation possibilities and futures. At the very least, such policy shifts would encourage projects that begin to address the existing inequalities that continue occurring across racial difference due to structural and colorblind forms of racism.

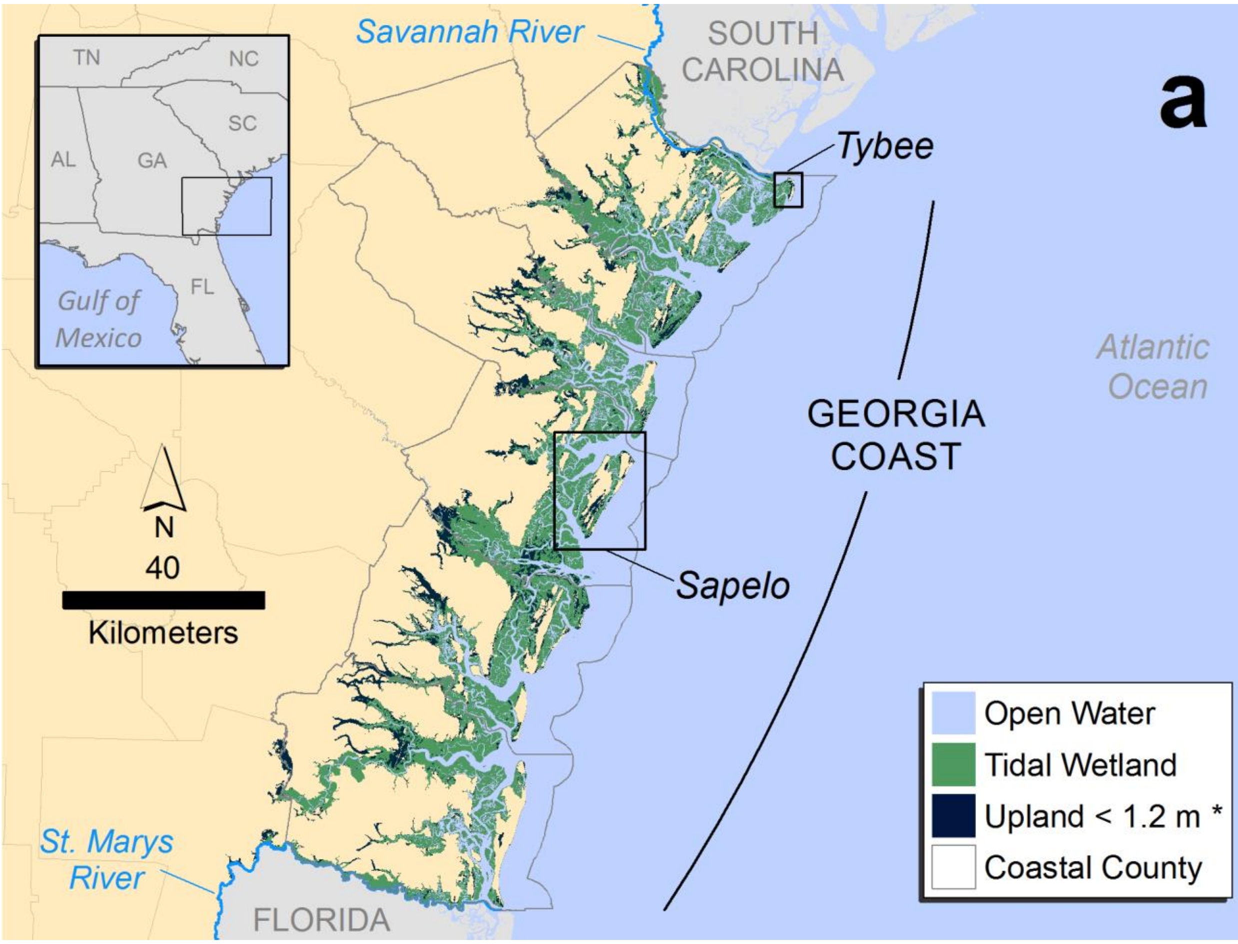

Figure 4.1 a) Coastal Georgia; (continued on next page)

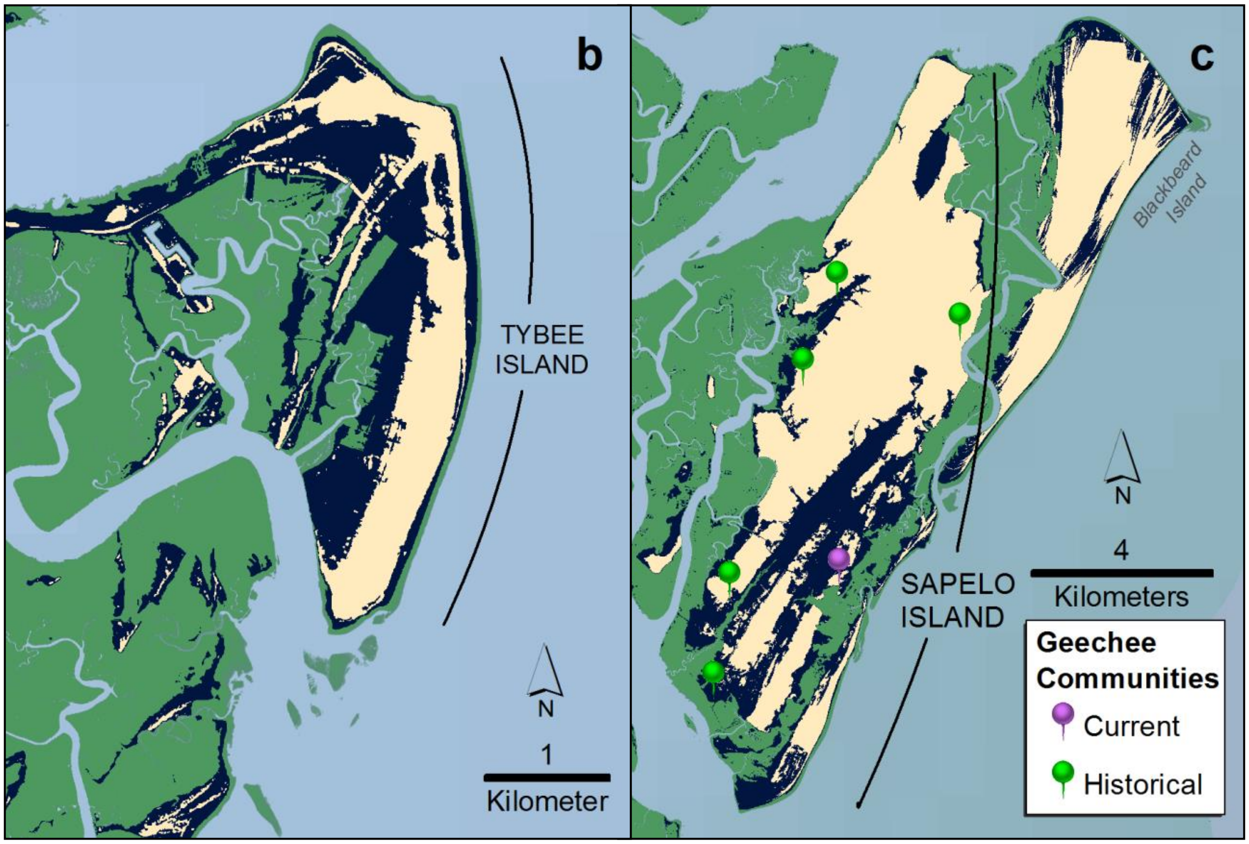

Figure 4.1 b) Tybee Island and land exposed to inundation; c) Sapelo Island and the land exposed to inundation with Geechee communities. Historical community locations are based on those that existed as of R.J. Reynolds purchasing of most of the island in 1934 (Sullivan and Gaddis 2014). *The upper end of NOAA's (Parris et al. 2012) "likely" sea-level rise scenario for the year 2100.

Figure 4.2 RTK GPS. Elicitation technique and accuracy assessment of elevation data. Photo is of the nuisance flooding in the parking lot caused by high tide at 10:23 AM at Sapelo's Marsh Landing on September 29, 2015. The nearest NOAA tidal gauge is at Fort Pulaski (~ 80 km to the northeast); it recorded high tide of 2.993 m at 9:54 AM relative to the station's mean lower low water datum. This day's recorded high tide was 0.706 m above the station's mean higher high water datum.

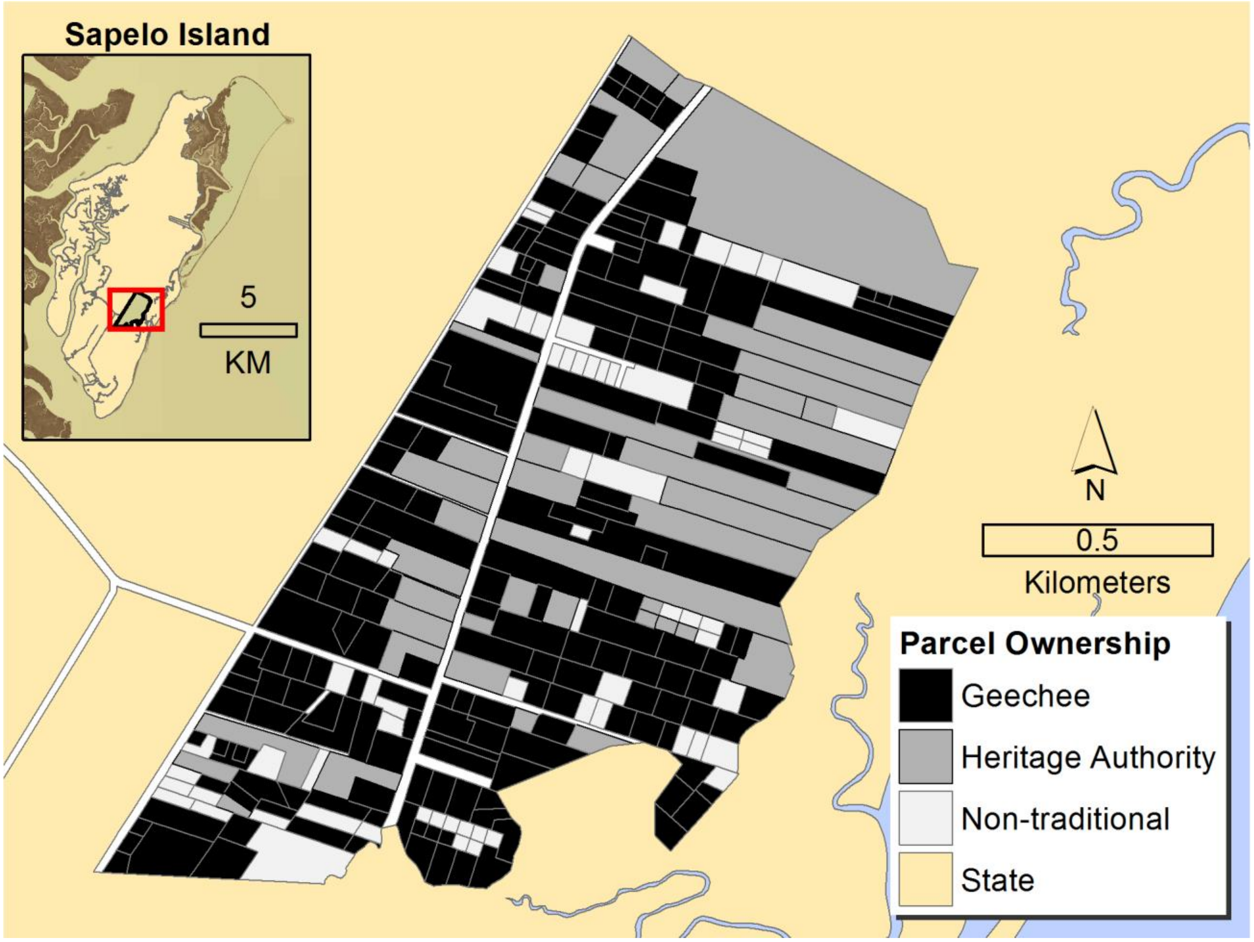

Figure 4.3 Hog Hammock property ownership status. Parcel data are from the McIntosh County Tax Assessor's Office and up-to-date as of May 2015. The first non-traditional property owner was reported in interviews to have purchased land in the late 1970s or early 1980s. Heritage Authority refers to the Sapelo Island Heritage Authority (see text for explanation); Non-traditional refers to non-Geechee property owners.

CHAPTER 5

RENDERING PLURAL EPISTEMOLOGIES OF VULNERABILITY TO SEA-LEVEL RISE [11]

[11] Hardy, R.D. To be submitted to *Applied Geography*.

Abstract

With sea-level rise forecast to accelerate rapidly this century, the everyday lives and livelihoods of millions of coastal people are predicted be unevenly vulnerable to the coming changes. Such a "super wicked" problem requires an open approach that embraces mixed methods and plural epistemologies. Accepting the partiality of different perspectives and the potential incommensurability of certain data types, analyses, and ways of knowing the world presents opportunities to gain insights precisely from the divergent results and epistemological interpretations. Vulnerability studies are classified broadly as either outcome or contextual, and respectively draw on positivist and critical theory philosophies to examine environmental hazards. I demonstrate how engaging with both of these perspectives on vulnerability has the potential to reveal new information through the explicit application of plural epistemologies. I conduct this parallel examination of vulnerability studies via an iterative and self-reflective case study of coastal Georgia in which I jointly examined vulnerability to sea-level rise as follows: an outcome vulnerability assessment via a regional risk model, where risk is defined as the intersection of social vulnerability and physical exposure to sea-level rise inundation; and a contextual analysis of barrier island life via ethnographic methods and narrative analysis.

Introduction

With the world's oceans forecast to rise significantly this century – predictions ranging from less than one meter (Church et al. 2013) to as high as two meters (DeConto and Pollard 2016; Hansen et al. 2016) – the number of people whose everyday lives and livelihoods could be affected is enormous. Globally by the year 2060, more than one billion people are projected to live in the low elevation coastal zone (the area less than 10 m above sea level; Neumann et al. 2015). In the US, more than 13 million people are projected to live within 1.8 m of the high tide line by the year 2100 (Hauer, Evans, and Mishra 2016). As a global phenomenon with local consequences, sea-level rise will have uneven consequences among nations (Chapter 2), but also within nations (Shearer 2012a), and across social differences (Chapter 4). While sea-level rise is not the only impact expected from climate change, these potential uneven impacts alone suggest a need for urgent action.

Climate change is a "super wicked" problem; one where the planning process is complex or "messy," requires urgent action, and has nearly non-existent or limited governing bodies capable of responding effectively (Bernstein et al. 2007; Lazarus 2008). Moreover, much of the research and planning related to global environmental change reads it merely as a global technocratic problem, calling for science, typically so-called "natural" science, to inform policy (Hulme 2011). This framing effects whose knowledge counts, what research questions are asked, and how climate change adaptation planning is addressed and funded, often silencing multiple other ways of knowing or being in the world, such as experiential knowledge (Rice, Burke, and Heynen 2015). While natural science investigations and findings are crucial to understanding many aspects of global climate change, all knowledges are situated and partial (Haraway 1988). The privileging in climate change discourse of one way of knowing effectively limits possibilities and opportunities for transformation (Hulme 2011; Castree et al. 2014; Nightingale 2016).

An alternative framing that is emerging from the growing field of political ecology sees climate change not as purely a biophysical problem, but as one that is a result of political economic conditions co-occurring with changing ecological conditions (O'Brien and Leichenko 2000; Peet, Robbins, and Watts 2010; Ogden et al. 2013). The prevailing biophysical emphasis misses out on discussions of power, violence, and inequality (Castree et al. 2014), factors that affect vulnerability, resilience, and adaptive capacity of populations. Comparing these two overarching approaches to examining climate change (i.e., biophysical vs. political ecological), "it is not possible to prove methodologically which conceptualisation [*sic*] or analytical entry point is better than another" (Nightingale 2016, 41). It is the insight gained from the productive tension of holding these two (as well as other) perspectives in contrast that promises a way forward. As a global problem of environmental change with local consequences that is caused primarily by anthropogenic forces (Crutzen and Stoermer 2000) and driven largely by political economic decisions, successfully responding to climate change (including sea-level rise) via adaptation and other undiscovered routes requires engagement with not only interdisciplinary approaches and mixed methods, but more importantly inter-epistemologies (Murphy 2011) and epistemological pluralism (Healy 2003).

A research design that includes epistemological pluralism can be conceptualized in at least two ways. First, it may compile scientific and non-scientific ways of knowing by, for example, encoding traditional ecological knowledge into a geographic information system (GIS) based scientific understanding of sea-level rise to bridge the gap between scientists' and indigenous peoples' knowledges (e.g., Bethel et al. 2014). Second, it may take a more self-reflective route and focus on multiple epistemological approaches from within academe by, for example, analyzing vulnerability to sea-level rise through both positivist and critical theory perspectives. In this paper, I follow the latter and argue that a research design inclusive of plural epistemologies offers a chance for more robust (i.e., more comprehensive) analyses of vulnerability to sea-level rise.

Acknowledging that all perspectives are partial, scholars have called for more iterative and self-reflective practices that focus on the processes (Hirsch et al. 2013) and analyses (Knigge and Cope 2006) of research projects, rather than integrated or synthetic products. Much interdisciplinary and inter-epistemological work either attempts to unify forms of knowledge through the assimilation of indigenous knowledge into environmental policy (as argued in McCreary and Milligan 2014), or the translation of qualitative data into quantitative data (e.g., Jung 2009). Yet, the politics of translating knowledges or transforming data types limits what we are able to know about an issue (Brosius 2006; Nightingale 2016). Accepting the partiality of different perspectives and the potential incommensurability of certain data types and ways of knowing the world presents opportunities to gain insights from the gaps that arise between the results and epistemological interpretations.

In this article, I demonstrate how a plural epistemology research design framework makes space for recursively reflecting on model-based investigations of sea-level rise as well as the social and cultural processes that lead to uneven vulnerabilities to sea-level rise. Specifically, I pose the question, how do ethnographic modes of inquiry articulate with model-based, spatial examinations of vulnerability to sea-level rise? In the following section, I briefly review two broad conceptualizations of vulnerability used in this article and outline the strengths and limitations of each. I then move to coastal Georgia as a case study example, drawing on previous work (Chapters 3 and 4), to demonstrate the potential for one way forward in plural epistemology research design focused on investigating vulnerability to sea-level rise.

Conceptualizing Vulnerability

There are many definitions and theoretical arguments around the concept of vulnerability (Cutter 1996; Oliver-Smith 2004; Wisner et al. 2004; Adger 2006) and even classifications of vulnerability studies (Wisner 2004; Füssel and Klein 2006). However, in both environmental hazards and climate change research, vulnerability can be broadly classified in two contrasting ways that are often epistemologically divergent (O'Brien et al. 2007; Birkenholtz 2012). First there are idiographic approaches that examine “contextual” vulnerability, more often drawing on political ecological inquiry of broader socio-political processes via ethnographic methods (O'Brien et al. 2007; Birkenholtz 2012). Contextual vulnerability is "based on a processual and multidimensional view of climate-society interactions," and takes on a human security framing (O'Brien et al. 2007, 76). Second there are empiricist-based approaches that are typically nomothetic in their examinations of “outcome” vulnerability through quantitative modeling and statistics (O'Brien et al. 2007; Birkenholtz 2012). Outcome vulnerability research tends to take on a scientific framing and is "considered a linear result of the projected impacts of climate change on a particular exposure unit (which can be either biophysical or social)” (O'Brien et al. 2007, 75). In comparison, contextual vulnerability is most concerned with understanding why certain social groups are more vulnerable than others while outcome vulnerability is more concerned with informing policy and response to hazards. Respectively, these can be viewed as “starting-point” and “end-point” types of vulnerability studies.

Critiquing these approaches from the vantage point of the other reveals many of the shortcomings that each possesses. From a contextual studies perspective, I argue that assessments of outcome vulnerability that employ quantitative models fall short on at least four fronts. First, they separate social and biophysical domains at the point of analysis, thereby foreclosing on the possibility of a co-produced social-ecological vulnerability. Second, they “un-situate” social characteristics from their place-based power relations, which are essential to understanding the production of social-ecological vulnerability. Third, due to challenges of weighting the model variables, they typically place diverse indicators of social vulnerability on level playing fields, suggesting that being over the age of 65 is akin to being a racial minority and/or impoverished with limited education (though see Frazier et al. 2013a for an example of weighting model indicators). Fourth, they struggle to effectively represent the complexity and multiplicity of the social-ecological landscape, often relying on static, two-dimensional cartographic visualizations (although new technologies are pushing these boundaries; e.g., Elwood 2009; Elwood, Goodchild, and Sui 2012).

Studies employing contextual vulnerability frameworks have their limitations as well when viewed from an outcome studies perspective. First, they have limited predictive power, which is necessary for analyzing future changes in social-ecological conditions. Second, they are typically in the form of intensive case studies, and while rigorous, their replication is not practical, limiting their generalizability to other sites (Birkenholtz 2012). Third and related to the previous shortcoming, their ability to inform policy has not succeeded as well as outcome approaches, partially due to the hegemony of scientific discourse creating policy expectations of a replicable methodology with generalizable results.

In comparison, each of these approaches offers information and knowledge for understanding vulnerability that the other lacks, with the greater potential to reveal unknowns when analyzed together, but without attempting to transform one data type into another. Outcome vulnerability assessments provide predictive power by employing quantitative models of social-ecological vulnerability by, for example, providing statistical analyses, ranges of uncertainty, and models of biophysical processes (e.g., sea-level rise inundation) as well as population projections. In contrast, contextual vulnerability studies have much stronger theoretical arguments for explaining how power and inequality operate, and how they could potentially affect climate change adaptation research, policy, and action. Emphasis is placed on social justice and equality, with scholars arguing that climate change adaptation is a human rights issue (Maldonado et al. 2013; Rice, Burke, and Heynen 2015) and a moment for transformation (Pelling 2011). Contextual approaches offer hope for more "socially inclusive adaptation solutions" (Nijbroek 2014, 1).

My goal in this article is not to blend or hybridize epistemologies, rather it is to propose a research design framework for investigations of vulnerability to sea-level rise that allows for co-exploration of objectivist (i.e., outcome) and constructionist (i.e., contextual) approaches. I make no attempt to blend or hybridize the epistemologies of the model-based outcome approach and the qualitative contextual approach. I intentionally hold them side-by-side and examine what emerges from their concomitant, but separate, analyses. This is the productive tension of epistemological *pluralism*.

In this article, I advance previous efforts by conjointly examining traditional spatial data modeling approaches for assessing social vulnerability along with qualitative inquiries into vulnerability across social difference (e.g. Frazier, Wood, and Yarnal 2010; Frazier et al. 2013b), but with particular attention to the role of race in the formation of vulnerability. I argue that only through this more textured, mixed-methods and plural epistemology approach can scholars understand the multiple meanings and representations of vulnerability to sea-level rise as understood and experienced by people living on the coast. In the following section, I specifically review the strengths and limitations of each vulnerability approach via a case study of the Georgia coast, highlighting the contributions that result from their joint application to assessing vulnerability to sea-level rise. I first briefly introduce the case study site and the methods of each approach. I then compare and contrast the strengths and limitations of each approach for analyzing social-ecological spaces, place-based power relations, predictive power, key social characteristics of vulnerability, as well as replicability and normative application of results.

The Vulnerabilities of Coastal Georgia

I situate this argument within an iterative and self-reflective case study of coastal Georgia where I jointly examined vulnerability to sea-level rise first via a regional risk model that analyzed the intersection of social vulnerability and physical exposure to sea-level rise inundation (Chapter 3; the outcome approach), and second, in a case study of barrier island life (Chapter 4; the contextual approach) (Figure 5.1). For the former, I evaluated social vulnerability using a modified version of the Social Vulnerability Index (Cutter, Boruff, and Shirley 2003) and overlaid this with forecasts of sea-level rise inundation to assess risk (see Chapter 3 for details). For the latter, I conducted nine months of fieldwork on two barrier islands (Tybee Island, Chatham County and Sapelo Island, McIntosh County), specifically investigating the role of race in vulnerability via participant observation, semi-structured interviews, and self-immersion in the landscape (see Chapter 4 for details). Throughout the duration of the project, I iterated between exploring US Census socioeconomic data, modeling inundation data, and interviewing local residents while observing and participating in local everyday activities. Local knowledge collected during interviews and conversations with coastal residents informed my understanding of demographic changes and maps of sea-level rise inundation as well as vice versa.

Social-Ecological Spaces

One of the more immediately apparent aspects of the outcome approach was the separation of the social and ecological (i.e., “natural”) domains in the modeling process. Following convention in this epistemological framing of hazards geography, I defined vulnerability as social, exposure as physical, and the two together as risk (Wisner et al. 2004; Emrich and Cutter 2011). With this framing, I was able to predict the areas along Georgia’s coast that will have, by mid-century, relatively high levels of risk; in other words, where high social vulnerability will intersect with high exposure to inundation due to rising seas (Chapter 3). Yet, scholars have convincingly argued that there is no separation of the social and the natural (e.g. Castree and Braun 2001; Meehan and Rice 2011; Braun 2015), and that vulnerability is co-produced through changing social and ecological conditions (Dooling and Simon 2012). Moreover, when the driver of the physical or ecological change is anthropogenic, the "social" becomes so vastly influential as to negate any distinction between the two; for example, consider the human fingerprint of sea-level rise accounting for more than half of global mean sea-level rise since 1970 (Slangen et al. 2016). Conceptualizing vulnerability as both contextual and social-ecological changes the questions of interest and, with a political ecological lens applied, raises concerns relating to inequality, power, and social justice.

In the contextual case study analysis, I articulated how structural and colorblind forms of racism reproduce inequalities across racial difference thereby affecting vulnerability to sea-level rise, partially via power over employment and the politics of land (Chapter 4). Moreover, analysis of interview data shows that natural amenity migration is viewed by locals as driving the demographic shifts occurring on both of these barrier islands. This is leading to the continued displacement of a blue collar worker community by an elderly retiree community in one instance (Tybee Island) and in another instance is leading to displacement of a culturally-distinct group (called Gullah/Geechee) with a subsistence-supported lifestyle to more affluent, second home owners (Sapelo Island).

More importantly, the explanation for *why* the demographic change is occurring resides in the contextual analysis, which is dependent on data collected from the in-depth qualitative case study. Parts of the shifting demographic patterns (e.g., age shifts) were visible in the outcome of the model-based risk assessment, but the details of finer scale shifts along the shoreline and islands were only evident via personal observation during fieldwork in the contextual case study. In other words, such micro-scale changes fall under the resolution of the regional risk model.

Place-Based Power Relations

As I contended above, models un-situate social and ecological characteristics from their place-based power relations. I argue that it is not possible to model power – specifically, the sociopolitical *processes* leading to power inequalities – but only its effects or outcomes. I suggest that it is only feasible to model the resulting *patterns* of power; such as with racial discrimination via redlining in mortgage lending (Holloway 1998). The power inequalities and sociopolitical relations that led to redlining are only revealed through critical analysis of historical lending documents and narratives as well as with broader social theory on race relations. Similarly, in McIntosh County where approximately 35% of the population are African American (US Census 2014), underrepresentation in local government (one out of five county commissioners, personal observation) is only explicable via local historical race relations of contentious elections (Greene 2006) as well as with critical race theory that explains how structural and colorblind forms of racism maintain the persistence of inequality in education, income, and life chances across racial difference in the US (Bonilla-Silva 2013; Omi and Winant 2014). These are factors that affect access to resources that would be needed to limit vulnerability and increase adaptive capacity in response to sea-level rise.

I extend this line of reasoning to employment opportunities on Sapelo Island, Georgia where during my fieldwork I estimated that 64% of island residents were African American (a higher rate than the county, or even Georgia at about 32%) (US Census 2014), yet of five leadership positions on the island available through the University of Georgia’s Marine Institute and the Georgia Department of Natural Resources, only one was filled by an African American person (personal observation). As these entities are key employers on the island (aside from a few part-time opportunities) and the most likely to plan for sea-level rise adaptation, the contextual approach revealed that the lack of African American representation in leadership positions facilitates barriers to engagement with the majority-minority African American community regarding adaptation planning. The data collection methods and analyses needed for this contextual understanding are outside the purview of the regional modeling approach, which is more focused on outcomes and impacts.

Predictive Power

The model-based approach provides a predicted outcome of risk associated with social vulnerability and sea-level rise inundation that conveys to the researcher the end-product of social and ecological change at a particular point in time. The outcome can be a powerful analytical result, as in the case of the model-based approach that predicts the coastal Georgia region becoming a majority-minority population by mid-century with higher rates of both poverty and low educational attainment, as well as higher rates of socially vulnerable populations as seas rise (Chapter 3). In contrast, the contextual assessment has limited predictive power, primarily applying social theory to narrative analysis of current or historical social-ecological spaces. However, it is capable of aiding the interpretation of the model results via detailed information that can be gathered using case study methods such as interviews and participant observation.

The model that I used to project population characteristics and social vulnerability assumes that the changes observed between 2000 and 2010 maintain for the next 40 years. Following a previous approach in qualitative GIS work (Knigge and Cope 2006), I investigated the broader landscape around one of the islands (the mainland area) via bicycle by tracing out the area that was approximately one meter above current high tide to assess the social-ecological landscape through self-immersion and observation. According to the model approach, all three US Census tracts in McIntosh County had higher than average annual population growth rates over 2000 to 2010. However, during the qualitative observations I documented numerous subdivisions in development that had been abandoned after the economic recession in 2008 (Figure 5.2), suggesting a potential over prediction by the model for future population growth trends in this area. The economic downturn and related slowed development has created a space for rezoning areas that would be exposed to sea-level rise inundation to limit their development. However, McIntosh County has limited resources, as reported to me during interviews with local officials, and consequently there is pressure to develop in order to generate revenue for the county.

Key Social Characteristics of Social Vulnerability

Identifying the key social characteristics of a region that affect social vulnerability can be a challenge. The model-based outcome approach that I used following the Social Vulnerability Index model, uses a well-known approach for this called principal components analysis (Cutter, Boruff, and Shirley 2003). The results from this particular study of coastal Georgia show that the primary socioeconomic indicators explaining social vulnerability shift from age and race/ethnicity in 2010 to education and race (African American, specifically) by 2050 (Chapter 3). In this study, a geographically-weighted modeling approach also conveyed how the socioeconomic variables relate to each other over the study region, showing specifically which variables mattered more for explaining social vulnerability in specific areas around the study site.

The contextual approach brings theory on access to resources to bear on vulnerability studies. In this particular case, critical race theory and hazards theory postulate that people who are racial minorities and/or have low income and/or have limited education in the US have fewer life chances (Bonilla-Silva 1997; Wisner et al. 2004), and are thereby less likely to have the resources needed to adapt. Those resources could include mobility (e.g., ability to relocate if inundated by rising seas), career flexibility (e.g., ability to find a secure income in a new location if relocation were necessary), or wealth. With the model-based approach, I was not able to analyze local sociopolitical relations or how they might shape vulnerability and knowledge related to sea-level rise; yet I was able to focus on race relations in the contextual study to demonstrate how multiple barriers to engagement (e.g., colorblind problem definition in the professional community) with an underrepresented community reproduce racial inequality in vulnerability to sea-level rise.

Although the contextual analysis cannot predict population change, narrative analysis of interview transcriptions contributed supporting evidence regarding a net positive migration of older residents (≥65) to the coastal region. In learning about this shifting demographic through interviews on Tybee and Sapelo Islands, I was motivated to revisit the population projections used in the vulnerability modeling. I learned that despite the vulnerability model not indicating age as a key explanatory variable of social vulnerability by the year 2050, Georgia's coastal counties will see a net gain in the proportion of the population aged 65 and up from 12.3% in 2010 to 15.7% in 2050. The case study results improved the robustness of the interpretation of the model results by providing the narrative for explaining the increase in the older population. Further, the modeling approach projected a majority-minority population for the Georgia coast as well as the census tract in McIntosh County where Sapelo Island is located. However, narratives and current land ownership records suggest that, as inundation of sea-level rise continues through mid-century, Hog Hammock on Sapelo Island may become majority white (Figure 5.3).

Replicability and Generalizability

Concurrent with the model-based outcome approach having more predictive power is that it is also more easily replicated, more readily generalizable, and can be tested for sensitivity, uncertainty, and reliability of results (Schmidtlein et al. 2008; Tate 2012; Tate 2013). These specific characteristics of the model often lead to its broad inclusion in federal, state, and local hazard policies and plans, but as aggregated indices less often (Evans et al. 2014b). This may be due to the fact that "validation of indices with external reference data has posed a persistent challenge in large part because social vulnerability is multidimensional and not directly observable" (Tate 2012, 325). Numerous case studies that take the contextual approach, while not replicable in a scientific sense, have consistently demonstrated that specific social characteristics are key indicators of social vulnerability (UCC 1987; Bullard 2000; Pulido 2000; Fothergill and Peek 2004; Masozera, Bailey, and Kerchner 2007; Collins 2010; Finewood 2012; Collins, Munoz, and JaJa 2016), and it is upon these case studies like these that social theory has been developed (Bullard 2000; Wisner et al. 2004). Moreover, the strong social theory that arises from the contextual approach is also what informs many indices such as the Social Vulnerability Index (Cutter and Morath 2014). In other words, for assessments of vulnerability to sea-level rise, contextual specifics of a region, even if from more localized sites, that are positioned in a larger body of social theory, help to both add detail and validate model-based outcome approaches.

Rendering a Way Forward

I use the term "rendering" in the title of this article as it plays on two points I am making with the call for more research design in geography that embraces epistemological pluralism that draws on GIS and political ecology. First, and perhaps most obvious to those in the GIScience community (or those more familiar with computer graphics), is that rendering refers to "the process of drawing to a display; the conversion of the geometry, coloring, texturing, lighting, and other characteristics of an object into a display image" (ESRI 2016). Second, and more relevant to the contextual end of the vulnerability studies spectrum, is given that all perspectives are partial, or situated knowledges (Haraway 1988), there is a "rendering" that is done of any landscape, object of inquiry, or social-ecological space in such examinations. As Castree (2001) has argued in making the case for socionatures, nature can only be known through the knower; or in other words, all knowledge is mediated through the researcher (Brosius 2006).

Of course, this extends beyond the natural, as there is no getting outside of our subjective experience as scholars and scientists of society and nature, or socionatures; there is no objective vantage point from which our positionality does not influence our view. I too, "would like to insist on the embodied nature of all vision and so reclaim the sensory system that has been used to signify a leap out of the marked body and into a conquering gaze" (Haraway 1988, 581). The only difference is that *what* is doing the rendering in the qualitative contextual vulnerability analysis changes from a computer system to the researcher's "system," pre-loaded with all the impressions, training, and biases she or he carries into the field as well as to the desk for writing.

This plural epistemology research design has not even broached the topic of non-academic and/or experiential knowledges that are needed in climate change adaptation research (Murphy 2011; Rice, Burke, and Heynen 2015). However, it has drawn on the strengths of two epistemologically divergent methods available in geography, GIS and political ecological analyses, to produce a more robust understanding of vulnerability to sea-level rise on Georgia's coast. Ideally, more work that continues to investigate the productive tension of these two approaches in vulnerability studies, rather than transforming data types, will uncover routes to link contextual findings into sea-level rise adaptation planning and policies.

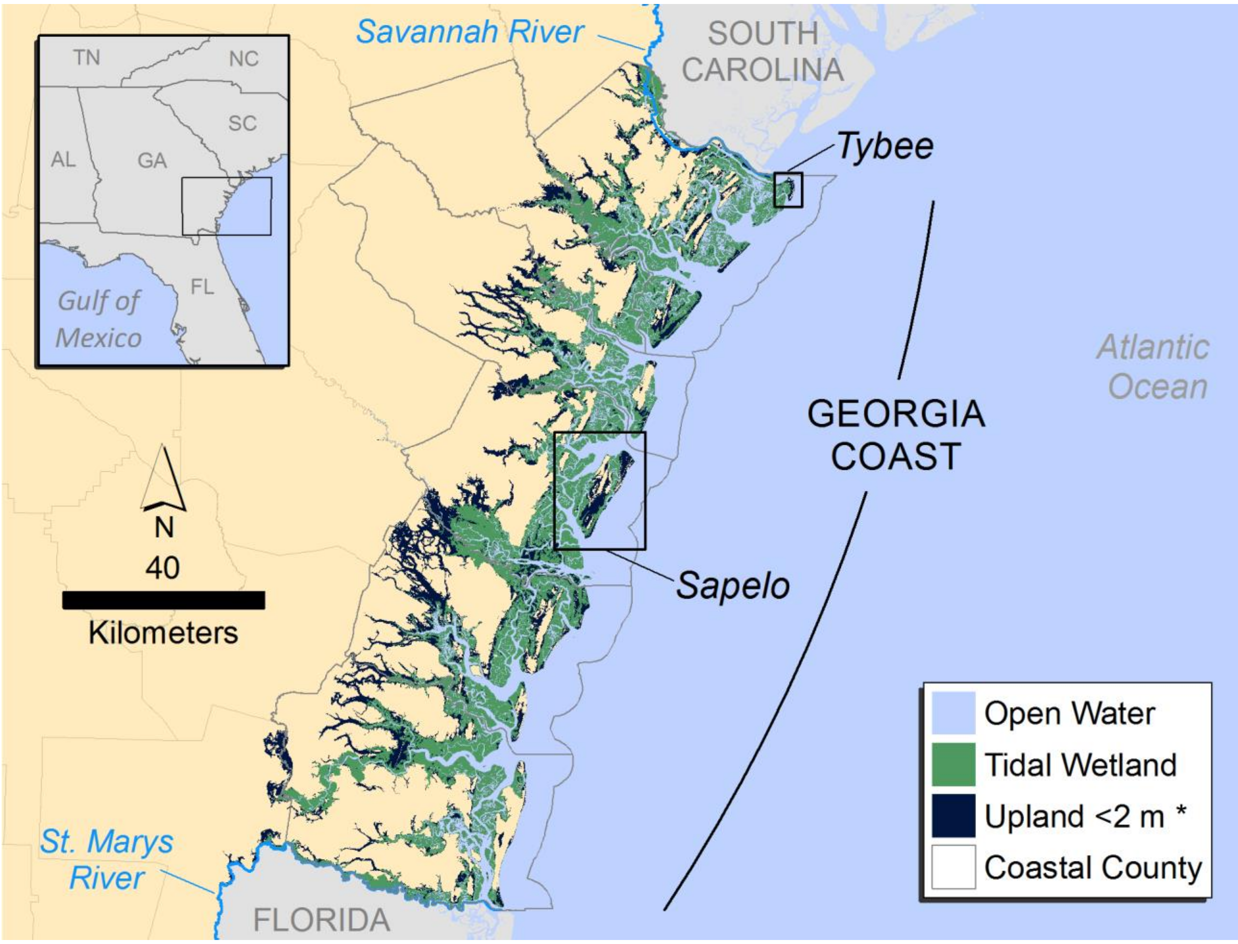

Figure 5.1 Coastal Georgia showing the locations of Tybee and Sapelo Islands. * The National Oceanic and Atmospheric Administration's high sea-level rise scenario for 2100 (Parris et al. 2012).

Figure 5.2 Example of one of many abandoned developments observed during fieldwork in McIntosh County, Georgia in the summer of 2013. This one is located on Old Shellman Bluff Road.

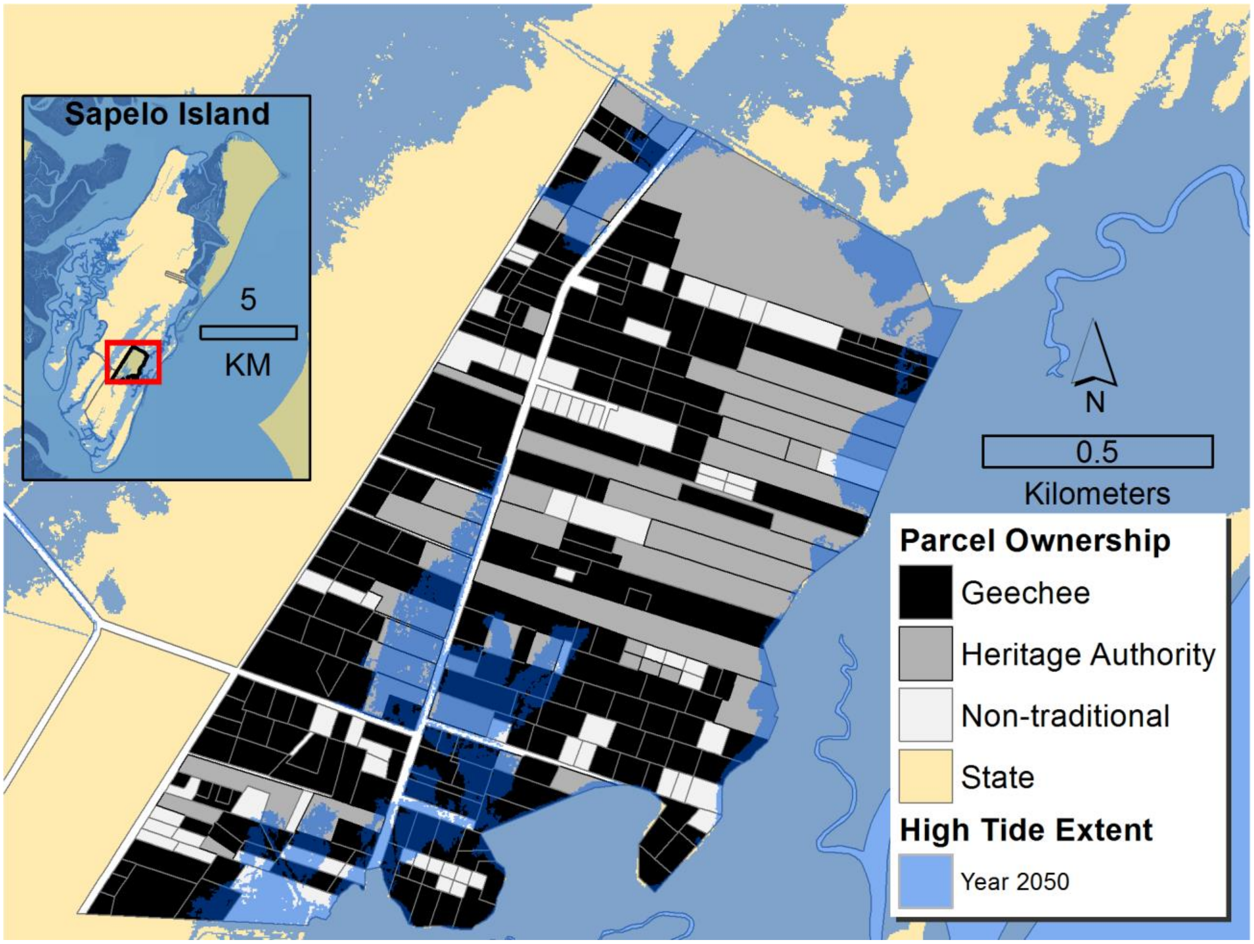

Figure 5.3 Current (as of May 2015) parcel ownership status (detailed methods in Chapter 4) and the potential extent of mean higher high water by the year 2050 (detailed methods in Chapter 3) for the community of Hog Hammock on Sapelo Island, Georgia.

CHAPTER 6

CONCLUSION

In this dissertation, my main objective was to apply an integrative approach to navigate multiple forms of inequality that are expected to emerge due to future sea-level rise. As it would be beyond the scope of any dissertation or project to capture all ways of knowing a problem, I chose to examine the inequalities of sea-level rise via three routes by applying mixed methods and plural epistemologies moving from the global to the local scale as follows: (1) a global scale, quantitative analysis of country responsibility and risk related to multi-millennial sea-level rise (Chapter 2); (2) a regional scale, quantitative analysis of spatiotemporal variation in risk to sea-level rise through the year 2050 (Chapter 3); and (3) a qualitative analysis of how racial inequalities continue to shape vulnerability to sea-level rise (Chapter 4). In Chapter 5 I conducted a meta-analysis of Chapters 3 and 4, reflecting on the process of an integrative and plural epistemology research design. Drawing from the framework laid out by Moon and Blackman (2014) and moving from the former to the latter approach, my assumed epistemological and ontological framing shifted from an objective naïve realism towards a constructionist critical realism. Below I briefly review each chapter's objective and "weave a needle" through the results while commenting on the epistemological and ontological position of each before offering the major conclusions of this dissertation project.

I met my objective for Chapter 2, which was to investigate global scale inequalities in responsibility and risk among nations related to Earth's rapidly growing commitment to multi-millennial sea-level rise. We defined responsibility as a nation's contribution to greenhouse gas emissions that will ultimately cause multi-millennial sea-level rise (what we define as sea-level rise commitment, or SLRC) and risk as the potential loss of land from those emissions, and found that those countries that are most responsible for contributing to SLRC are also the most at risk of land loss[12]. These include the US, China, and Russia among others. This is a very particular and narrow way of defining "risk," however.

To widen the scope, we examined risk as both total risk to a country (measured as its percentage loss) and relative to all global lands that would be lost (measured as the total absolute area of a country). The former approach highlights questions of an existential nature that, for example, while the US may be predicted to lose more land in absolute terms, the percentage loss to the country is much smaller than for Vietnam or Bangladesh. Moreover, a definition of risk that took into account the social realm including vulnerability and adaptive capacity would certainly come to a different conclusion regarding levels of risk. This would require, however, a different ontology and epistemology. Due to our chosen framing, however, we did not unpack this argument in great detail.

Aside from thinking globally as a scholar about national inequalities of climate change, which limits the focus on intra-national inequalities and issues such as race (Shearer 2012b), the most relevant contribution from this chapter to the dissertation was the combination of countries' greenhouse gas emissions (Ward and Mahowald 2014) with the multi-millennial temperature-to-

[12] I recognize that this definition of risk is limited to physical exposure, whereas others have defined risk as the intersection of physical exposure and social vulnerability (e.g., Wisner et al. 2004; Chapter 3). Examining social vulnerability over a two millennium time frame would be impractical, however, so in Chapter 2 we chose to define risk as simply land loss threatened from commitment to multi-millennial sea-level rise. Moreover, the insurance industry and hazards fields have often defined risk as simply exposure; hence the calls since the 1970s (O'Keefe, Westgate, and Wisner 1976) by hazards geographers for more emphasis on the social domain in risk/vulnerability studies, a call which continues today (Gaillard et al. 2014).

sea-level rise conversion factor (Levermann et al. 2013), which showed that Earth is *already* committed to approximately 1.3 m of global sea-level rise above the current mean level, which corresponds with a prior assessment (Strauss 2013). This implies that it is not a question of *if*, but *when* Earth will reach one plus meters above the current level, including the Georgia coast, the site of the other dissertation chapters.

Linking Chapter 2 to Chapter 3, we applied the results of the semi-empirical, global sea-level rise model (Vermeer and Rahmstorf 2009) from Chapter 2, which is based on a comprehensive assessment of modeled greenhouse gas emissions over the period 1850 to 2100 (Ward and Mahowald 2014), to create locally-adjusted estimates of sea-level rise for Georgia's coast through the year 2050. We use these locally-adjusted estimates to evaluate physical exposure of US Census tracts to inundation.

This locally-adjusted sea-level rise model aided our objective in Chapter 3 of identifying future populations at risk to sea-level rise on Georgia's coast. We defined risk (differently than in Chapter 2) as the product of physical exposure to sea-level rise and future social vulnerability following others (Wisner et al. 2004; Emrich and Cutter 2011). We measured social vulnerability via projected tract populations' characteristics, or the socioeconomic indicators of vulnerability that are found in U.S Census data including age, race, ethnicity, sex, poverty status, and educational attainment level. We found that overall, the percentage of the population living in tracts indicated as having relatively high levels of social vulnerability increases nearly four-fold in the region between 2010 and 2050. We also found that educational attainment and race (African American specifically) are predicted to become more important variables for explaining most of the social vulnerability in the region over the 40-year analysis window.

In this dissertation, there is slippage in the definitions of risk and vulnerability between the two ends of the ontology/epistemology spectrum I mentioned in the introductory paragraph. First, risk is redefined as not only the potential for harm via physical exposure as in Chapter 2, but in Chapter 3 also includes social vulnerability as measured by indicators derived from social theory. For example, racial minorities are identified as more socially vulnerable due to a number of social factors that affect life chances and livelihood mobility and flexibility (Bonilla-Silva 1997; Bonilla-Silva 2013). Consequently, measuring social vulnerability is a much more challenging and subjective affair, yet the modeling approach that is applied in Chapter 3 necessitates assuming that we can extract these social characteristics from their socionatural entanglements and place-based power relations. It is not race or sex that make an individual or group more vulnerable than another. There is no physical property about a black body, a female body, or an elderly body that make them more vulnerable to sea-level rise. However, the social structure and context in which these characteristics (and others) are embedded does influence relative degrees of vulnerability by affecting access to resources and/or creating power inequalities, which was my focus for examining social-ecological vulnerability (in lieu of risk) in Chapter 4.

In Chapter 4, I moved to the local scale and worked to salvage some of the details that are lost in the extraction of social characteristics from their socionatural entanglements for modeling purposes, as in Chapter 3. I conducted a comparative case study of barrier island life (Sapelo and Tybee Islands) using ethnographic methods of participant observation, semi-structured interviews, and what I called "grounded exploration." I put forward two key arguments. First, I argued that due to anthropogenic climate change, not only are disasters no longer natural, but that hazards are often no longer solely environmental. Aiming this argument at sea-level rise, I contended that in order to advance the agenda of climate change adaptation as a human rights issue (Maldonado et al. 2013), a moment for transformation (Pelling 2011), and a space that takes seriously other forms of knowledge (Maldonado 2014) for coastal communities exposed to sea-level rise, it must be recognized as the social-ecological phenomenon that it is. As more than half of all observable sea-level rise since 1970 is attributable to anthropogenic changes to the climate system (Slangen et al. 2016), the idea of a socionatural coast has new value as the "fingerprint" of human activities extends even to shores uninhabited by humans. In other words, such a reframing of sea-level rise makes space for stronger claims that it is a social justice issue.

In line with this first argument, the second key argument of Chapter 4 is that structural and colorblind forms of racism reproduce systemic racial inequalities within sea-level rise adaptation research due to three barriers to engagement including a colorblind problem definition, worry capital allocation, divergent discourses of environmental/climatic change, and strained historical relations. I suggest that these contribute to the persistence of increased levels of vulnerability for racial minorities living in coastal areas, but I specifically focus this argument on Sapelo Island, where I estimate that 64% of the island's 69 full and part time residents are African American. To make these claims requires different ontological and epistemological understandings about how the world works compared to those used in Chapters 2 and 3. This is the opposite end along the ontology/epistemology spectrum from that applied in Chapter 2. Essentially, I am arguing that the reality of vulnerability to sea-level rise for Sapelo's African American residents is one of a socially-constructed inequality that hinders life chances and opportunities that would make adaptation to sea-level rise both more likely and easier.

In Chapter 5, I moved to a meta-analysis of the approaches taken in Chapters 3 and 4, examining how insights from both approaches produce a more robust understanding of vulnerability to sea-level rise along Georgia's coast. Specifically, I argued for epistemological pluralism in research designs. In this case, I employed the theoretical perspectives of positivism and critical theory to bridge the objectivist (Chapter 3) and constructionist (Chapter 4) epistemological approaches (Blackman and Moon 2014) of outcome and contextual vulnerability studies, respectively (O'Brien et al. 2007). This also answered a call to human geographers that we engage more with critical race theory when mapping environmental injustices (Pulido 2000). I compared and contrasted the strengths and limitations of each approach for analyzing the following: (1) social-ecological spaces, (2) place-based power relations, (3) predictive power, (4) key social characteristics of vulnerability, and (5) replicability and normative application of results.

In Chapter 5, I present some of the major overarching findings of this dissertation project, as it is a meta-analysis of Chapters 3 and 4. For example, as when I wrote, "[p]arts of the shifting demographic patterns (e.g., age shifts) were visible in the outcome of the model-based risk assessment, but the details of finer scale demographic shifts along the shoreline and islands were only evident via personal observation during fieldwork in the contextual case study. In other words, such micro-scale changes fall under the resolution of the regional risk model. More importantly, the explanation for *why* the demographic change is occurring resides in the contextual analysis, which is dependent on data collected from the in-depth qualitative case study" (Chapter 5). In vulnerability assessments, particularly for gradual environmental changes such as sea-level rise that will unfold over decades, combining the predictive power of socioeoonomic models with the rich contextual detail of ethnographic investigations produces more comprehensive interpretations of the results of each approach.

Fortunately, I was able to meet all of the objectives that I set out to accomplish (Table 1.1), nearly anyway. One that I was not able to achieve was the mapping of sea-level rise inundation impacts on livelihood spaces (i.e., daily activity spaces; e.g., see Kwan and Ding 2008). I had originally proposed to investigate how livelihood use space overlapped with projections of sea-level rise inundation, but due to time constraints, and the overall research design, I was not able to carry out this part of the project. I imagine it as a future project, however. A second objective that I had originally proposed was to code the transcribed interviews and import them into a GIS database for concurrent exploration with the sea-level rise inundation maps. This I did not complete due to time constraints as well. Instead, I less formally (but of no less value) explored the landscape with a mobile map of inundation and my memories of stories discussed during interviews. I think that both of these unmet objectives would be rich opportunities for future research.

While I had to overcome many smaller hurdles that are common with the dissertation process (e.g., writing it), one of the most challenging was the integrative factor. Deciding how to be integrative (and what that meant) led me to a mixed methods, plural epistemology research design; one that proved quite an intellectual task regarding levels of expertise needed for the different approaches (i.e., quantitative modeling versus qualitative ethnographic investigation). Both approaches required critical thinking regarding the methods and theory needed to do the research, but interestingly the quantitative investigation demanded that I willingly suspend my critical social theory thinking in order to carry out the work. For example, the simplification of risk to be measured only as "land loss" in Chapter 2, or the complete disembodiment of race and poverty in Chapter 3 in order to model them, were both particularly unsettling for me from the perspective of a critical social theory framing. But, embracing that each has strengths and weaknesses, as outlined in Chapter 5, I moved forward.

Another particularly difficult challenge was learning to speak the common languages of each approach, but even more was learning the style of writing for each. The mental gymnastics that it took to compose a single document containing such divergent writing styles and worldviews was, to say the least, frustrating, but also rewarding. Scholars who are capable of writing in multiple styles are in the literature (e.g., Collins 2010; Collins et al. 2013), and perhaps becoming even more common with the increasing calls for integrative and transdisciplinarity education opportunities (McBride et al. 2011; Wei, Burnside, and Che-Castaldo 2014; Welch-Devine et al. 2014). One limitation of this version of an integrative approach, however, is that depth is sacrificed for breadth. I believe that any one of my dissertation chapters (2 – 5) could be expanded into a much more narrowly-aimed dissertation project. From a more optimistic perspective, as a career goal, I feel better positioned to have productive conversations with both scholars of critical social theory and quantitative modeling of sea-level rise and climate change.

In this dissertation, I have worked to integratively navigate the problem of inequalities related to future sea-level rise. I have shown how the same problem can be examined through multiple methods and epistemologies, and that each perspective depends on the positionality a researcher chooses with respect to these. Andrea Nightingale perhaps recently said it most clearly while citing Hulme (2011), “ontological understandings of research problems are derived from logical thinking, established theories, history and habit. Methodologies similarly stem from simplifications of complex phenomenon and (perhaps more often than researchers like to admit) known methods and disciplinary biases” (Nightingale 2016, 42). In Chapter 1, I stated that “[t]o be integrative and do integrative research simultaneously means avoiding the politics of dismissal and defensiveness while not avoiding self-reflective critical thinking or external critique (especially other disciplinary and non-academic forms)" (Chapter 1, 2). The diverse epistemological framings and methodologies presented in this dissertation embody this sentiment with the goal, in part, of showing how it is possible to work via an integrative approach that takes seriously the measureable effects of climate change on a global array of social-ecological systems while also recognizing it as a major human rights and social justice issue.

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APPENDIX A

SUPPLEMENTARY MATERIAL FOR CHAPTER 2

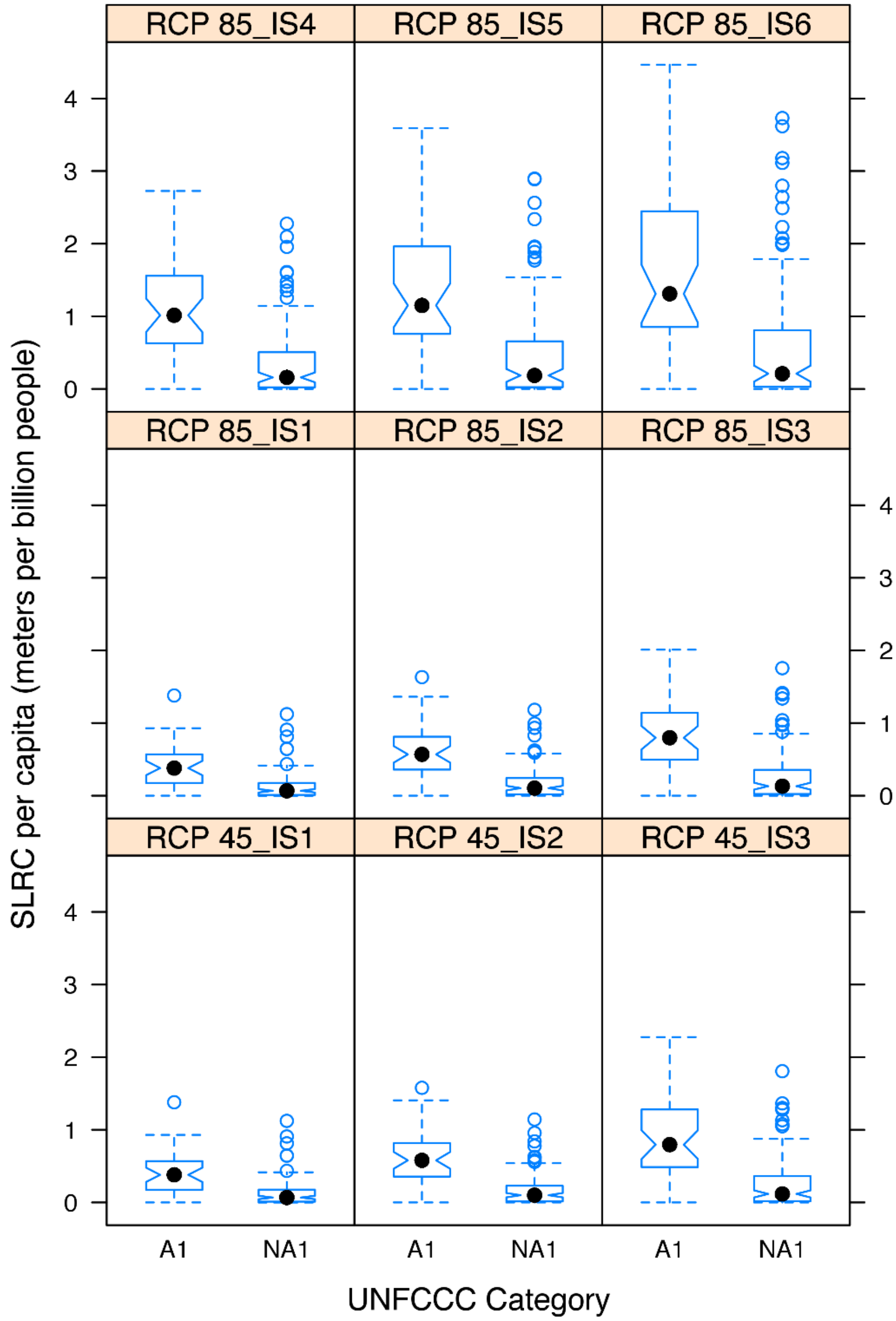

Figure A.1 Country group per capita rate box plots for each one-meter increment of global SLRC for RCP 8.5 and RCP 4.5. IS# indicates the SLRC inundation stage in meters. Note that IS1 for both scenarios is the same, as the data are based on historical emissions until 1995. See the text for details of how per capita rates were calculated.

Table A.1 Country contributions (meters, percent, and per capita) and land exposure (km^2, country percentage, and global percentage) for each one-meter increment of global SLRC under scenario RCP 8.5. Intrinsic and extrinsic risk indices for 6 m of global SLRC are also included.

COUNTRY	**ISO3**	**UNFCCC**	**SLRCM _IS1**	**SLRCM _IS2**	**SLRCM _IS3**	**SLRCM _IS4**	**SLRCM _IS5**	**SLRCM _IS6**	**SLRCP _IS1**	**SLRCP _IS2**	**SLRCP _IS3**	**SLRCP _IS4**	**SLRCP _IS5**	**SLRCP _IS6**
AFGHANISTAN	AFG	NA1	0.001	0.002	0.003	0.004	0.005	0.006	0.001	0.001	0.001	0.001	0.001	0.001
ALBANIA	ALB	NA1	0.001	0.002	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
ALGERIA	DZA	NA1	0.002	0.007	0.014	0.022	0.030	0.040	0.002	0.003	0.004	0.005	0.006	0.007
ANGOLA	AGO	NA1	0.000	0.000	0.002	0.003	0.005	0.007	0.000	0.000	0.001	0.001	0.001	0.001
ARGENTINA	ARG	NA1	0.004	0.010	0.016	0.025	0.033	0.041	0.004	0.005	0.005	0.006	0.007	0.007
ARMENIA	ARM	NA1	0.001	0.001	0.002	0.002	0.002	0.003	0.001	0.001	0.001	0.000	0.000	0.000
ARUBA	ABW	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AUSTRALIA	AUS	A1	0.008	0.018	0.028	0.037	0.044	0.053	0.008	0.009	0.009	0.009	0.009	0.009
AUSTRIA	AUT	A1	0.002	0.003	0.005	0.007	0.008	0.010	0.002	0.002	0.002	0.002	0.002	0.002
AZERBAIJAN	AZE	NA1	0.002	0.003	0.004	0.005	0.006	0.008	0.002	0.001	0.001	0.001	0.001	0.001
BAHAMAS	BHS	NA1	0.000	0.000	0.001	0.001	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000
BAHRAIN	BHR	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BANGLADESH	BGD	NA1	0.002	0.004	0.007	0.009	0.010	0.012	0.002	0.002	0.002	0.002	0.002	0.002
BARBADOS	BRB	NA1	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
BELARUS	BLR	A1	0.009	0.012	0.016	0.021	0.025	0.029	0.009	0.006	0.005	0.005	0.005	0.005
BELGIUM	BEL	A1	0.004	0.006	0.008	0.009	0.010	0.012	0.004	0.003	0.003	0.002	0.002	0.002
BELIZE	BLZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BENIN	BEN	NA1	0.000	0.001	0.002	0.003	0.004	0.006	0.000	0.001	0.001	0.001	0.001	0.001
BHUTAN	BTN	NA1	0.000	0.001	0.002	0.002	0.003	0.003	0.000	0.001	0.001	0.001	0.001	0.001
BOLIVIA	BOL	NA1	0.001	0.003	0.004	0.005	0.006	0.008	0.001	0.001	0.001	0.001	0.001	0.001
BOSNIA_HERZEG.	BIH	NA1	0.001	0.002	0.003	0.004	0.005	0.007	0.001	0.001	0.001	0.001	0.001	0.001
BOTSWANA	BWA	NA1	0.000	0.001	0.002	0.003	0.004	0.005	0.000	0.000	0.001	0.001	0.001	0.001
BRAZIL	BRA	NA1	0.033	0.061	0.087	0.114	0.141	0.166	0.033	0.030	0.029	0.028	0.028	0.028
BRUNEI	BRN	NA1	0.000	0.001	0.002	0.002	0.003	0.004	0.000	0.001	0.001	0.001	0.001	0.001

COUNTRY	ISO3	UNFCCC	SLRCM _IS1	SLRCM _IS2	SLRCM _IS3	SLRCM _IS4	SLRCM _IS5	SLRCM _IS6	SLRCP _IS1	SLRCP _IS2	SLRCP _IS3	SLRCP _IS4	SLRCP _IS5	SLRCP _IS6
BULGARIA	BGR	A1	0.002	0.003	0.005	0.006	0.008	0.009	0.002	0.002	0.002	0.002	0.002	0.002
BURKINA_FASO	BFA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BURUNDI	BDI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CAMBODIA	KHM	NA1	0.001	0.003	0.004	0.006	0.007	0.008	0.001	0.001	0.001	0.001	0.001	0.001
CAMEROON	CMR	NA1	0.003	0.005	0.008	0.010	0.012	0.014	0.003	0.003	0.003	0.003	0.002	0.002
CANADA	CAN	A1	0.040	0.066	0.088	0.108	0.126	0.144	0.040	0.033	0.029	0.027	0.025	0.024
CENTRAL_AFR._REP.	CAF	NA1	0.000	0.001	0.003	0.004	0.004	0.005	0.000	0.001	0.001	0.001	0.001	0.001
CHAD	TCD	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CHILE	CHL	NA1	0.003	0.006	0.010	0.015	0.020	0.023	0.003	0.003	0.003	0.004	0.004	0.004
CHINA	CHN	NA1	0.089	0.311	0.547	0.788	1.030	1.266	0.089	0.155	0.181	0.196	0.205	0.211
COLOMBIA	COL	NA1	0.009	0.013	0.021	0.028	0.035	0.042	0.009	0.007	0.007	0.007	0.007	0.007
CONGO	COG	NA1	0.000	0.001	0.002	0.004	0.005	0.006	0.000	0.000	0.001	0.001	0.001	0.001
COSTA_RICA	CRI	NA1	0.000	0.001	0.001	0.002	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000
COTE_D_IVOIRE	CIV	NA1	0.002	0.004	0.007	0.009	0.009	0.010	0.002	0.002	0.002	0.002	0.002	0.002
CROATIA	HRV	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CUBA	CUB	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CYPRUS	CYP	A1	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
CZECH_REPUBLIC	CZE	A1	0.009	0.014	0.019	0.024	0.029	0.033	0.009	0.007	0.006	0.006	0.006	0.006
DEM_REP_CONGO	COD	NA1	0.007	0.021	0.037	0.050	0.062	0.073	0.007	0.011	0.012	0.012	0.012	0.012
DENMARK	DNK	A1	0.003	0.005	0.006	0.007	0.008	0.009	0.003	0.002	0.002	0.002	0.002	0.001
DJIBOUTI	DJI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOMINICAN_REP.	DOM	NA1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
ECUADOR	ECU	NA1	0.002	0.004	0.007	0.010	0.012	0.014	0.002	0.002	0.002	0.002	0.002	0.002
EGYPT	EGY	NA1	0.001	0.006	0.013	0.021	0.029	0.038	0.001	0.003	0.004	0.005	0.006	0.006
EL_SALVADOR	SLV	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EQ._GUINEA	GNQ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ERITREA	ERI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ESTONIA	EST	A1	0.001	0.001	0.002	0.002	0.003	0.004	0.001	0.001	0.001	0.001	0.001	0.001
ETHIOPIA	ETH	NA1	0.002	0.003	0.004	0.005	0.007	0.008	0.002	0.002	0.001	0.001	0.001	0.001

COUNTRY	ISO3	UNFCCC	SLRCM _IS1	SLRCM _IS2	SLRCM _IS3	SLRCM _IS4	SLRCM _IS5	SLRCM _IS6	SLRCP _IS1	SLRCP _IS2	SLRCP _IS3	SLRCP _IS4	SLRCP _IS5	SLRCP _IS6
GERMANY	DEU	A1	0.046	0.066	0.083	0.098	0.112	0.125	0.046	0.033	0.027	0.024	0.022	0.021
FINLAND	FIN	A1	0.002	0.005	0.006	0.008	0.010	0.011	0.002	0.002	0.002	0.002	0.002	0.002
FORMER_YEMEN	YEM	NA1	0.000	0.001	0.001	0.001	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000
FRANCE	FRA	A1	0.023	0.035	0.045	0.054	0.063	0.071	0.023	0.017	0.015	0.013	0.012	0.012
FR._POLYNESIA	PYF	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GABON	GAB	NA1	0.001	0.002	0.004	0.006	0.007	0.009	0.001	0.001	0.001	0.001	0.001	0.001
GEORGIA	GEO	NA1	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.001	0.001	0.001	0.001	0.001
GHANA	GHA	NA1	0.001	0.002	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
GREECE	GRC	A1	0.001	0.003	0.005	0.007	0.009	0.010	0.001	0.002	0.002	0.002	0.002	0.002
GUAM	GUM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GUATEMALA	GTM	NA1	0.001	0.002	0.004	0.005	0.006	0.007	0.001	0.001	0.001	0.001	0.001	0.001
GUINEA	GIN	NA1	0.000	0.001	0.001	0.002	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000
GUINEA_BISSAU	GNB	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GUYANA	GUY	NA1	0.000	0.001	0.001	0.001	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000
HAITI	HTI	NA1	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
HONDURAS	HND	NA1	0.001	0.002	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
HONG_KONG	HKG	NA1	0.001	0.002	0.003	0.004	0.005	0.006	0.001	0.001	0.001	0.001	0.001	0.001
HUNGARY	HUN	A1	0.003	0.005	0.006	0.008	0.010	0.012	0.003	0.002	0.002	0.002	0.002	0.002
ICELAND	ISL	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INDIA	IND	NA1	0.025	0.080	0.138	0.194	0.249	0.303	0.025	0.040	0.046	0.048	0.050	0.050
INDONESIA	IDN	NA1	0.041	0.064	0.091	0.116	0.137	0.160	0.041	0.032	0.030	0.029	0.027	0.027
IRAN	IRN	NA1	0.004	0.019	0.039	0.063	0.089	0.116	0.004	0.010	0.013	0.016	0.018	0.019
IRAQ	IRQ	NA1	0.001	0.005	0.010	0.016	0.023	0.030	0.001	0.003	0.003	0.004	0.005	0.005
IRELAND	IRL	A1	0.001	0.002	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
ISRAEL	ISR	NA1	0.000	0.001	0.001	0.002	0.003	0.004	0.000	0.000	0.000	0.000	0.001	0.001
ITALY	ITA	A1	0.009	0.018	0.026	0.034	0.041	0.047	0.009	0.009	0.009	0.008	0.008	0.008
JAMAICA	JAM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
JAPAN	JPN	A1	0.024	0.054	0.080	0.102	0.123	0.143	0.024	0.027	0.026	0.025	0.024	0.024
JORDAN	JOR	NA1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000

COUNTRY	ISO3	UNFCCC	SLRCM _IS1	SLRCM _IS2	SLRCM _IS3	SLRCM _IS4	SLRCM _IS5	SLRCM _IS6	SLRCP _IS1	SLRCP _IS2	SLRCP _IS3	SLRCP _IS4	SLRCP _IS5	SLRCP _IS6
KAZAKHSTAN	KAZ	NA1	0.006	0.012	0.018	0.024	0.031	0.038	0.006	0.006	0.006	0.006	0.006	0.006
KENYA	KEN	NA1	0.000	0.001	0.002	0.002	0.003	0.004	0.000	0.001	0.001	0.001	0.001	0.001
NORTH_KOREA	PRK	NA1	0.002	0.005	0.007	0.010	0.012	0.014	0.002	0.002	0.002	0.002	0.002	0.002
SOUTH_KOREA	KOR	NA1	0.004	0.016	0.027	0.039	0.051	0.062	0.004	0.008	0.009	0.010	0.010	0.010
KUWAIT	KWT	NA1	0.001	0.004	0.008	0.013	0.018	0.024	0.001	0.002	0.003	0.003	0.004	0.004
KYRGYZSTAN	KGZ	NA1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000
LAO	LAO	NA1	0.001	0.002	0.003	0.004	0.005	0.006	0.001	0.001	0.001	0.001	0.001	0.001
LATVIA	LVA	A1	0.002	0.002	0.003	0.003	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.001
LEBANON	LBN	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LESOTHO	LSO	NA1	0.000	0.001	0.002	0.003	0.004	0.005	0.000	0.001	0.001	0.001	0.001	0.001
LIBERIA	LBR	NA1	0.002	0.004	0.006	0.008	0.008	0.009	0.002	0.002	0.002	0.002	0.002	0.001
LIBYA	LBY	NA1	0.000	0.002	0.004	0.006	0.009	0.011	0.000	0.001	0.001	0.002	0.002	0.002
LITHUANIA	LTU	A1	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.000	0.000	0.000	0.000
LUXEMBOURG	LUX	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MACEDONIA	MKD	NA1	0.001	0.001	0.002	0.002	0.002	0.003	0.001	0.001	0.000	0.000	0.000	0.000
MADAGASCAR	MDG	NA1	0.000	0.002	0.004	0.005	0.006	0.008	0.000	0.001	0.001	0.001	0.001	0.001
MALAWI	MWI	NA1	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
MALAYSIA	MYS	NA1	0.006	0.014	0.020	0.026	0.031	0.036	0.006	0.007	0.007	0.006	0.006	0.006
MALI	MLI	NA1	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
MALTA	MLT	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAURITANIA	MRT	NA1	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
MEXICO	MEX	NA1	0.011	0.026	0.045	0.066	0.088	0.106	0.011	0.013	0.015	0.016	0.018	0.018
MOLDOVA	MDA	NA1	0.001	0.002	0.002	0.003	0.003	0.004	0.001	0.001	0.001	0.001	0.001	0.001
MONGOLIA	MNG	NA1	0.001	0.001	0.002	0.003	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
MOROCCO	MAR	NA1	0.001	0.002	0.004	0.006	0.008	0.011	0.001	0.001	0.001	0.001	0.002	0.002
MOZAMBIQUE	MOZ	NA1	0.000	0.001	0.002	0.003	0.003	0.004	0.000	0.001	0.001	0.001	0.001	0.001
MYANMAR	MMR	NA1	0.005	0.013	0.019	0.023	0.027	0.031	0.005	0.006	0.006	0.006	0.005	0.005
NAMIBIA	NAM	NA1	0.000	0.001	0.001	0.002	0.003	0.004	0.000	0.000	0.000	0.001	0.001	0.001
NEPAL	NPL	NA1	0.001	0.003	0.005	0.006	0.008	0.009	0.001	0.002	0.002	0.002	0.002	0.001

COUNTRY	ISO3	UNFCCC	SLRCM _IS1	SLRCM _IS2	SLRCM _IS3	SLRCM _IS4	SLRCM _IS5	SLRCM _IS6	SLRCP _IS1	SLRCP _IS2	SLRCP _IS3	SLRCP _IS4	SLRCP _IS5	SLRCP _IS6
NETHERLANDS	NLD	A1	0.008	0.013	0.017	0.021	0.024	0.027	0.008	0.006	0.006	0.005	0.005	0.005
NEW_CALEDONIA	NCL	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NEW_ZEALAND	NZL	A1	0.002	0.003	0.005	0.006	0.008	0.010	0.002	0.002	0.002	0.002	0.002	0.002
NICARAGUA	NIC	NA1	0.001	0.001	0.002	0.002	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.000
NIGER	NER	NA1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
NIGERIA	NGA	NA1	0.005	0.010	0.015	0.021	0.027	0.034	0.005	0.005	0.005	0.005	0.005	0.006
NORWAY	NOR	A1	0.001	0.002	0.003	0.004	0.005	0.006	0.001	0.001	0.001	0.001	0.001	0.001
OMAN	OMN	NA1	0.000	0.001	0.002	0.003	0.005	0.006	0.000	0.000	0.001	0.001	0.001	0.001
PAKISTAN	PAK	NA1	0.002	0.007	0.013	0.019	0.026	0.032	0.002	0.004	0.004	0.005	0.005	0.005
PANAMA	PAN	NA1	0.001	0.002	0.002	0.003	0.004	0.004	0.001	0.001	0.001	0.001	0.001	0.001
PAPUA_NEW_GUINEA	PNG	NA1	0.001	0.002	0.004	0.005	0.006	0.007	0.001	0.001	0.001	0.001	0.001	0.001
PARAGUAY	PRY	NA1	0.001	0.001	0.003	0.004	0.006	0.007	0.001	0.001	0.001	0.001	0.001	0.001
PERU	PER	NA1	0.003	0.007	0.010	0.014	0.017	0.021	0.003	0.003	0.003	0.003	0.003	0.004
PHILIPPINES	PHL	NA1	0.005	0.008	0.011	0.013	0.015	0.017	0.005	0.004	0.004	0.003	0.003	0.003
POLAND	POL	A1	0.025	0.038	0.051	0.065	0.080	0.094	0.025	0.019	0.017	0.016	0.016	0.016
PORTUGAL	PRT	A1	0.001	0.002	0.003	0.003	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
PUERTO_RICO	PRI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
QATAR	QAT	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ROMANIA	ROU	A1	0.008	0.012	0.015	0.019	0.023	0.026	0.008	0.006	0.005	0.005	0.005	0.004
RUSSI	RUS	A1	0.089	0.148	0.213	0.280	0.347	0.415	0.089	0.074	0.071	0.069	0.069	0.069
RWANDA	RWA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SAUDI_ARABIA	SAU	NA1	0.004	0.019	0.040	0.065	0.092	0.121	0.004	0.010	0.013	0.016	0.018	0.020
SENEGAL	SEN	NA1	0.000	0.000	0.001	0.001	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000
SIERRA_LEONE	SLE	NA1	0.000	0.000	0.001	0.001	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000
SINGAPORE	SGP	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SLOVAKIA	SVK	A1	0.005	0.007	0.010	0.012	0.015	0.017	0.005	0.004	0.003	0.003	0.003	0.003
SLOVENIA	SVN	A1	0.001	0.001	0.002	0.002	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001
SOMALIA	SOM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOUTH_AFRICA	ZAF	NA1	0.007	0.020	0.036	0.055	0.076	0.097	0.007	0.010	0.012	0.014	0.015	0.016

COUNTRY	ISO3	UNFCCC	SLRCM _IS1	SLRCM _IS2	SLRCM _IS3	SLRCM _IS4	SLRCM _IS5	SLRCM _IS6	SLRCP _IS1	SLRCP _IS2	SLRCP _IS3	SLRCP _IS4	SLRCP _IS5	SLRCP _IS6
SPAIN	ESP	A1	0.005	0.013	0.020	0.027	0.033	0.038	0.005	0.007	0.007	0.007	0.006	0.006
SRI_LANKA	LKA	NA1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
SUDAN	SDN	NA1	0.001	0.002	0.004	0.006	0.009	0.011	0.001	0.001	0.001	0.002	0.002	0.002
SURINAME	SUR	NA1	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
SWAZILAND	SWZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SWEDEN	SWE	A1	0.003	0.004	0.006	0.007	0.008	0.009	0.003	0.002	0.002	0.002	0.002	0.001
SWITZERLAND	CHE	A1	0.003	0.006	0.008	0.010	0.012	0.014	0.003	0.003	0.003	0.002	0.002	0.002
SYRIAN_ARAB_REP.	SYR	NA1	0.001	0.003	0.007	0.011	0.015	0.019	0.001	0.002	0.002	0.003	0.003	0.003
TANZANIA	TZA	NA1	0.000	0.001	0.002	0.003	0.003	0.004	0.000	0.001	0.001	0.001	0.001	0.001
THAILAND	THA	NA1	0.007	0.017	0.027	0.037	0.048	0.058	0.007	0.008	0.009	0.009	0.010	0.010
TOGO	TGO	NA1	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
TRINIDA_TOBAGO	TTO	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TUNISIA	TUN	NA1	0.000	0.001	0.002	0.002	0.003	0.004	0.000	0.000	0.001	0.001	0.001	0.001
TURKEY	TUR	A1	0.004	0.011	0.017	0.022	0.028	0.033	0.004	0.006	0.006	0.006	0.005	0.005
TURKMENISTAN	TKM	NA1	0.002	0.003	0.005	0.007	0.009	0.012	0.002	0.002	0.002	0.002	0.002	0.002
UGANDA	UGA	NA1	0.001	0.002	0.003	0.003	0.003	0.004	0.001	0.001	0.001	0.001	0.001	0.001
UKRAINE	UKR	A1	0.021	0.031	0.041	0.052	0.064	0.075	0.021	0.015	0.014	0.013	0.013	0.013
UNITED_ARAB_EMIR.	ARE	NA1	0.000	0.002	0.004	0.007	0.010	0.013	0.000	0.001	0.001	0.002	0.002	0.002
UNITED_KINGDOM	GBR	A1	0.040	0.053	0.065	0.074	0.084	0.093	0.040	0.027	0.021	0.018	0.017	0.015
UNITED_STATES	USA	A1	0.243	0.416	0.565	0.696	0.819	0.937	0.243	0.208	0.187	0.173	0.163	0.156
URUGUAY	URY	NA1	0.000	0.000	0.001	0.001	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000
UZBEKISTAN	UZB	NA1	0.005	0.008	0.011	0.014	0.018	0.021	0.005	0.004	0.004	0.004	0.003	0.003
VENEZUELA	VEN	NA1	0.003	0.009	0.015	0.022	0.029	0.036	0.003	0.004	0.005	0.005	0.006	0.006
VIET_NAM	VNM	NA1	0.004	0.009	0.014	0.018	0.023	0.027	0.004	0.004	0.005	0.005	0.005	0.004
ZAMBIA	ZMB	NA1	0.001	0.001	0.003	0.004	0.005	0.006	0.001	0.001	0.001	0.001	0.001	0.001
ZIMBABWE	ZWE	NA1	0.000	0.001	0.002	0.003	0.004	0.005	0.000	0.001	0.001	0.001	0.001	0.001

Table A.1 *continued*.

COUNTRY	ISO3	UNFCCC	PERC _IS1	PERC _IS2	PERC _IS3	PERC _IS4	PERC _IS5	PERC _IS6	AREA _IS1	AREA _IS2	AREA _IS3	AREA _IS4	AREA _IS5	AREA _IS6

COUNTRY	ISO3	UNFCCC	PERC _IS1	PERC _IS2	PERC _IS3	PERC _IS4	PERC _IS5	PERC _IS6	AREA _IS1	AREA _IS2	AREA _IS3	AREA _IS4	AREA _IS5	AREA _IS6
AFGHANISTAN	AFG	NA1	0.040	0.038	0.047	0.060	0.075	0.094	0	0	0	0	0	0
ALBANIA	ALB	NA1	0.308	0.619	0.985	1.415	1.960	2.644	212	364	489	581	720	997
ALGERIA	DZA	NA1	0.057	0.141	0.242	0.361	0.496	0.644	5	17	262	345	448	525
ANGOLA	AGO	NA1	-0.001	0.013	0.026	0.035	0.044	0.057	38	101	350	669	964	1216
ARGENTINA	ARG	NA1	0.127	0.200	0.297	0.424	0.565	0.695	315	2836	7761	13401	18177	23654
ARMENIA	ARM	NA1	0.364	0.482	0.627	0.818	1.051	1.325	0	0	0	0	0	0
ARUBA	ABW	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0	0	1	1	1	2
AUSTRALIA	AUS	A1	0.436	0.653	0.832	0.998	1.137	1.288	3050	6861	12714	23612	35113	47810
AUSTRIA	AUT	A1	0.255	0.395	0.582	0.779	0.967	1.152	0	0	0	0	0	0
AZERBAIJAN	AZE	NA1	0.214	0.253	0.350	0.474	0.613	0.763	0	0	0	0	0	0
BAHAMAS	BHS	NA1	0.813	0.993	1.414	1.956	2.563	3.113	391	1096	2140	4133	5772	7055
BAHRAIN	BHR	NA1	0.000	0.000	0.000	0.000	0.000	0.000	3	21	47	77	112	143
BANGLADESH	BGD	NA1	0.017	0.024	0.034	0.043	0.054	0.067	64	789	1035	3697	6460	13906
BARBADOS	BRB	NA1	0.123	0.414	0.778	1.255	1.769	2.231	0	0	0	0	0	1
BELARUS	BLR	A1	0.845	1.362	2.010	2.708	3.444	4.160	0	0	0	0	0	0
BELGIUM	BEL	A1	0.392	0.497	0.605	0.707	0.801	0.888	319	518	751	1274	1768	2147
BELIZE	BLZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	69	218	454	730	957	1159
BENIN	BEN	NA1	0.070	0.096	0.109	0.125	0.144	0.165	75	280	361	1313	1511	1670
BHUTAN	BTN	NA1	0.643	1.182	1.756	2.275	2.896	3.618	0	0	0	0	0	0
BOLIVIA	BOL	NA1	0.099	0.205	0.244	0.308	0.356	0.445	0	0	0	0	0	0
BOSNIA_HERZEG.	BIH	NA1	0.313	0.593	1.039	1.610	2.338	3.179	9	15	21	26	28	31
BOTSWANA	BWA	NA1	0.200	0.336	0.522	0.745	1.000	1.287	0	0	0	0	0	0
BRAZIL	BRA	NA1	0.200	0.268	0.366	0.489	0.632	0.784	1452	8572	15415	29464	46734	62636
BRUNEI	BRN	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	4	32
BULGARIA	BGR	A1	0.221	0.541	0.960	1.453	2.008	2.572	33	75	90	111	140	151
BURKINA_FASO	BFA	NA1	0.001	0.001	0.001	0.001	0.002	0.002	0	0	0	0	0	0
BURUNDI	BDI	NA1	0.026	0.011	0.009	0.008	0.007	0.007	0	0	0	0	0	0
CAMBODIA	KHM	NA1	0.136	0.156	0.191	0.230	0.277	0.331	4	106	396	1636	3205	5455
CAMEROON	CMR	NA1	0.246	0.163	0.170	0.173	0.175	0.182	7	10	21	40	94	174

COUNTRY	ISO3	UNFCCC	PERC _IS1	PERC _IS2	PERC _IS3	PERC _IS4	PERC _IS5	PERC _IS6	AREA _IS1	AREA _IS2	AREA _IS3	AREA _IS4	AREA _IS5	AREA _IS6
CANADA	CAN	A1	1.379	1.632	1.996	2.339	2.650	2.958	2901	6060	9695	13993	20465	25745
CENTRAL_AFR._REP.	CAF	NA1	0.121	0.229	0.327	0.364	0.395	0.444	0	0	0	0	0	0
CHAD	TCD	NA1	0.002	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0
CHILE	CHL	NA1	0.196	0.288	0.477	0.694	0.944	1.131	73	161	285	439	721	1055
CHINA	CHN	NA1	0.073	0.220	0.404	0.633	0.900	1.193	7957	19675	36737	53697	79720	103290
COLOMBIA	COL	NA1	0.229	0.253	0.377	0.525	0.688	0.877	307	806	1676	3333	5416	7621
CONGO	COG	NA1	0.123	0.149	0.218	0.257	0.274	0.285	1	3	4	7	15	83
COSTA_RICA	CRI	NA1	0.141	0.155	0.217	0.313	0.425	0.522	5	13	29	50	104	219
COTE_D_IVOIRE	CIV	NA1	0.145	0.143	0.154	0.137	0.123	0.114	16	62	168	439	667	805
CROATIA	HRV	A1	0.000	0.000	0.000	0.000	0.000	0.000	8	14	72	79	89	105
CUBA	CUB	NA1	0.000	0.002	0.004	0.006	0.008	0.010	472	1341	2984	5186	7811	10650
CYPRUS	CYP	A1	0.098	0.247	0.375	0.485	0.600	0.718	2	11	16	24	29	36
CZECH_REPUBLIC	CZE	A1	0.892	1.339	1.901	2.500	3.146	3.746	0	0	0	0	0	0
DEM_REP_CONGO	COD	NA1	0.175	0.181	0.196	0.197	0.202	0.205	0	10	33	183	278	350
DENMARK	DNK	A1	0.577	0.754	0.909	1.043	1.163	1.284	574	1194	2249	3182	3912	4902
DJIBOUTI	DJI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	7	11	27	71	115	162
DOMINICAN_REP.	DOM	NA1	0.006	0.017	0.028	0.044	0.063	0.081	44	119	219	370	737	939
ECUADOR	ECU	NA1	0.162	0.207	0.298	0.389	0.470	0.569	248	698	1258	1773	2337	3288
EGYPT	EGY	NA1	0.020	0.053	0.085	0.121	0.157	0.196	2263	4898	7206	9341	11310	12994
EL_SALVADOR	SLV	NA1	0.000	0.000	0.000	0.000	0.000	0.000	4	7	17	31	75	171
EQ._GUINEA	GNQ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	1	4	5	7	15	24
ERITREA	ERI	NA1	0.001	0.004	0.005	0.007	0.008	0.009	36	109	229	453	752	1089
ESTONIA	EST	A1	0.473	0.979	1.604	2.303	3.078	3.872	12	49	99	243	359	520
ETHIOPIA	ETH	NA1	0.040	0.022	0.023	0.025	0.029	0.032	0	0	0	0	0	0
GERMANY	DEU	A1	0.561	0.834	1.110	1.391	1.660	1.932	1128	2453	4029	5326	6624	7817
FINLAND	FIN	A1	0.463	0.791	1.107	1.383	1.652	1.919	2	8	18	32	67	125
FORMER_YEMEN	YEM	NA1	0.015	0.016	0.021	0.027	0.035	0.044	191	386	595	832	1132	1427
FRANCE	FRA	A1	0.390	0.514	0.634	0.745	0.846	0.942	1689	3131	4339	5345	6405	7342
FR._POLYNESIA	PYF	NA1	0.000	0.000	0.000	0.000	0.000	0.000	10	18	29	35	37	45

COUNTRY	ISO3	UNFCCC	PERC _IS1	PERC _IS2	PERC _IS3	PERC _IS4	PERC _IS5	PERC _IS6	AREA _IS1	AREA _IS2	AREA _IS3	AREA _IS4	AREA _IS5	AREA _IS6
GABON	GAB	NA1	1.123	0.933	1.338	1.600	1.809	2.077	9	22	71	213	516	765
GEORGIA	GEO	NA1	0.341	0.518	0.661	0.822	1.017	1.207	156	283	460	579	696	836
GHANA	GHA	NA1	0.061	0.058	0.061	0.062	0.067	0.071	343	627	933	1152	1365	1593
GREECE	GRC	A1	0.104	0.323	0.550	0.797	1.065	1.332	361	736	1115	1675	2005	2339
GUAM	GUM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0	1	2	3	4	5
GUATEMALA	GTM	NA1	0.094	0.112	0.136	0.156	0.179	0.201	12	22	79	132	240	371
GUINEA	GIN	NA1	0.016	0.028	0.041	0.047	0.047	0.049	37	166	440	961	1464	1994
GUINEA_BISSAU	GNB	NA1	0.016	0.039	0.053	0.061	0.066	0.072	8	34	94	253	643	1542
GUYANA	GUY	NA1	0.315	0.623	0.970	1.473	1.947	2.798	103	403	1265	2435	3536	4498
HAITI	HTI	NA1	0.009	0.023	0.038	0.057	0.080	0.101	5	28	120	208	310	400
HONDURAS	HND	NA1	0.224	0.242	0.294	0.328	0.384	0.459	69	108	562	1186	1730	2633
HONG_KONG	HKG	NA1	0.082	0.204	0.342	0.495	0.656	0.808	3	14	19	27	28	30
HUNGARY	HUN	A1	0.293	0.489	0.752	1.047	1.382	1.721	0	0	0	0	0	0
ICELAND	ISL	A1	0.144	0.247	0.341	0.429	0.509	0.592	55	99	159	268	375	526
INDIA	IND	NA1	0.026	0.053	0.081	0.111	0.143	0.177	664	3456	13684	25632	37407	50488
INDONESIA	IDN	NA1	0.209	0.218	0.284	0.354	0.423	0.499	1069	3411	8103	15299	26709	43941
IRAN	IRN	NA1	0.073	0.220	0.427	0.721	1.107	1.564	547	1715	4265	7275	10343	13416
IRAQ	IRQ	NA1	0.071	0.100	0.126	0.152	0.176	0.200	37	270	1181	8300	12252	14878
IRELAND	IRL	A1	0.314	0.404	0.502	0.602	0.698	0.787	91	206	290	420	567	708
ISRAEL	ISR	NA1	0.021	0.060	0.097	0.136	0.176	0.216	0	3	5	18	66	92
ITALY	ITA	A1	0.150	0.308	0.467	0.631	0.791	0.940	1285	2716	3950	5105	6198	7282
JAMAICA	JAM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	35	60	126	170	242	301
JAPAN	JPN	A1	0.197	0.451	0.739	1.031	1.347	1.657	1047	2054	4017	5854	7969	9865
JORDAN	JOR	NA1	0.007	0.018	0.030	0.043	0.058	0.074	0	0	0	0	0	0
KAZAKHSTAN	KAZ	NA1	0.386	0.579	0.792	1.026	1.275	1.526	0	0	0	0	0	0
KENYA	KEN	NA1	0.014	0.017	0.019	0.021	0.024	0.027	18	70	197	369	1082	1315
NORTH_KOREA	PRK	NA1	0.101	0.183	0.270	0.366	0.465	0.566	20	83	215	462	971	1536
SOUTH_KOREA	KOR	NA1	0.097	0.299	0.536	0.834	1.177	1.545	29	163	281	443	754	1059
KUWAIT	KWT	NA1	0.645	0.829	1.395	2.096	2.888	3.730	85	316	595	800	921	1038

COUNTRY	ISO3	UNFCCC	PERC _IS1	PERC _IS2	PERC _IS3	PERC _IS4	PERC _IS5	PERC _IS6	AREA _IS1	AREA _IS2	AREA _IS3	AREA _IS4	AREA _IS5	AREA _IS6
KYRGYZSTAN	KGZ	NA1	0.138	0.107	0.110	0.123	0.139	0.156	0	0	0	0	0	0
LAO	LAO	NA1	0.161	0.238	0.311	0.369	0.448	0.543	0	0	0	0	0	0
LATVIA	LVA	A1	0.771	1.307	1.813	2.355	2.914	3.482	11	32	308	629	879	1071
LEBANON	LBN	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0	1	3	10	10	23
LESOTHO	LSO	NA1	0.262	0.481	0.693	0.941	1.209	1.515	0	0	0	0	0	0
LIBERIA	LBR	NA1	0.908	0.600	0.681	0.671	0.614	0.589	11	27	48	123	227	327
LIBYA	LBY	NA1	0.086	0.253	0.454	0.714	1.010	1.343	1486	2052	3072	3596	4161	4580
LITHUANIA	LTU	A1	0.253	0.428	0.581	0.731	0.883	1.034	108	206	285	358	426	502
LUXEMBOURG	LUX	A1	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0
MACEDONIA	MKD	NA1	0.326	0.515	0.775	1.074	1.417	1.788	0	0	0	0	0	0
MADAGASCAR	MDG	NA1	0.033	0.051	0.067	0.069	0.075	0.083	179	520	1143	1913	2751	4241
MALAWI	MWI	NA1	0.011	0.027	0.024	0.020	0.018	0.017	0	0	0	0	0	0
MALAYSIA	MYS	NA1	0.308	0.381	0.503	0.612	0.737	0.875	65	118	273	627	1991	3641
MALI	MLI	NA1	0.009	0.011	0.012	0.013	0.014	0.014	0	0	0	0	0	0
MALTA	MLT	A1	0.000	0.000	0.000	0.000	0.000	0.000	0	1	2	3	3	3
MAURITANIA	MRT	NA1	0.023	0.026	0.034	0.042	0.050	0.058	4614	6443	7924	9105	10213	11136
MEXICO	MEX	NA1	0.115	0.180	0.273	0.395	0.543	0.682	4685	12524	21732	30459	39921	48950
MOLDOVA	MDA	NA1	0.287	0.437	0.659	0.954	1.355	1.783	38	107	172	282	370	451
MONGOLIA	MNG	NA1	0.268	0.389	0.553	0.719	0.898	1.074	0	0	0	0	0	0
MOROCCO	MAR	NA1	0.019	0.048	0.087	0.135	0.192	0.259	298	539	730	869	1162	1356
MOZAMBIQUE	MOZ	NA1	0.005	0.030	0.034	0.033	0.031	0.031	73	303	597	2729	7115	10604
MYANMAR	MMR	NA1	0.110	0.209	0.302	0.372	0.451	0.540	678	2225	4001	6182	13834	22217
NAMIBIA	NAM	NA1	0.126	0.210	0.311	0.425	0.548	0.687	123	376	697	990	1257	1534
NEPAL	NPL	NA1	0.070	0.101	0.136	0.173	0.217	0.273	0	0	0	0	0	0
NETHERLANDS	NLD	A1	0.505	0.729	0.960	1.179	1.377	1.573	1499	2799	3755	4545	5312	6143
NEW_CALEDONIA	NCL	NA1	0.000	0.000	0.000	0.000	0.000	0.000	10	47	114	206	290	368
NEW_ZEALAND	NZL	A1	0.480	0.616	0.814	1.106	1.377	1.654	105	226	428	747	1349	2030
NICARAGUA	NIC	NA1	0.193	0.214	0.248	0.286	0.324	0.369	58	303	931	1615	2672	3951
NIGER	NER	NA1	0.008	0.007	0.007	0.007	0.008	0.008	0	0	0	0	0	0

COUNTRY	ISO3	UNFCCC	PERC _IS1	PERC _IS2	PERC _IS3	PERC _IS4	PERC _IS5	PERC _IS6	AREA _IS1	AREA _IS2	AREA _IS3	AREA _IS4	AREA _IS5	AREA _IS6
NIGERIA	NGA	NA1	0.047	0.039	0.039	0.042	0.045	0.049	87	360	725	1466	3383	6309
NORWAY	NOR	A1	0.257	0.398	0.523	0.628	0.725	0.817	100	240	383	571	779	1005
OMAN	OMN	NA1	0.062	0.178	0.339	0.524	0.747	1.002	106	280	850	1352	1773	2129
PAKISTAN	PAK	NA1	0.014	0.030	0.043	0.057	0.071	0.087	226	1949	4730	7668	10352	12556
PANAMA	PAN	NA1	0.435	0.341	0.391	0.486	0.605	0.689	32	70	242	468	657	912
PAPUA_NEW_GUINEA	PNG	NA1	0.207	0.235	0.289	0.320	0.346	0.382	44	112	218	333	508	816
PARAGUAY	PRY	NA1	0.133	0.185	0.286	0.445	0.612	0.733	0	0	0	0	0	0
PERU	PER	NA1	0.146	0.184	0.241	0.316	0.393	0.495	948	1589	2340	2881	3341	3782
PHILIPPINES	PHL	NA1	0.075	0.067	0.073	0.081	0.090	0.101	157	447	970	1888	3024	4860
POLAND	POL	A1	0.642	1.010	1.542	2.191	3.009	3.924	470	840	1512	1794	2051	2255
PORTUGAL	PRT	A1	0.060	0.172	0.284	0.402	0.526	0.649	135	288	449	565	700	804
PUERTO_RICO	PRI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	35	102	235	335	413	495
QATAR	QAT	NA1	0.000	0.000	0.000	0.000	0.000	0.000	18	66	235	473	795	1164
ROMANIA	ROU	A1	0.344	0.648	0.993	1.411	1.861	2.322	644	1826	2427	2911	3207	3763
RUSSIA	RUS	A1	0.603	1.066	1.655	2.276	2.911	3.505	6212	22646	44185	63622	81290	102002
RWANDA	RWA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0
SAUDI_ARABIA	SAU	NA1	0.214	0.502	0.879	1.354	1.887	2.489	622	1665	3085	4538	6026	7585
SENEGAL	SEN	NA1	0.010	0.014	0.017	0.019	0.021	0.023	76	672	2268	4420	6425	7760
SIERRA_LEONE	SLE	NA1	0.048	0.050	0.074	0.098	0.115	0.136	51	142	386	870	1457	1968
SINGAPORE	SGP	NA1	0.012	0.013	0.016	0.020	0.023	0.027	1	2	2	5	6	8
SLOVAKIA	SVK	A1	0.930	1.351	2.002	2.726	3.591	4.464	0	0	0	0	0	0
SLOVENIA	SVN	A1	0.370	0.597	0.907	1.262	1.653	2.013	0	0	0	0	0	1
SOMALIA	SOM	NA1	0.004	0.003	0.003	0.003	0.003	0.003	101	288	482	728	1148	1749
SOUTH_AFRICA	ZAF	NA1	0.174	0.334	0.552	0.816	1.113	1.454	5	12	28	52	134	616
SPAIN	ESP	A1	0.125	0.287	0.451	0.628	0.813	0.982	322	981	1915	2482	2880	3207
SRI_LANKA	LKA	NA1	0.003	0.012	0.022	0.035	0.049	0.065	41	96	267	558	943	1444
SUDAN	SDN	NA1	0.034	0.041	0.053	0.066	0.079	0.093	121	333	587	904	1176	1412
SURINAME	SUR	NA1	0.415	0.592	0.853	1.133	1.484	2.007	138	461	1469	2246	2848	3422
SWAZILAND	SWZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0

COUNTRY	ISO3	UNFCCC	PERC _IS1	PERC _IS2	PERC _IS3	PERC _IS4	PERC _IS5	PERC _IS6	AREA _IS1	AREA _IS2	AREA _IS3	AREA _IS4	AREA _IS5	AREA _IS6
SWEDEN	SWE	A1	0.347	0.420	0.490	0.544	0.593	0.639	30	91	192	358	503	890
SWITZERLAND	CHE	A1	0.420	0.603	0.781	0.944	1.097	1.239	0	0	0	0	0	0
SYRIAN_ARAB_REP.	SYR	NA1	0.057	0.123	0.195	0.284	0.383	0.498	0	1	7	14	26	41
TANZANIA	TZA	NA1	0.013	0.014	0.015	0.014	0.014	0.013	15	35	89	218	366	544
THAILAND	THA	NA1	0.116	0.246	0.430	0.664	0.958	1.277	85	350	1370	4173	8426	15961
TOGO	TGO	NA1	0.010	0.013	0.016	0.018	0.018	0.020	36	50	82	212	287	350
TRINIDAD_TOBAGO	TTO	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0	2	28	47	58	72
TUNISIA	TUN	NA1	0.027	0.066	0.117	0.182	0.257	0.342	333	825	1181	1516	1886	2225
TURKEY	TUR	A1	0.070	0.128	0.179	0.232	0.291	0.357	538	1171	1900	2660	3341	3844
TURKMENISTAN	TKM	NA1	0.401	0.557	0.815	1.143	1.536	1.983	0	0	0	0	0	0
UGANDA	UGA	NA1	0.055	0.035	0.026	0.022	0.021	0.021	0	0	0	0	0	0
UKRAINE	UKR	A1	0.404	0.742	1.170	1.663	2.209	2.740	1043	2222	3130	4128	4960	5761
UNITED_ARAB_EMIR.	ARE	NA1	0.135	0.187	0.344	0.534	0.747	0.995	138	416	773	1129	1830	2603
UNITED_KINGDOM	GBR	A1	0.684	0.763	0.859	0.956	1.049	1.141	501	1420	5056	6467	7767	8966
UNITED_STATES	USA	A1	0.912	1.175	1.459	1.700	1.917	2.130	21751	38202	56649	76442	96863	119561
URUGUAY	URY	NA1	0.062	0.119	0.230	0.351	0.475	0.585	82	163	653	2046	2576	3262
UZBEKISTAN	UZB	NA1	0.219	0.230	0.296	0.388	0.497	0.622	0	0	0	0	0	0
VENEZUELA	VEN	NA1	0.157	0.244	0.357	0.505	0.672	0.839	747	1416	2266	4747	6602	8080
VIET_NAM	VNM	NA1	0.049	0.086	0.123	0.161	0.205	0.250	1527	10070	23907	35855	44290	50097
ZAMBIA	ZMB	NA1	0.065	0.060	0.061	0.061	0.067	0.065	0	0	0	0	0	0
ZIMBABWE	ZWE	NA1	0.041	0.069	0.077	0.089	0.099	0.117	0	0	0	0	0	0

Table A.1 ***continued***.

COUNTRY	ISO3	UNFCCC	CEXP _IS1	CEXP _IS2	CEXP _IS3	CEXP _IS4	CEXP _IS5	CEXP _IS6	GEXP _IS1	GEXP _IS2	GEXP _IS3	GEXP _IS4	GEXP _IS5	GEXP _IS6	RI _IS6	RE _IS6
AFGHANISTAN	AFG	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ALBANIA	ALB	NA1	0.008	0.013	0.018	0.021	0.026	0.036	0.003	0.002	0.001	0.001	0.001	0.001	0.000	0.036
ALGERIA	DZA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000
ANGOLA	AGO	NA1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.001
ARGENTINA	ARG	NA1	0.000	0.001	0.003	0.005	0.007	0.008	0.004	0.015	0.022	0.025	0.024	0.024	0.000	0.008

COUNTRY	ISO3	UNFCCC	CEXP _IS1	CEXP _IS2	CEXP _IS3	CEXP _IS4	CEXP _IS5	CEXP _IS6	GEXP _IS1	GEXP _IS2	GEXP _IS3	GEXP _IS4	GEXP _IS5	GEXP _IS6	RI _IS6	RE _IS6
ARMENIA	ARM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ARUBA	ABW	NA1	0.000	0.000	0.006	0.006	0.006	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
AUSTRALIA	AUS	A1	0.000	0.001	0.002	0.003	0.005	0.006	0.038	0.036	0.037	0.044	0.047	0.048	0.000	0.006
AUSTRIA	AUT	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AZERBAIJAN	AZE	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BAHAMAS	BHS	NA1	0.033	0.092	0.179	0.345	0.482	0.589	0.005	0.006	0.006	0.008	0.008	0.007	0.000	0.589
BAHRAIN	BHR	NA1	0.005	0.036	0.080	0.132	0.192	0.245	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.245
BANGLADESH	BGD	NA1	0.000	0.006	0.008	0.027	0.047	0.101	0.001	0.004	0.003	0.007	0.009	0.014	0.000	0.101
BARBADOS	BRB	NA1	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
BELARUS	BLR	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BELGIUM	BEL	A1	0.011	0.017	0.025	0.042	0.059	0.071	0.004	0.003	0.002	0.002	0.002	0.002	0.000	0.071
BELIZE	BLZ	NA1	0.003	0.010	0.020	0.033	0.043	0.052	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.052
BENIN	BEN	NA1	0.001	0.002	0.003	0.011	0.013	0.014	0.001	0.001	0.001	0.002	0.002	0.002	0.000	0.014
BHUTAN	BTN	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BOLIVIA	BOL	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BOSNIA_HERZEG.	BIH	NA1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
BOTSWANA	BWA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BRAZIL	BRA	NA1	0.000	0.001	0.002	0.003	0.005	0.007	0.018	0.045	0.045	0.055	0.062	0.063	0.000	0.007
BRUNEI	BRN	NA1	0.000	0.000	0.000	0.000	0.001	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
BULGARIA	BGR	A1	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
BURKINA_FASO	BFA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BURUNDI	BDI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CAMBODIA	KHM	NA1	0.000	0.001	0.002	0.009	0.018	0.030	0.000	0.001	0.001	0.003	0.004	0.006	0.000	0.030
CAMEROON	CMR	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CANADA	CAN	A1	0.000	0.001	0.001	0.001	0.002	0.003	0.036	0.032	0.028	0.026	0.027	0.026	0.000	0.003
CENTRAL_AFR._REP.	CAF	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CHAD	TCD	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CHILE	CHL	NA1	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.001
CHINA	CHN	NA1	0.001	0.002	0.004	0.006	0.008	0.011	0.099	0.103	0.106	0.100	0.106	0.104	0.002	0.009

COUNTRY	ISO3	UNFCCC	CEXP _IS1	CEXP _IS2	CEXP _IS3	CEXP _IS4	CEXP _IS5	CEXP _IS6	GEXP _IS1	GEXP _IS2	GEXP _IS3	GEXP _IS4	GEXP _IS5	GEXP _IS6	RI _IS6	RE _IS6
COLOMBIA	COL	NA1	0.000	0.001	0.001	0.003	0.005	0.007	0.004	0.004	0.005	0.006	0.007	0.008	0.000	0.007
CONGO	COG	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
COSTA_RICA	CRI	NA1	0.000	0.000	0.001	0.001	0.002	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
COTE_D_IVOIRE	CIV	NA1	0.000	0.000	0.001	0.001	0.002	0.002	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.002
CROATIA	HRV	A1	0.000	0.000	0.001	0.001	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
CUBA	CUB	NA1	0.004	0.012	0.027	0.047	0.071	0.097	0.006	0.007	0.009	0.010	0.010	0.011	0.000	0.097
CYPRUS	CYP	A1	0.000	0.002	0.003	0.004	0.005	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
CZECH_REPUBLIC	CZE	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEM_REP_CONGO	COD	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DENMARK	DNK	A1	0.014	0.029	0.055	0.078	0.096	0.120	0.007	0.006	0.006	0.006	0.005	0.005	0.000	0.120
DJIBOUTI	DJI	NA1	0.000	0.001	0.001	0.003	0.005	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
DOMINICAN_REP.	DOM	NA1	0.001	0.002	0.005	0.008	0.015	0.019	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.019
ECUADOR	ECU	NA1	0.001	0.003	0.005	0.007	0.009	0.013	0.003	0.004	0.004	0.003	0.003	0.003	0.000	0.013
EGYPT	EGY	NA1	0.002	0.005	0.007	0.009	0.011	0.013	0.028	0.026	0.021	0.017	0.015	0.013	0.000	0.013
EL_SALVADOR	SLV	NA1	0.000	0.000	0.001	0.002	0.004	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008
EQ._GUINEA	GNQ	NA1	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
ERITREA	ERI	NA1	0.000	0.001	0.002	0.004	0.006	0.009	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.009
ESTONIA	EST	A1	0.000	0.001	0.002	0.005	0.008	0.011	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.011
ETHIOPIA	ETH	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GERMANY	DEU	A1	0.003	0.007	0.012	0.015	0.019	0.022	0.014	0.013	0.012	0.010	0.009	0.008	0.000	0.022
FINLAND	FIN	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FORMER_YEMEN	YEM	NA1	0.000	0.001	0.001	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.000	0.003
FRANCE	FRA	A1	0.003	0.005	0.007	0.008	0.010	0.012	0.021	0.016	0.013	0.010	0.008	0.007	0.000	0.011
FR._POLYNESIA	PYF	NA1	0.003	0.006	0.009	0.011	0.011	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014
GABON	GAB	NA1	0.000	0.000	0.000	0.001	0.002	0.003	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.003
GEORGIA	GEO	NA1	0.002	0.004	0.007	0.008	0.010	0.012	0.002	0.001	0.001	0.001	0.001	0.001	0.000	0.012
GHANA	GHA	NA1	0.001	0.003	0.004	0.005	0.006	0.007	0.004	0.003	0.003	0.002	0.002	0.002	0.000	0.007
GREECE	GRC	A1	0.003	0.006	0.009	0.013	0.015	0.018	0.005	0.004	0.003	0.003	0.003	0.002	0.000	0.018
GUAM	GUM	NA1	0.000	0.002	0.004	0.005	0.007	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009

COUNTRY	ISO3	UNFCCC	CEXP _IS1	CEXP _IS2	CEXP _IS3	CEXP _IS4	CEXP _IS5	CEXP _IS6	GEXP _IS1	GEXP _IS2	GEXP _IS3	GEXP _IS4	GEXP _IS5	GEXP _IS6	RI _IS6	RE _IS6
GUATEMALA	GTM	NA1	0.000	0.000	0.001	0.001	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
GUINEA	GIN	NA1	0.000	0.001	0.002	0.004	0.006	0.008	0.000	0.001	0.001	0.002	0.002	0.002	0.000	0.008
GUINEA_BISSAU	GNB	NA1	0.000	0.001	0.003	0.008	0.019	0.047	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.047
GUYANA	GUY	NA1	0.000	0.002	0.006	0.011	0.017	0.021	0.001	0.002	0.004	0.005	0.005	0.005	0.000	0.021
HAITI	HTI	NA1	0.000	0.001	0.004	0.008	0.011	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015
HONDURAS	HND	NA1	0.001	0.001	0.005	0.011	0.015	0.023	0.001	0.001	0.002	0.002	0.002	0.003	0.000	0.023
HONG_KONG	HKG	NA1	0.003	0.014	0.018	0.026	0.027	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029
HUNGARY	HUN	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ICELAND	ISL	A1	0.001	0.001	0.002	0.003	0.004	0.005	0.001	0.001	0.000	0.000	0.000	0.001	0.000	0.005
INDIA	IND	NA1	0.000	0.001	0.004	0.008	0.012	0.016	0.008	0.018	0.040	0.048	0.050	0.051	0.001	0.015
INDONESIA	IDN	NA1	0.001	0.002	0.004	0.008	0.014	0.023	0.013	0.018	0.023	0.028	0.035	0.044	0.001	0.023
IRAN	IRN	NA1	0.000	0.001	0.003	0.004	0.006	0.008	0.007	0.009	0.012	0.014	0.014	0.014	0.000	0.008
IRAQ	IRQ	NA1	0.000	0.001	0.003	0.019	0.028	0.034	0.000	0.001	0.003	0.015	0.016	0.015	0.000	0.034
IRELAND	IRL	A1	0.001	0.003	0.004	0.006	0.008	0.010	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.010
ISRAEL	ISR	NA1	0.000	0.000	0.000	0.001	0.003	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
ITALY	ITA	A1	0.004	0.009	0.013	0.017	0.021	0.025	0.016	0.014	0.011	0.010	0.008	0.007	0.000	0.024
JAMAICA	JAM	NA1	0.003	0.005	0.011	0.015	0.022	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027
JAPAN	JPN	A1	0.003	0.006	0.011	0.016	0.021	0.026	0.013	0.011	0.012	0.011	0.011	0.010	0.001	0.026
JORDAN	JOR	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KAZAKHSTAN	KAZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KENYA	KEN	NA1	0.000	0.000	0.000	0.001	0.002	0.002	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.002
NORTH_KOREA	PRK	NA1	0.000	0.001	0.002	0.004	0.008	0.013	0.000	0.000	0.001	0.001	0.001	0.002	0.000	0.013
SOUTH_KOREA	KOR	NA1	0.000	0.002	0.003	0.004	0.008	0.011	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.011
KUWAIT	KWT	NA1	0.005	0.018	0.034	0.046	0.053	0.059	0.001	0.002	0.002	0.001	0.001	0.001	0.000	0.059
KYRGYZSTAN	KGZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LAO	LAO	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LATVIA	LVA	A1	0.000	0.000	0.005	0.010	0.014	0.017	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.017
LEBANON	LBN	NA1	0.000	0.000	0.000	0.001	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
LESOTHO	LSO	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

COUNTRY	ISO3	UNFCCC	CEXP _IS1	CEXP _IS2	CEXP _IS3	CEXP _IS4	CEXP _IS5	CEXP _IS6	GEXP _IS1	GEXP _IS2	GEXP _IS3	GEXP _IS4	GEXP _IS5	GEXP _IS6	RI _IS6	RE _IS6
LIBERIA	LBR	NA1	0.000	0.000	0.001	0.001	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
LIBYA	LBY	NA1	0.001	0.001	0.002	0.002	0.003	0.003	0.019	0.011	0.009	0.007	0.006	0.005	0.000	0.003
LITHUANIA	LTU	A1	0.002	0.003	0.004	0.006	0.007	0.008	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.008
LUXEMBOURG	LUX	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MACEDONIA	MKD	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MADAGASCAR	MDG	NA1	0.000	0.001	0.002	0.003	0.005	0.007	0.002	0.003	0.003	0.004	0.004	0.004	0.000	0.007
MALAWI	MWI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MALAYSIA	MYS	NA1	0.000	0.000	0.001	0.002	0.006	0.011	0.001	0.001	0.001	0.001	0.003	0.004	0.000	0.011
MALI	MLI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MALTA	MLT	A1	0.000	0.003	0.006	0.009	0.009	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009
MAURITANIA	MRT	NA1	0.004	0.006	0.008	0.009	0.010	0.011	0.058	0.034	0.023	0.017	0.014	0.011	0.000	0.011
MEXICO	MEX	NA1	0.002	0.006	0.011	0.016	0.020	0.025	0.058	0.066	0.063	0.057	0.053	0.049	0.000	0.025
MOLDOVA	MDA	NA1	0.001	0.003	0.005	0.009	0.011	0.014	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.014
MONGOLIA	MNG	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MOROCCO	MAR	NA1	0.000	0.001	0.001	0.001	0.002	0.002	0.004	0.003	0.002	0.002	0.002	0.001	0.000	0.002
MOZAMBIQUE	MOZ	NA1	0.000	0.000	0.001	0.003	0.009	0.013	0.001	0.002	0.002	0.005	0.009	0.011	0.000	0.013
MYANMAR	MMR	NA1	0.001	0.003	0.006	0.009	0.021	0.033	0.008	0.012	0.012	0.012	0.018	0.022	0.000	0.033
NAMIBIA	NAM	NA1	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.000	0.002
NEPAL	NPL	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NETHERLANDS	NLD	A1	0.066	0.123	0.165	0.199	0.233	0.269	0.019	0.015	0.011	0.008	0.007	0.006	0.001	0.268
NEW_CALEDONIA	NCL	NA1	0.001	0.002	0.006	0.011	0.015	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019
NEW_ZEALAND	NZL	A1	0.000	0.001	0.002	0.003	0.005	0.008	0.001	0.001	0.001	0.001	0.002	0.002	0.000	0.008
NICARAGUA	NIC	NA1	0.000	0.002	0.007	0.012	0.021	0.031	0.001	0.002	0.003	0.003	0.004	0.004	0.000	0.031
NIGER	NER	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NIGERIA	NGA	NA1	0.000	0.000	0.001	0.002	0.004	0.007	0.001	0.002	0.002	0.003	0.004	0.006	0.000	0.007
NORWAY	NOR	A1	0.000	0.001	0.001	0.002	0.002	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.003
OMAN	OMN	NA1	0.000	0.001	0.003	0.004	0.006	0.007	0.001	0.001	0.002	0.003	0.002	0.002	0.000	0.007
PAKISTAN	PAK	NA1	0.000	0.002	0.005	0.009	0.012	0.014	0.003	0.010	0.014	0.014	0.014	0.013	0.000	0.014
PANAMA	PAN	NA1	0.000	0.001	0.003	0.006	0.009	0.012	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.012

COUNTRY	ISO3	UNFCCC	CEXP _IS1	CEXP _IS2	CEXP _IS3	CEXP _IS4	CEXP _IS5	CEXP _IS6	GEXP _IS1	GEXP _IS2	GEXP _IS3	GEXP _IS4	GEXP _IS5	GEXP _IS6	RI _IS6	RE _IS6
PAPUA_NEW_GUINEA	PNG	NA1	0.000	0.000	0.000	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.002
PARAGUAY	PRY	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PERU	PER	NA1	0.001	0.001	0.002	0.002	0.003	0.003	0.012	0.008	0.007	0.005	0.004	0.004	0.000	0.003
PHILIPPINES	PHL	NA1	0.001	0.002	0.003	0.006	0.010	0.016	0.002	0.002	0.003	0.004	0.004	0.005	0.000	0.016
POLAND	POL	A1	0.002	0.003	0.005	0.006	0.007	0.007	0.006	0.004	0.004	0.003	0.003	0.002	0.000	0.007
PORTUGAL	PRT	A1	0.001	0.003	0.005	0.006	0.008	0.009	0.002	0.002	0.001	0.001	0.001	0.001	0.000	0.009
PUERTO_RICO	PRI	NA1	0.004	0.011	0.026	0.037	0.046	0.055	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.055
QATAR	QAT	NA1	0.002	0.006	0.021	0.042	0.071	0.104	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.104
ROMANIA	ROU	A1	0.003	0.008	0.010	0.012	0.014	0.016	0.008	0.010	0.007	0.005	0.004	0.004	0.000	0.016
RUSSIA	RUS	A1	0.000	0.001	0.003	0.004	0.005	0.006	0.078	0.119	0.128	0.118	0.108	0.103	0.000	0.006
RWANDA	RWA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SAUDI_ARABIA	SAU	NA1	0.000	0.001	0.002	0.002	0.003	0.004	0.008	0.009	0.009	0.008	0.008	0.008	0.000	0.004
SENEGAL	SEN	NA1	0.000	0.003	0.011	0.022	0.033	0.039	0.001	0.004	0.007	0.008	0.009	0.008	0.000	0.039
SIERRA_LEONE	SLE	NA1	0.001	0.002	0.005	0.012	0.020	0.027	0.001	0.001	0.001	0.002	0.002	0.002	0.000	0.027
SINGAPORE	SGP	NA1	0.002	0.004	0.004	0.010	0.012	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016
SLOVAKIA	SVK	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SLOVENIA	SVN	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOMALIA	SOM	NA1	0.000	0.000	0.001	0.001	0.002	0.003	0.001	0.002	0.001	0.001	0.002	0.002	0.000	0.003
SOUTH_AFRICA	ZAF	NA1	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
SPAIN	ESP	A1	0.001	0.002	0.004	0.005	0.006	0.006	0.004	0.005	0.006	0.005	0.004	0.003	0.000	0.006
SRI_LANKA	LKA	NA1	0.001	0.001	0.004	0.008	0.014	0.022	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.022
SUDAN	SDN	NA1	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.000	0.001
SURINAME	SUR	NA1	0.001	0.003	0.010	0.015	0.019	0.023	0.002	0.002	0.004	0.004	0.004	0.003	0.000	0.023
SWAZILAND	SWZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SWEDEN	SWE	A1	0.000	0.000	0.000	0.001	0.001	0.002	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.002
SWITZERLAND	CHE	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SYRIAN_ARAB_REP.	SYR	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TANZANIA	TZA	NA1	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
THAILAND	THA	NA1	0.000	0.001	0.003	0.008	0.016	0.031	0.001	0.002	0.004	0.008	0.011	0.016	0.000	0.031

COUNTRY	ISO3	UNFCCC	CEXP _IS1	CEXP _IS2	CEXP _IS3	CEXP _IS4	CEXP _IS5	CEXP _IS6	GEXP _IS1	GEXP _IS2	GEXP _IS3	GEXP _IS4	GEXP _IS5	GEXP _IS6	RI _IS6	RE _IS6
TOGO	TGO	NA1	0.001	0.001	0.001	0.004	0.005	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
TRINIDAD_TOBAGO	TTO	NA1	0.000	0.000	0.005	0.009	0.011	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014
TUNISIA	TUN	NA1	0.002	0.005	0.008	0.010	0.012	0.014	0.004	0.004	0.003	0.003	0.002	0.002	0.000	0.014
TURKEY	TUR	A1	0.001	0.001	0.002	0.003	0.004	0.005	0.007	0.006	0.005	0.005	0.004	0.004	0.000	0.005
TURKMENISTAN	TKM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
UGANDA	UGA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
UKRAINE	UKR	A1	0.002	0.004	0.005	0.007	0.008	0.010	0.013	0.012	0.009	0.008	0.007	0.006	0.000	0.010
UNITED_ARAB_EMIR.	ARE	NA1	0.002	0.006	0.011	0.016	0.026	0.037	0.002	0.002	0.002	0.002	0.002	0.003	0.000	0.036
UNITED_KINGDOM	GBR	A1	0.002	0.006	0.021	0.027	0.032	0.037	0.006	0.007	0.015	0.012	0.010	0.009	0.001	0.036
UNITED_STATES	USA	A1	0.002	0.004	0.006	0.008	0.010	0.013	0.271	0.200	0.164	0.142	0.128	0.121	0.002	0.011
URUGUAY	URY	NA1	0.000	0.001	0.004	0.012	0.014	0.018	0.001	0.001	0.002	0.004	0.003	0.003	0.000	0.018
UZBEKISTAN	UZB	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VENEZUELA	VEN	NA1	0.001	0.002	0.002	0.005	0.007	0.009	0.009	0.007	0.007	0.009	0.009	0.008	0.000	0.009
VIET_NAM	VNM	NA1	0.005	0.030	0.072	0.109	0.134	0.152	0.019	0.053	0.069	0.067	0.059	0.051	0.001	0.151
ZAMBIA	ZMB	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ZIMBABWE	ZWE	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.2 Country contributions (meters, percent, and per capita) and land exposure for each one-meter increment of global SLRC under scenario RCP 4.5. Exposure assessments for 1 to 3 m of SLRC would be the same as in Table A.1. Intrinsic and extrinsic risk indices for 3 m of global SLRC are also included.

COUNTRY	**ISO3**	**UNFCCC**	**SLRCM_IS1**	**SLRCM_IS2**	**SLRCM_IS3**	**SLRCP_IS1**	**SLRCP_IS2**	**SLRCP_IS3**	**PERC_IS1**	**PERC_IS2**	**PERC_IS3**	**RI_IS3**	**RE_IS3**
AFGHANISTAN	AFG	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.040	0.034	0.043	0.000	0.000
ALBANIA	ALB	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.308	0.628	1.132	0.000	0.018
ALGERIA	DZA	NA1	0.002	0.007	0.014	0.002	0.003	0.005	0.057	0.134	0.224	0.000	0.000
ANGOLA	AGO	NA1	0.000	0.000	0.002	0.000	0.000	0.001	-0.001	0.011	0.017	0.000	0.000
ARGENTINA	ARG	NA1	0.004	0.010	0.016	0.004	0.005	0.005	0.127	0.192	0.280	0.000	0.003
ARMENIA	ARM	NA1	0.001	0.001	0.002	0.001	0.001	0.001	0.364	0.492	0.737	0.000	0.000
ARUBA	ABW	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
AUSTRALIA	AUS	A1	0.008	0.018	0.028	0.008	0.009	0.009	0.436	0.618	0.732	0.000	0.002
AUSTRIA	AUT	A1	0.002	0.003	0.005	0.002	0.002	0.002	0.255	0.392	0.600	0.000	0.000
AZERBAIJAN	AZE	NA1	0.002	0.003	0.004	0.002	0.001	0.001	0.214	0.249	0.368	0.000	0.000
BAHAMAS	BHS	NA1	0.000	0.000	0.001	0.000	0.000	0.000	0.813	0.957	1.364	0.000	0.179
BAHRAIN	BHR	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080
BANGLADESH	BGD	NA1	0.002	0.004	0.007	0.002	0.002	0.002	0.017	0.023	0.034	0.000	0.008
BARBADOS	BRB	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.123	0.414	0.811	0.000	0.000
BELARUS	BLR	A1	0.009	0.012	0.016	0.009	0.006	0.005	0.845	1.407	2.212	0.000	0.000
BELGIUM	BEL	A1	0.004	0.006	0.008	0.004	0.003	0.003	0.392	0.489	0.593	0.000	0.025
BELIZE	BLZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020
BENIN	BEN	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.070	0.084	0.083	0.000	0.003
BHUTAN	BTN	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.643	1.142	1.807	0.000	0.000
BOLIVIA	BOL	NA1	0.001	0.003	0.004	0.001	0.001	0.001	0.099	0.191	0.218	0.000	0.000
BOSNIA_HERZEG.	BIH	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.313	0.617	1.276	0.000	0.000
BOTSWANA	BWA	NA1	0.000	0.001	0.002	0.000	0.000	0.001	0.200	0.315	0.478	0.000	0.000
BRAZIL	BRA	NA1	0.033	0.061	0.087	0.033	0.031	0.029	0.200	0.262	0.380	0.000	0.002
BRUNEI	BRN	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000

COUNTRY	ISO3	UNFCCC	SLRCM_IS1	SLRCM_IS2	SLRCM_IS3	SLRCP_IS1	SLRCP_IS2	SLRCP_IS3	PERC_IS1	PERC_IS2	PERC_IS3	RI_IS3	RE_IS3
BULGARIA	BGR	A1	0.002	0.003	0.005	0.002	0.002	0.002	0.221	0.574	1.194	0.000	0.001
BURKINA_FASO	BFA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000
BURUNDI	BDI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.010	0.006	0.000	0.000
CAMBODIA	KHM	NA1	0.001	0.003	0.004	0.001	0.001	0.001	0.136	0.146	0.176	0.000	0.002
CAMEROON	CMR	NA1	0.003	0.005	0.008	0.003	0.003	0.003	0.246	0.144	0.126	0.000	0.000
CANADA	CAN	A1	0.040	0.066	0.088	0.041	0.033	0.029	1.379	1.578	1.874	0.000	0.001
CENTRAL_AFR._REP.	CAF	NA1	0.000	0.001	0.003	0.000	0.001	0.001	0.121	0.207	0.262	0.000	0.000
CHAD	TCD	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
CHILE	CHL	NA1	0.003	0.006	0.010	0.003	0.003	0.003	0.196	0.280	0.480	0.000	0.000
CHINA	CHN	NA1	0.089	0.311	0.547	0.090	0.156	0.182	0.073	0.221	0.457	0.001	0.003
COLOMBIA	COL	NA1	0.009	0.013	0.021	0.009	0.007	0.007	0.229	0.247	0.395	0.000	0.001
CONGO	COG	NA1	0.000	0.001	0.002	0.000	0.000	0.001	0.123	0.129	0.150	0.000	0.000
COSTA_RICA	CRI	NA1	0.000	0.001	0.001	0.000	0.000	0.000	0.141	0.150	0.222	0.000	0.001
COTE_D_IVOIRE	CIV	NA1	0.002	0.004	0.007	0.002	0.002	0.002	0.145	0.125	0.106	0.000	0.001
CROATIA	HRV	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
CUBA	CUB	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.000	0.027
CYPRUS	CYP	A1	0.000	0.000	0.001	0.000	0.000	0.000	0.098	0.240	0.368	0.000	0.003
CZECH_REPUBLIC	CZE	A1	0.009	0.014	0.019	0.009	0.007	0.006	0.892	1.360	2.045	0.000	0.000
DEM_REP_CONGO	COD	NA1	0.007	0.021	0.037	0.007	0.011	0.012	0.175	0.154	0.134	0.000	0.000
DENMARK	DNK	A1	0.003	0.005	0.006	0.003	0.002	0.002	0.577	0.740	0.870	0.000	0.055
DJIBOUTI	DJI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
DOMINICAN_REPUBLIC	DOM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.016	0.028	0.000	0.005
ECUADOR	ECU	NA1	0.002	0.004	0.007	0.002	0.002	0.002	0.162	0.195	0.276	0.000	0.005
EGYPT	EGY	NA1	0.001	0.006	0.013	0.001	0.003	0.004	0.020	0.049	0.072	0.000	0.007
EL_SALVADOR	SLV	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
EQUATORIAL_GUINEA	GNQ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ERITREA	ERI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.004	0.000	0.002
ESTONIA	EST	A1	0.001	0.001	0.002	0.001	0.001	0.001	0.473	1.009	1.794	0.000	0.002
ETHIOPIA	ETH	NA1	0.002	0.003	0.004	0.002	0.002	0.001	0.040	0.020	0.019	0.000	0.000
GERMANY	DEU	A1	0.046	0.066	0.083	0.046	0.033	0.028	0.561	0.845	1.206	0.000	0.011

COUNTRY	ISO3	UNFCCC	SLRCM_IS1	SLRCM_IS2	SLRCM_IS3	SLRCP_IS1	SLRCP_IS2	SLRCP_IS3	PERC_IS1	PERC_IS2	PERC_IS3	RI_IS3	RE_IS3
FINLAND	FIN	A1	0.002	0.005	0.006	0.002	0.002	0.002	0.463	0.786	1.093	0.000	0.000
FORMER_YEMEN	YEM	NA1	0.000	0.001	0.001	0.000	0.000	0.000	0.015	0.015	0.018	0.000	0.001
FRANCE	FRA	A1	0.023	0.035	0.045	0.023	0.017	0.015	0.390	0.505	0.616	0.000	0.007
FRENCH_POLYNESIA	PYF	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009
GABON	GAB	NA1	0.001	0.002	0.004	0.001	0.001	0.001	1.123	0.841	1.076	0.000	0.000
GEORGIA	GEO	NA1	0.002	0.002	0.002	0.002	0.001	0.001	0.341	0.533	0.775	0.000	0.007
GHANA	GHA	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.061	0.053	0.049	0.000	0.004
GREECE	GRC	A1	0.001	0.003	0.005	0.001	0.002	0.002	0.104	0.330	0.628	0.000	0.009
GUAM	GUM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
GUATEMALA	GTM	NA1	0.001	0.002	0.004	0.001	0.001	0.001	0.094	0.102	0.116	0.000	0.001
GUINEA	GIN	NA1	0.000	0.001	0.001	0.000	0.000	0.000	0.016	0.025	0.030	0.000	0.002
GUINEA_BISSAU	GNB	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.035	0.042	0.000	0.003
GUYANA	GUY	NA1	0.000	0.001	0.001	0.000	0.000	0.000	0.315	0.617	1.048	0.000	0.006
HAITI	HTI	NA1	0.000	0.000	0.001	0.000	0.000	0.000	0.009	0.022	0.036	0.000	0.004
HONDURAS	HND	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.224	0.229	0.282	0.000	0.005
HONG_KONG	HKG	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.082	0.201	0.349	0.000	0.018
HUNGARY	HUN	A1	0.003	0.005	0.006	0.003	0.002	0.002	0.293	0.504	0.850	0.000	0.000
ICELAND	ISL	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.144	0.241	0.335	0.000	0.002
INDIA	IND	NA1	0.025	0.080	0.138	0.025	0.040	0.046	0.026	0.051	0.079	0.000	0.004
INDONESIA	IDN	NA1	0.041	0.064	0.091	0.041	0.032	0.030	0.209	0.210	0.280	0.000	0.004
IRAN	IRN	NA1	0.004	0.019	0.039	0.004	0.010	0.013	0.073	0.215	0.468	0.000	0.003
IRAQ	IRQ	NA1	0.001	0.005	0.010	0.001	0.003	0.003	0.071	0.087	0.088	0.000	0.003
IRELAND	IRL	A1	0.001	0.002	0.003	0.001	0.001	0.001	0.314	0.390	0.478	0.000	0.004
ISRAEL	ISR	NA1	0.000	0.001	0.001	0.000	0.000	0.000	0.021	0.055	0.081	0.000	0.000
ITALY	ITA	A1	0.009	0.018	0.026	0.009	0.009	0.009	0.150	0.311	0.505	0.000	0.013
JAMAICA	JAM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011
JAPAN	JPN	A1	0.024	0.054	0.080	0.025	0.027	0.027	0.197	0.465	0.840	0.000	0.010
JORDAN	JOR	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.017	0.026	0.000	0.000
KAZAKHSTAN	KAZ	NA1	0.006	0.012	0.018	0.006	0.006	0.006	0.386	0.559	0.743	0.000	0.000
KENYA	KEN	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.014	0.015	0.014	0.000	0.000

COUNTRY	ISO3	UNFCCC	SLRCM_IS1	SLRCM_IS2	SLRCM_IS3	SLRCP_IS1	SLRCP_IS2	SLRCP_IS3	PERC_IS1	PERC_IS2	PERC_IS3	RI_IS3	RE_IS3
NORTH_KOREA	PRK	NA1	0.002	0.005	0.007	0.002	0.002	0.002	0.101	0.181	0.278	0.000	0.002
SOUTH_KOREA	KOR	NA1	0.004	0.016	0.027	0.004	0.008	0.009	0.097	0.298	0.604	0.000	0.003
KUWAIT	KWT	NA1	0.001	0.004	0.008	0.001	0.002	0.003	0.645	0.778	1.300	0.000	0.034
KYRGYZSTAN	KGZ	NA1	0.001	0.001	0.001	0.001	0.000	0.000	0.138	0.102	0.102	0.000	0.000
LAO	LAO	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.161	0.222	0.288	0.000	0.000
LATVIA	LVA	A1	0.002	0.002	0.003	0.002	0.001	0.001	0.771	1.360	2.043	0.000	0.005
LEBANON	LBN	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LESOTHO	LSO	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.262	0.455	0.610	0.000	0.000
LIBERIA	LBR	NA1	0.002	0.004	0.006	0.002	0.002	0.002	0.908	0.527	0.506	0.000	0.000
LIBYA	LBY	NA1	0.000	0.002	0.004	0.000	0.001	0.001	0.086	0.241	0.445	0.000	0.002
LITHUANIA	LTU	A1	0.001	0.001	0.001	0.001	0.001	0.000	0.253	0.442	0.636	0.000	0.004
LUXEMBOURG	LUX	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MACEDONIA	MKD	NA1	0.001	0.001	0.002	0.001	0.001	0.001	0.326	0.521	0.866	0.000	0.000
MADAGASCAR	MDG	NA1	0.000	0.002	0.004	0.000	0.001	0.001	0.033	0.045	0.047	0.000	0.002
MALAWI	MWI	NA1	0.000	0.001	0.001	0.000	0.000	0.000	0.011	0.023	0.016	0.000	0.000
MALAYSIA	MYS	NA1	0.006	0.014	0.020	0.006	0.007	0.007	0.308	0.362	0.481	0.000	0.001
MALI	MLI	NA1	0.000	0.000	0.001	0.000	0.000	0.000	0.009	0.009	0.008	0.000	0.000
MALTA	MLT	A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
MAURITANIA	MRT	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.023	0.026	0.000	0.008
MEXICO	MEX	NA1	0.011	0.026	0.045	0.011	0.013	0.015	0.115	0.172	0.270	0.000	0.011
MOLDOVA	MDA	NA1	0.001	0.002	0.002	0.001	0.001	0.001	0.287	0.455	0.844	0.000	0.005
MONGOLIA	MNG	NA1	0.001	0.001	0.002	0.001	0.001	0.001	0.268	0.371	0.512	0.000	0.000
MOROCCO	MAR	NA1	0.001	0.002	0.004	0.001	0.001	0.001	0.019	0.046	0.085	0.000	0.001
MOZAMBIQUE	MOZ	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.005	0.026	0.024	0.000	0.001
MYANMAR	MMR	NA1	0.005	0.013	0.019	0.005	0.006	0.006	0.110	0.203	0.309	0.000	0.006
NAMIBIA	NAM	NA1	0.000	0.001	0.001	0.000	0.000	0.000	0.126	0.191	0.258	0.000	0.001
NEPAL	NPL	NA1	0.001	0.003	0.005	0.002	0.002	0.002	0.070	0.097	0.137	0.000	0.000
NETHERLANDS	NLD	A1	0.008	0.013	0.017	0.008	0.006	0.006	0.505	0.723	0.974	0.001	0.164
NEW_CALEDONIA	NCL	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
NEW_ZEALAND	NZL	A1	0.002	0.003	0.005	0.002	0.002	0.002	0.480	0.594	0.772	0.000	0.002

COUNTRY	ISO3	UNFCCC	SLRCM_IS1	SLRCM_IS2	SLRCM_IS3	SLRCP_IS1	SLRCP_IS2	SLRCP_IS3	PERC_IS1	PERC_IS2	PERC_IS3	RI_IS3	RE_IS3
NICARAGUA	NIC	NA1	0.001	0.001	0.002	0.001	0.001	0.001	0.193	0.204	0.244	0.000	0.007
NIGER	NER	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.006	0.004	0.000	0.000
NIGERIA	NGA	NA1	0.005	0.010	0.015	0.005	0.005	0.005	0.047	0.034	0.028	0.000	0.001
NORWAY	NOR	A1	0.001	0.002	0.003	0.001	0.001	0.001	0.257	0.382	0.479	0.000	0.001
OMAN	OMN	NA1	0.000	0.001	0.002	0.000	0.000	0.001	0.062	0.173	0.324	0.000	0.003
PAKISTAN	PAK	NA1	0.002	0.007	0.013	0.002	0.004	0.004	0.014	0.028	0.038	0.000	0.005
PANAMA	PAN	NA1	0.001	0.002	0.002	0.001	0.001	0.001	0.435	0.322	0.363	0.000	0.003
PAPUA_NEW_GUINEA	PNG	NA1	0.001	0.002	0.004	0.001	0.001	0.001	0.207	0.214	0.239	0.000	0.000
PARAGUAY	PRY	NA1	0.001	0.001	0.003	0.001	0.001	0.001	0.133	0.176	0.274	0.000	0.000
PERU	PER	NA1	0.003	0.007	0.010	0.004	0.003	0.003	0.146	0.175	0.230	0.000	0.002
PHILIPPINES	PHL	NA1	0.005	0.008	0.011	0.005	0.004	0.004	0.075	0.063	0.066	0.000	0.003
POLAND	POL	A1	0.025	0.038	0.051	0.025	0.019	0.017	0.642	1.040	1.821	0.000	0.005
PORTUGAL	PRT	A1	0.001	0.002	0.003	0.001	0.001	0.001	0.060	0.175	0.317	0.000	0.005
PUERTO_RICO	PRI	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026
QATAR	QAT	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021
ROMANIA	ROU	A1	0.008	0.012	0.015	0.008	0.006	0.005	0.344	0.675	1.188	0.000	0.010
RUSSIAN_FEDERATION	RUS	A1	0.089	0.148	0.213	0.090	0.075	0.071	0.603	1.094	1.768	0.000	0.002
RWANDA	RWA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SAUDI_ARABIA	SAU	NA1	0.004	0.019	0.040	0.004	0.010	0.013	0.214	0.471	0.832	0.000	0.002
SENEGAL	SEN	NA1	0.000	0.000	0.001	0.000	0.000	0.000	0.010	0.012	0.011	0.000	0.011
SIERRA_LEONE	SLE	NA1	0.000	0.000	0.001	0.000	0.000	0.000	0.048	0.045	0.062	0.000	0.005
SINGAPORE	SGP	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.013	0.017	0.000	0.004
SLOVAKIA	SVK	A1	0.005	0.007	0.010	0.005	0.004	0.003	0.930	1.381	2.277	0.000	0.000
SLOVENIA	SVN	A1	0.001	0.001	0.002	0.001	0.001	0.001	0.370	0.605	0.989	0.000	0.000
SOMALIA	SOM	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.003	0.002	0.000	0.001
SOUTH_AFRICA	ZAF	NA1	0.007	0.020	0.036	0.007	0.010	0.012	0.174	0.324	0.531	0.000	0.000
SPAIN	ESP	A1	0.005	0.013	0.020	0.005	0.007	0.007	0.125	0.288	0.494	0.000	0.004
SRI_LANKA	LKA	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.012	0.025	0.000	0.004
SUDAN	SDN	NA1	0.001	0.002	0.004	0.001	0.001	0.001	0.034	0.036	0.041	0.000	0.000
SURINAME	SUR	NA1	0.000	0.000	0.001	0.000	0.000	0.000	0.415	0.578	0.875	0.000	0.010

COUNTRY	ISO3	UNFCCC	SLRCM_IS1	SLRCM_IS2	SLRCM_IS3	SLRCP_IS1	SLRCP_IS2	SLRCP_IS3	PERC_IS1	PERC_IS2	PERC_IS3	RI_IS3	RE_IS3
SWAZILAND	SWZ	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SWEDEN	SWE	A1	0.003	0.004	0.006	0.003	0.002	0.002	0.347	0.408	0.446	0.000	0.000
SWITZERLAND	CHE	A1	0.003	0.006	0.008	0.003	0.003	0.003	0.420	0.584	0.740	0.000	0.000
SYRIAN_ARAB_REP	SYR	NA1	0.001	0.003	0.007	0.001	0.002	0.002	0.057	0.114	0.177	0.000	0.000
TANZANIA	TZA	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.013	0.012	0.010	0.000	0.000
THAILAND	THA	NA1	0.007	0.017	0.027	0.007	0.008	0.009	0.116	0.249	0.510	0.000	0.003
TOGO	TGO	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.012	0.011	0.000	0.001
TRINIDAD_TOBAGO	TTO	NA1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005
TUNISIA	TUN	NA1	0.000	0.001	0.002	0.000	0.000	0.001	0.027	0.064	0.118	0.000	0.008
TURKEY	TUR	A1	0.004	0.011	0.017	0.004	0.006	0.006	0.070	0.124	0.179	0.000	0.002
TURKMENISTAN	TKM	NA1	0.002	0.003	0.005	0.002	0.002	0.002	0.401	0.540	0.843	0.000	0.000
UGANDA	UGA	NA1	0.001	0.002	0.003	0.001	0.001	0.001	0.055	0.030	0.018	0.000	0.000
UKRAINE	UKR	A1	0.021	0.031	0.041	0.021	0.015	0.014	0.404	0.777	1.373	0.000	0.005
UNITED_ARAB_EMIR.	ARE	NA1	0.000	0.002	0.004	0.000	0.001	0.001	0.135	0.177	0.323	0.000	0.011
UNITED_KINGDOM	GBR	A1	0.040	0.053	0.065	0.040	0.027	0.021	0.684	0.745	0.820	0.000	0.020
UNITED_STATES	USA	A1	0.243	0.416	0.565	0.244	0.209	0.188	0.912	1.138	1.352	0.001	0.005
URUGUAY	URY	NA1	0.000	0.000	0.001	0.000	0.000	0.000	0.062	0.118	0.236	0.000	0.004
UZBEKISTAN	UZB	NA1	0.005	0.008	0.011	0.005	0.004	0.004	0.219	0.223	0.304	0.000	0.000
VENEZUELA	VEN	NA1	0.003	0.009	0.015	0.004	0.004	0.005	0.157	0.232	0.340	0.000	0.002
VIET_NAM	VNM	NA1	0.004	0.009	0.014	0.004	0.005	0.005	0.049	0.083	0.124	0.000	0.072
ZAMBIA	ZMB	NA1	0.001	0.001	0.003	0.001	0.001	0.001	0.065	0.051	0.039	0.000	0.000
ZIMBABWE	ZWE	NA1	0.000	0.001	0.002	0.000	0.001	0.001	0.041	0.062	0.062	0.000	0.000

APPENDIX B

IRB APPROVAL LETTER AND INTERVIEW GUIDE

Phone 706-542-3199

The University of Georgia

Office of the Vice President for Research
Institutional Review Board

APPROVAL OF PROTOCOL

December 15, 2015

Dear Marguerite Madden:

On 12/15/2015, the IRB reviewed the following submission:

Type of Review:	Continuing Review
Title of Study:	Mapping socioeconomic vulnerabilities to coastal hazards
Investigator:	Marguerite Madden
IRB ID:	MOD00002242
Funding:	Name: Center for Research and Engagement in Diversity; Name: NATIONAL SCIENCE FOUNDATION;
Grant ID:	

The IRB approved the protocol from 1/16/2016 to 1/15/2017 inclusive. Before 1/15/2017 or within 30 days of study closure, whichever is earlier, you are to submit a continuing review with required explanations. You can submit a continuing review by navigating to the active study and clicking Create Modification / CR.

If continuing review approval is not granted before the expiration date of 1/15/2017, approval of this study expires on that date.

To document consent, use the consent documents that were approved and stamped by the IRB. Go to the Documents tab to download them.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103).

Sincerely,

Dr. Gerald E. Crites, MD, MEd
University of Georgia
Institutional Review Board Chairperson

310 East Campus Rd, Tucker Hall Room 212 • Athens, Georgia 30602
An Equal Opportunity/Affirmative Action Institution

Interview Guide

Notes: **[]** = probes or possible follow-ups to original question(s); **{}** = other possible things to inquire about relating to the question; **l.a.** = livelihood assessment; **r.a.** = race assessment; **c.a.** = class assessment; **k.u.** = knowledge & understandings assessment

A. Introduction of Project

B. Community

1. How long have you lived here? What does it feel like to live in this community?
2. Can you tell me about your community? How do you define it spatially and socially? **[**pay attention to, and probe, how they define it, how it fits into the coastal community, who is part of it**]**
3. What's a typical day like for you here? **[**probe about *everyday practices* and daily/weekly activity spaces**]**
4. What do you think will be the most significant challenges, especially environmental challenges, facing your community?
5. Can you think of any **{**environmental**}** stresses or challenges that your community has faced in the past or is currently facing?
6. What were (are) the (expected) impacts from these stresses and/or challenges? **[**probe as to impacts on people of different social groups, particularly their own.**]**
7. How did (is) the community respond(ing)? **[**What things were done (or are being done) within the community?**]**

C. Sea-Level Rise (k.u.)

8. Are you familiar with the concept of sea-level rise? Do you believe that the global sea-level is rising?

9. What do you think are the critical factors affecting sea-level rise? How much do you think the sea will rise by 2050? 2100?
10. Have you noticed evidence of rising seas in your time on the coast? If so, how has this affected you personally? **[**your property, livelihood, income, job security, etc.**]** (l.a.)
11. Are you concerned about sea-level rise affecting your community? How do you think sea-level rise will affect your community? How do you think your community will respond to sea-level rise? **[**seawalls, armoring, living shorelines, retreat, elevating homes**]**.
12. Where have you learned about sea-level rise? **[**news sources, group organizations, family, friends, coworkers**]**. How do you feel about your access to knowledge concerning sea-level rise? **[**good, bad, okay, etc.**]**.
13. Do you talk to others about sea-level rise? Who and how frequently? What particular aspects do you talk to them about? Could you share an example with me?
14. Do you know if your local government has taken any action on addressing issues related to sea-level rise? In what ways? What actions do you think that your local government should take to respond to the possibility of a rise in sea-level? Do you see a role for yourself in policy development regarding sea-level rise?

D. Livelihood – Occupation/Profession (l.a.)

15. What is(are) your current occupation(s) or profession?
16. Is it affected by weather or climate? How would adverse weather conditions or climate affect your ability to make a living? Do you have alternate sources of income, or other friends or family that you could turn to, in the event of a natural disaster **{**or climate change**}** affecting your ability to work? **[**While leaving open possibility of other weather and climate events, probe on sea-level rise more specifically**]**

17. Could adverse sea-level rise affect the work or lives of your friends and family? In other words, their access to income and work and their personal property?
18. How do you think sea-level rise specifically might affect people of different professions? **[**fisheries, tourists, commercial business, residents, retired people**]** Are some more vulnerable than others? How so?

E. Role of Race and Class in Vulnerability (r.a. & c.a.)

19. How do you think environmental change might affect people of different social groups? What about people of difference income levels? Of difference races? **[**probe about race and racism here**]**.
20. Have you ever been personally affected by natural disasters (fire, flooding, tornado, hurricane, etc)? If so, how were you affected and how did you respond? How did government agencies respond? Do you think your race or class affected their response?
21. Do you feel prepared for rising seas and a changing climate in the future? What personal actions are you taking to prepare for these?
22. Are you able, i.e. do you have the time, to attend public government meetings. Are you involved in any organizations working on improving your community? Why or why not?
23. How do you think your race or class status affect your ability to access public funding and support for adapting to environmental changes such as sea-level rise in your community?

F. Sketch Mapping (k.u. & l.a.)

24. Would you mind sketching the areas on this map of your community that you think are below three feet in elevation? In other words, that would be inundated by rising seas of three feet? (k.u.)

25. Would you mind sketching or outlining the areas on this map that you visit on a frequent basis, more or less daily? For example the your regular grocery store, your place(s) of work, your home? (l.a.)

APPENDIX C

STRATEGIC COMMUNICATION

The following sections are included as part of the Integrative Conservation Ph.D. Programs strategic communication requirement. I wrote three newspaper articles for a local newspaper located in Darien, GA near Sapelo Island, *The Darien News*, as outreach to communicate my research as it relates to the causes, measurements, and impacts of sea-level rise. Additionally, as part of a follow up to the interactive presentation workshop that I held at the Hog Hammock Public Library, I donated a poster of sea-level rise inundation and impacts to the library (Figure C.x) as part of a new collection called *Sea-Level Rise and FEMA*, that included ten books and two documentaries about sea-level rise and climate change (located online at this following web address: http://sapelocollections.blogspot.com/p/sea-level-rise-collection.html). This collection was funded by The University of Georgia, Franklin College, Center for Research and Engagement in Diversity's 2015 Seed Grant.

Getting to Know Sea-Level Rise Part 1: Causes [13]

My first memories of the ocean are from visiting my grandpa's home in Morehead City, North Carolina as a toddler. My mom tells me that Grandpa called me a wild one compared to my obedient brother and sister, and she says that I never sat still at his house. At low tide, I went clamming with my mom, and at high tide I found every opportunity to jump off the dock even though I wasn't allowed.

[13] Hardy, R.D. 2016. *The Darien News*. January 27.
Reprinted here with permission from the publisher.

I didn't get to grow up on the coast, being from Douglas, GA, a two hour drive inland from Darien. So I don't have the deep personal knowledge of the coastal environment that many folks from McIntosh County have, but I like to imagine that a love for the sea runs in my family. I suspect these experiences are at least partially why my graduate studies came to be about understanding how Georgia's coastal communities might be affected by rising seas.

Sea-level rise is a global phenomenon. The world's oceans have risen and fallen for hundreds of thousands of years due to natural forces including measurable cycles of sun activity and the Earth's orbit. During previous ice ages, sea levels were much lower compared to today. Since the peak of the last ice age, about 20,000 years ago, global sea level has risen nearly 400 feet. And millions of years ago when there was no ice and the oceans were much warmer, global sea level was as high as 300 feet or more above today's level. Way back then, the ocean would have been as far inland as the Georgia fall line that runs from Augusta to Columbus.

These changes were entirely due to natural forces; yet since the mid-1800s, humans have been pumping gases into the atmosphere through burning fossil fuels, cutting and burning trees, and even through cement production. The greenhouse gases, especially the CO_2, released from these human activities increases average global temperature by trapping heat, much like a backyard greenhouse stays warm at night due to the plants putting off CO_2. Scientists have measured an increase in average global temperature of about 1.6° Fahrenheit since the mid-1800s. So what does a warmer planet mean for future global sea level?

According to the 2014 National Climate Assessment (http://nca2014.globalchange.gov/), the average sea level for Earth is likely to increase from one to four feet above the 1990 level (with a smaller possibility of reaching up to six and a half feet) by the end of this century (see graph). However, as scientists collect more data on the melting ice sheets in the Arctic and

Antarctic, the upper ranges are becoming more likely, with NASA recently reporting that three feet seems more like a minimum estimate now.

There are many factors that cause sea-level rise, and they work at different scales. At the global scale, for example, the human activities that are warming the atmosphere are also leading to the oceans warming up too, which leads to their expansion. And much like how we humans like to spread out when it's hot, so do the water molecules in the world's oceans when they warm up. In other words, warmer water takes up more space than cooler water. Ocean expansion is expected to be the most significant contributor to global sea-level rise in the long-term (think, past our lifetimes), but right now, melting ice plays the largest role.

As many folks have likely heard, the polar ice caps are melting at an increasing rate, sending trillions of gallons of water into the sea every year. The Antarctic and Greenland ice sheets are estimated to be melting at a rate of approximately 121 trillion gallons per year, which is roughly 35 times the amount of water that flows from the Altamaha River annually. That's a lot of water! Other sources of melting ice that contribute to sea-level rise include mountain glaciers and smaller land-based ice sheets near the poles. The important point here is that this is water that was previously locked up as ice on land and it's now being added to the world's ocean basins, filling them above previous levels and contributing to rising seas.

While average global sea level has been naturally increasing since the last ice age, and has accelerated since human activities started pumping greenhouse gases into the atmosphere, local sea level is dependent on a number of factors. Regional and local factors that drive sea level change include land movement (sinking or uplift), such as in Charleston, where much of the observed rate of sea-level rise over the past century has been due to the land sinking relative to sea level. You'll notice that I said sea level "change" in the previous sentence. That's because local sea level is not always rising. For example, along much of the Alaskan coast the land is lifting up, so local sea level there is dropping. Such land movement as in Charleston or Alaska can be caused by many things. These include ground water and mineral resource extraction or changing patterns in river sediment dynamics. For example, the Mississippi delta is sinking due offshore drilling and lower sedimentation rates because levees prevent the dirt in the river water from settling out on floodplains. Also, the world's continents have been leveling out since the last ice age (remember plate tectonics from grade school?).

For that last cause, you can mimic it as a home experiment by putting a piece of foam in your bathtub and imagining it's a continent floating on magma. Let's say the foam represents North America. Now place something heavy, like a chunk of ice from your freezer on one side of it that represents Alaska to the north. That heavy ice lifts up the "southern" end of the floating foam and if you remove it, the foam levels off. This is what's still happening with the continents, it just takes thousands of years for the huge continents floating on thick magma to level off, even after most of the ice has melted. It's also partially why Charleston's land is sinking and Alaska's land is uplifting relative to sea level.

There are many other factors that go into land movement, too many to go into here. Just know that land moves, and even if only fractions of an inch each year, these fractions add up over time and affect local sea level measurements. If you want to learn more about land movement, read Dr. Fred Marland's *Darien News* article from August 27, 2015, in which he goes into a bit more detail about this. If you want to learn more about how sea level changes are measured, stay tuned for part two of this three part series, "Getting to Know Sea-Level Rise."

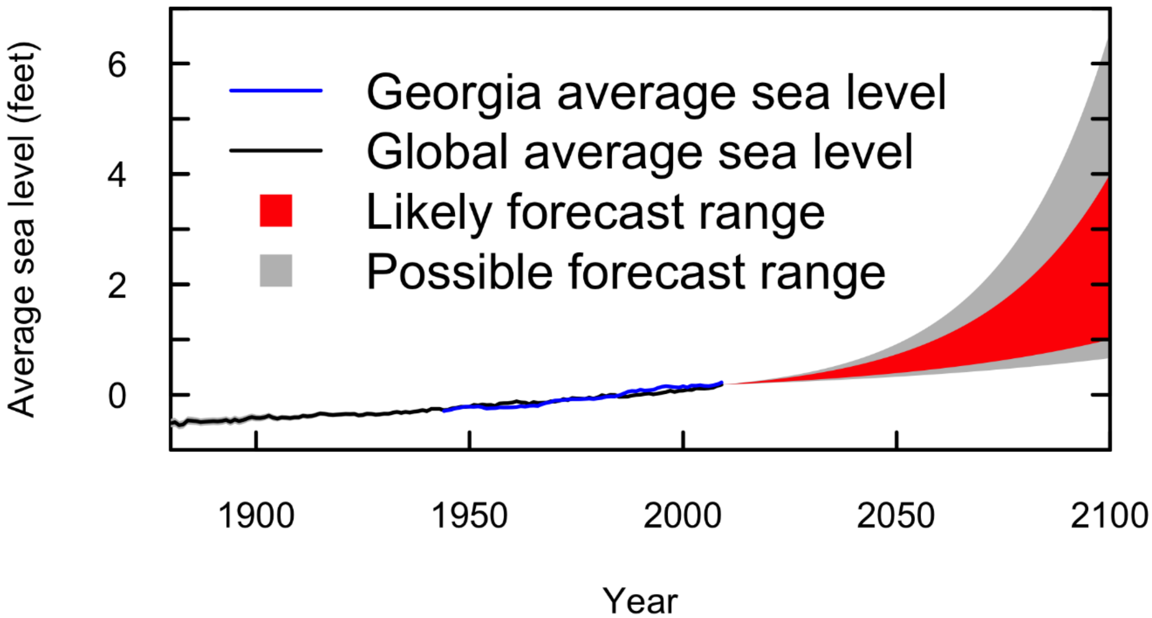

Figure C.1 Global mean sea level has risen about 7.9 inches since 1880 (black line). Georgia's local sea level has risen slightly faster, rising about the same amount (7.8 inches) just since the 1930s (blue line). NOAA predicts that global sea level will likely rise from 1-4 feet by the end of this century (red cone), with a possibility of being as little as 8 inches or as high as 6.6 feet (grey cone). The graph is set relative to average global sea level in 1990, which is why it starts below zero feet.

Getting to Know Sea-Level Rise Part 2: Measurements [14]

Ever wonder how the tide is measured? How sea level is measured? How sea-level *rise* is measured? In part one (published on January 27, 2016) of this three-part series, I wrote about the causes of sea-level rise. As a brief reminder, the two most important causes include melting land ice (glaciers and polar ice caps) and ocean water expanding as it warms. Here, I'll cover some of the basic ways that sea level has been measured since as far back as 1807, when the Office of Coast Survey (the US's oldest federal scientific agency) was created by Thomas Jefferson.

But first, what is sea level? With all the wind, waves, and currents moving the 330 million cubic miles of water that fills the ocean basins, is the sea even "level" anyway? Of course not! You certainly can't use a ruler on the shore to measure it accurately. What we call average (or mean) sea level is a reference to where the ocean height would be if all the movement caused by wind, tides, and other sources stopped and the oceans became still like a pond. To determine local sea level and tide in the United States, scientists who work for NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) record measurements of water levels at many stations along our coasts (Figure C.2). These measurements are made over many years (typically about 19 years) and then the average water level over that period of time is calculated as local sea level.

The first US tide gauges installed in the early 1800s required manual measurements by Coast Survey technicians. To help overcome much of the water movement that would make measurements more challenging, a common tide gauge design includes pipes (called stilling wells) that are placed in the water. These pipes extend above and below the water's surface. The first self-recording tide gauge (and the oldest active one in the US) was installed in San

[14] Hardy, R.D. To be submitted to *The Darien News*.

Francisco in 1854 and used a rotating paper drum attached to a wire on a pulley system with a float inside the stilling well (Figure C.3). As the drum turned and the water raised and lowered the float attached to the pen, the pen marked the height of the water on the paper.

Nowadays things are a bit fancier, as many of the US tide gauge stations use height measurements taken with acoustic sensors that bounce sound off the water's surface inside sounding tubes (which serve a similar purpose to the stilling wells). These stations also have special GPS units to keep super precise track of location and time (Figure C.4). Throughout the 20^{th} century, the US and other countries' tide gauges around the world measured an average global sea-level rise of about seven inches, but since 1993, sea level has been rising at a rate nearer to 12 inches per century.

Why is understanding sea level measurements important? Well, every time you use an elevation map, you are using information based on sea level. The elevation numbers that we use on maps in the US refer to mean sea level, which is actually determined by the mean tide level measured at a specific location in Canada (Father Point in Quebec located at the mouth of the St. Lawrence River). Even though every location has its own unique, local sea level (or mean tide level), using one location as the sea level reference makes maps standardized and easier to read.

Tide gauges are not everywhere, and there is a lot of land where we can't place tide gauges, because there's no water to place them in! To determine local sea level between tide gauges and where there is land, scientists put the data collected at tide gauges into complex mathematical models. This allows them to calculate a locally specific sea level even, for example, underneath Brasstown Bald (Georgia's highest peak).

The difference between the standard reference point used for maps (Father Point) and local sea level varies quite a bit. For example, the difference between the reference sea level at

Father Point in Canada and Fort Pulaski on the Savannah River in Georgia is less than half of an inch, but there's more than a three-foot difference between Father Point's and San Francisco's tide gauges. What this means is that when a map shows a location in San Francisco as 10 feet above mean sea level, locally it's actually only about seven feet above local mean sea level, or the mean tide level.

Tide gauge measurements of sea level go back over two centuries, but in 1992 the US and French space agencies worked together to launch a satellite (called TOPEX/Poseidon, named after the Greek god of the sea) that would begin a new period of global sea level measurements from space that are accurate to within less than two inches. Since the first satellite in 1992, three more satellites have been launched to extend the project to measure the height of the world's sea surface. These were called Jason 1, Jason 2, and Jason 3.

All of these satellites measure distance by bouncing microwave radar off the sea's surface, much like the new type of tide gauges. The satellite knows exactly where it is in relation to the center of the Earth. Using that information and the time the radar signal takes to bounce back to the satellite, it's possible to calculate the sea level. The advantage of the satellite measurements over the tide gauges is that it only takes 10 days to measure the height of the oceans around nearly the entire globe!

Being able to measure sea level and how fast it is changing helps scientists predict future sea-level rise. Not only is this useful for helping people know how high above sea level a place is on a map, but it provides useful information for future planning and development purposes, such as where to build roads and emergency facilities. Interestingly, as sea level rises in many places and changes our nation's shorelines, the elevation of mountains will have to be changed on maps. If you climbed a mountain in Georgia today, you would likely be higher above sea level than if you climbed it in 50 years because sea level will have risen one to two feet.

Stay tuned for the final part of this three-part series where I'll discuss the possible impacts of future sea-level rise to Georgia's coast. For now, if you want to learn a little more of the technical details about how sea level is measured, check out this visually-friendly YouTube video by Minute Physics: https://youtu.be/q65O3qA0-n4.

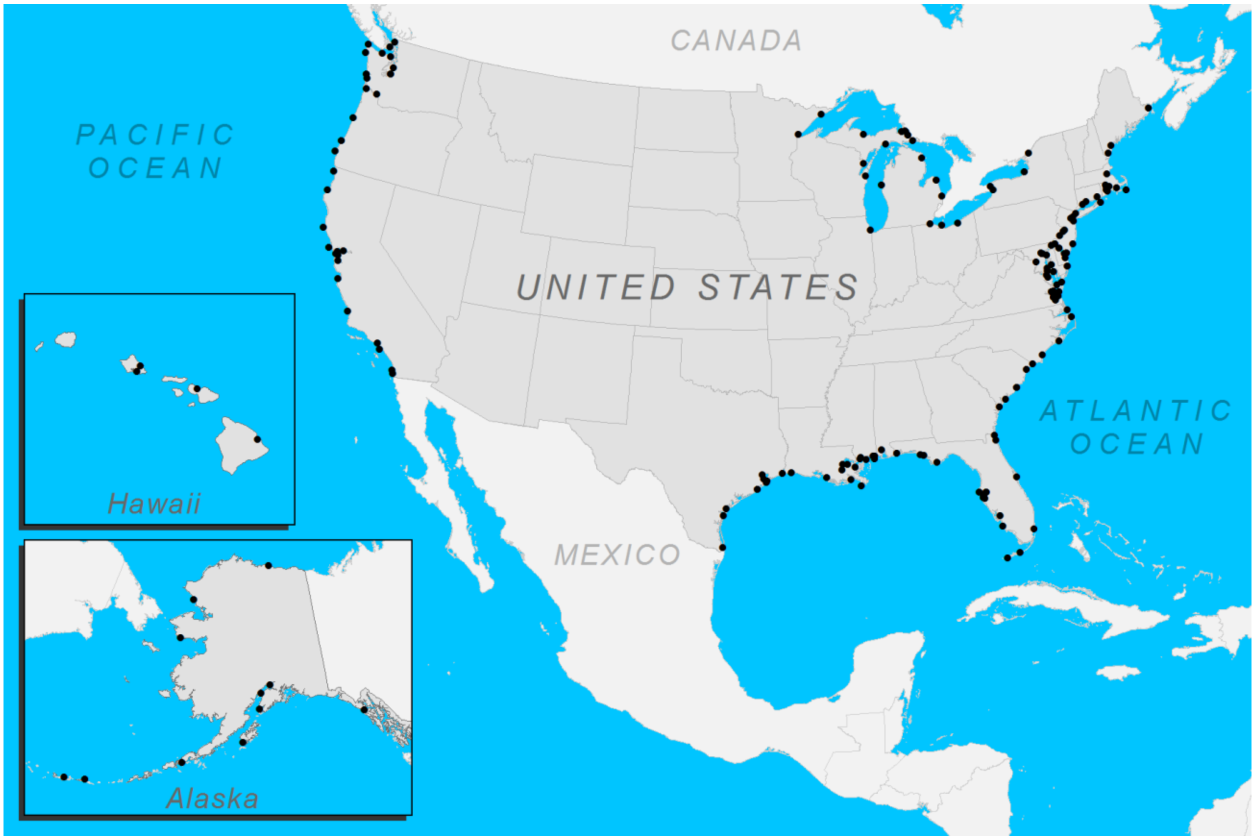

Figure C.2 This map shows the location of 195 US tide stations that are currently operated and maintained by NOAA's National Ocean Service.

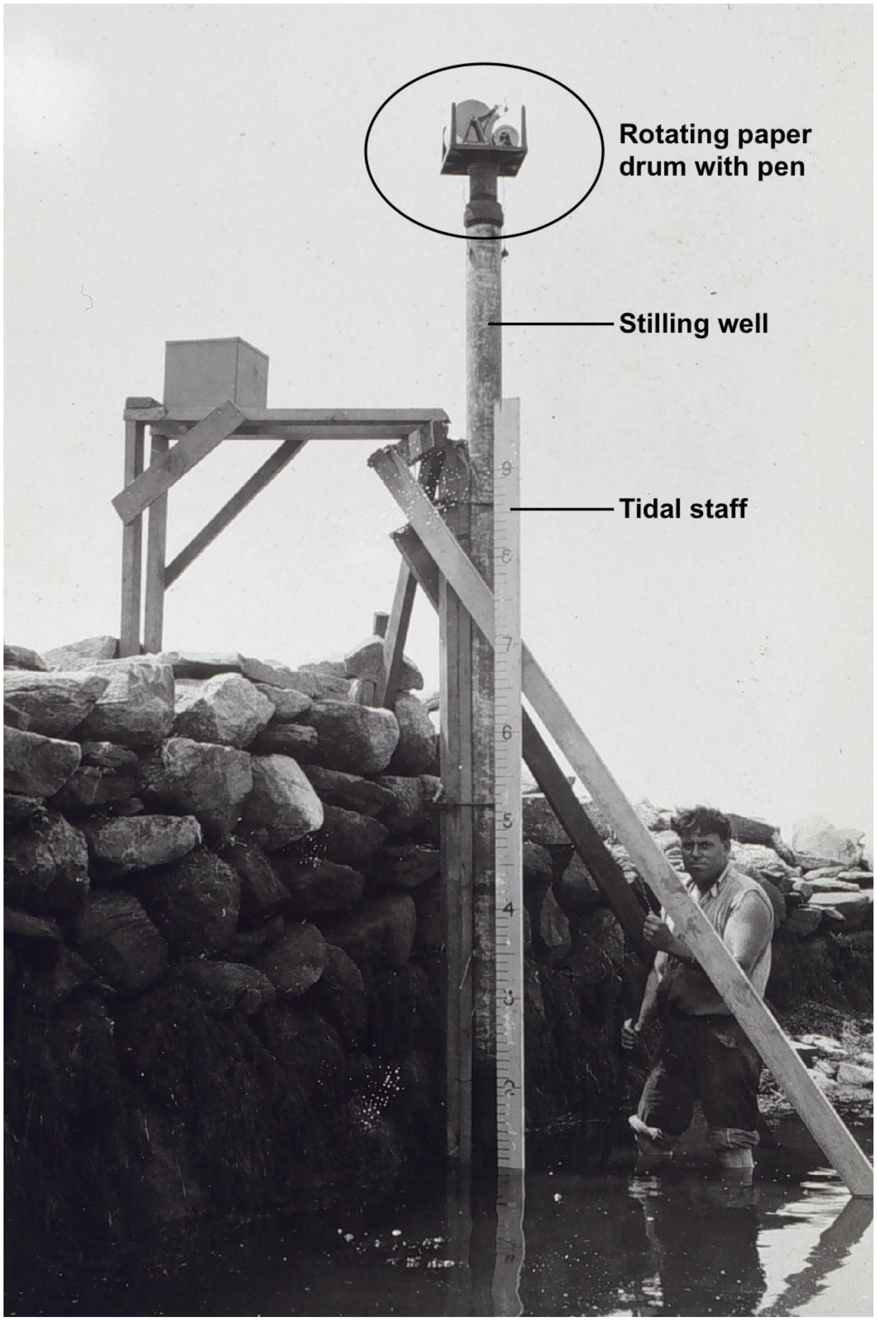

Figure C.3 Photograph taken in 1931 of US Office of Coast Survey checking tide gauge in Buzzard's Bay area, Massachusetts. The photo shows a portable station, but permanent versions were stored in tide station houses to protect them from the extreme weather conditions of the coastal environment. Photo credit: NOAA's Historic Coast & Geodetic Survey Collection (http://www.photolib.noaa.gov/cgs/, accessed 7/19/2016).

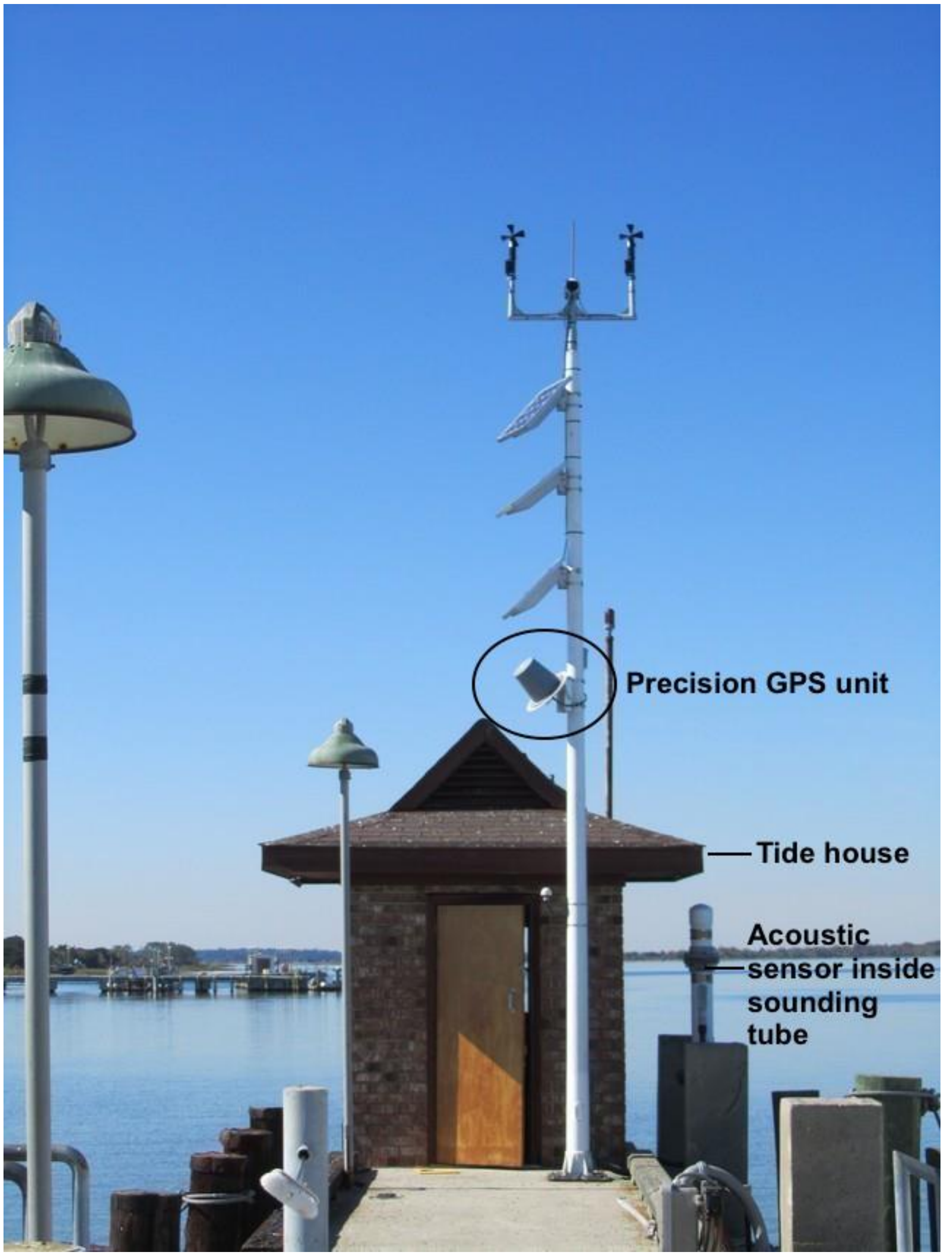

Figure C.4 Recent photograph of Fort Pulaski tide gauge located on the Savannah River. Photo credit: NOAA's CO-OPS (http://tidesandcurrents.noaa.gov/, accessed 7/19/2016). To learn more about how CO-OPS measures water levels, visit http://oceanservice.noaa.gov/education/tutorial_tides.

Getting to Know Sea-Level Rise Part 3: Impacts [15]

Standing on the shores of Tybee Island's white sandy beaches, Jekyll Island's enchanting driftwood beach, and Sapelo Island's quiet beach of solitude, I have often found myself amazed at the beauty and mystery that lay before me. Jekyll was my go-to childhood beach, just a short two-hour drive from Coffee County, but my first time to visit McIntosh County was to work as an intern in the splendidly muddy marshes near Sapelo Island and the mouth of the Altamaha River.

I was warned by my coworkers that the rice grass (which grows over six feet tall in the brackish marshes along the river) would feel smooth to my arms when I bent down to collect marsh mud, But, I was also told to watch out for the grass's "bite" when I stood back up. I realized that I had a few options to deal with the razor sharp rice grass, the heat, the mosquitos, and the mud.

Abandoning my job was an option, of course, but I wasn't raised to be a quitter (even if it *was* an unpaid internship). I did abandon the idea of wearing short sleeve t-shirts or shorts though (Figure C.5). To armor myself against the grass, I learned that wearing long sleeves and pants was important, even when it was 100 degrees. Covering up helped keep the pesky mosquitos off, too. This is also when I adapted to walking quickly through the marsh mud to get back to the boat, before the tide came in and I would be swimming with the gators (or worse, stuck in the muck and just sitting there!). This combo approach of armoring, adapting, and abandoning (some things anyway) was necessary to make it in my new job and environment.

I want to share a few examples of these three approaches of armoring, adapting, and abandoning (the triple A's I like to call them) that coastal communities have used to cope with

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[15] Hardy, R.D. To be submitted to *The Darien News*.

their changing environments as seas rise. Then I'll move on to sharing some of the potential impacts from sea-level rise that could occur to Georgia's coast and McIntosh County more specifically.

Armoring is perhaps the most well-known approach, building sea walls or bulkheading shorelines. Downtown Darien has plenty of examples of this type of defense. This helps keep the increasing water levels from flooding and eroding the shoreline, but also leads to higher rates of marsh and beach loss. This is because the waves (the energy in the water) is reflected back from the wall and takes a lot of the dirt, and sometimes the plants, with it when it goes back out to sea or the tidal channel.

Sea walls and the like will not work everywhere though. For example, Miami Beach has porous limestone as their bedrock, and so it has had to adapt to rising sea level by elevating roadways and designing below-street-level sidewalks that occasionally flood during the highest of tides. In Georgia, Tybee Island has also begun to adapt to rising seas by installing one-way storm drains that allow the rainwater to go out at low tide and the seawater not to come in at high tide. They've also started to experiment with the idea of living shorelines. Instead of armoring with a sea wall, they have started seeding artificial oyster beds as buffers against rising seas with the help of Georgia Sea Grant. Other communities, such as San Francisco, have planted artificial wetlands along their shores.

Unfortunately, there is also at least one community in Louisiana, the Isle de Jean Charles, that has chosen to abandon their homes and relocate. This is because since 1951 they have lost 98% of the land they call home. This area of Louisiana loses nearly a football field per day of land to the sea through a combination of the land sinking and the sea rising. While any potential abandonment of parts of coastal Georgia is hopefully far off, planning now for armoring and adapting to the rising sea would be wise, in my opinion.

Based on some of my own research and other independent research by colleagues, as many as 40,000 or more of Georgia's future coastal residents could be directly at risk to the effects of sea level rise by the year 2050, including increased flooding of roadways and property (Figure C.6). In McIntosh County, the number of people predicted to be impacted by rising sea level in the next 35 years is between about 2,000 and 4,000. The actual number affected depends on population growth rates and how much seas rise (Figure C.7). Currently, the best science predicts that by 2050 the Georgia's sea-level will be somewhere between 10 to 24 inches above the 1992 sea level (the same height roughly equal to the mean tide level on tidal charts). What this means is that where the high tide is now could reach about as high as either your ankles, or nearly as high as your knees in the next 30 to 40 years!

What the numbers above don't account for is all the people who could be affected indirectly. What I mean by this is that even if you don't live on the water, your access to work and other resources including the grocery store could be impacted by flooded roads. If your job depends on Georgia's bountiful and lively marsh (maybe as a fish guide for tourists), your income could be affected because the marshes might be affected by sea-level rise. The marshes may grow upwards as seas rise, or they may be eroded and washed away by the higher water levels. Scientists are working hard to figure out just what will happen to our coastal marshes under the stress of rising seas right in McIntosh County.

Ever been out to Sapelo Island, or around the Altamaha mouth and wondered what those white PVC pipes everywhere in the marsh where being used for? Many of these mark research sites for the dozens of scientists working at the University of Georgia's Marine Institute on

Sapelo. A good portion of these scientists are studying the potential effect that sea-level rise will have on the salt marsh ecosystem including the plants and fisheries, like shrimps, crabs, and fishes (including one of my favorites, the tasty red drum).

Much like how I had to use the triple A approach (armor, abandon, and adapt) to cope with the new environment for my internship in the marshes, Georgia's coastal communities will likely need to take a similar combination approach to deal with the expected changes in coastal ecosystems as seas rise in the coming decades. According to Climate Central (a group that studies the effects of climate change and sea-level rise), if sea-level rise follows the fast scenario, the chance that a flood that is four feet above mean higher high water will occur every year is nearly 100 percent by the year 2060 (it'd be only 2% under the slow scenario).

For some perspective, the really high tide we had last October 29, 2015 was only 2.93 feet above mean higher high water as recorded at the Fort Pulaski tide gauge near Savannah, GA. For those who remember, US highway 80 going out to Tybee Island flooded and closed, downtown Brunswick flooded, as did Sapelo's Marsh Landing, where the ferry docks. As seas continue to rise, flooding like that event last year will become much more common. Planning for it now may help us figure out how best to armor and, most importantly, adapt to the changing environment that will come with rising sea level.

For more detailed information about rising seas, be sure to search online for one of the many options to view sea-level rise and the related effects it may have on Georgia's coast. Here are three examples that I recommend checking out:

Climate Central: http://riskfinder.climatecentral.org/

NOAA: https://coast.noaa.gov/slr/

Georgia Coastal Hazards Portal: http://gchp.skio.usg.edu/

Figure C.5 This is an photograph of me with two coworkers in the salt marsh of McIntosh County taken in 2001 by T. Dale Bishop. Left to right: Dean Hardy, Gayle Albers, and Monica Palta.

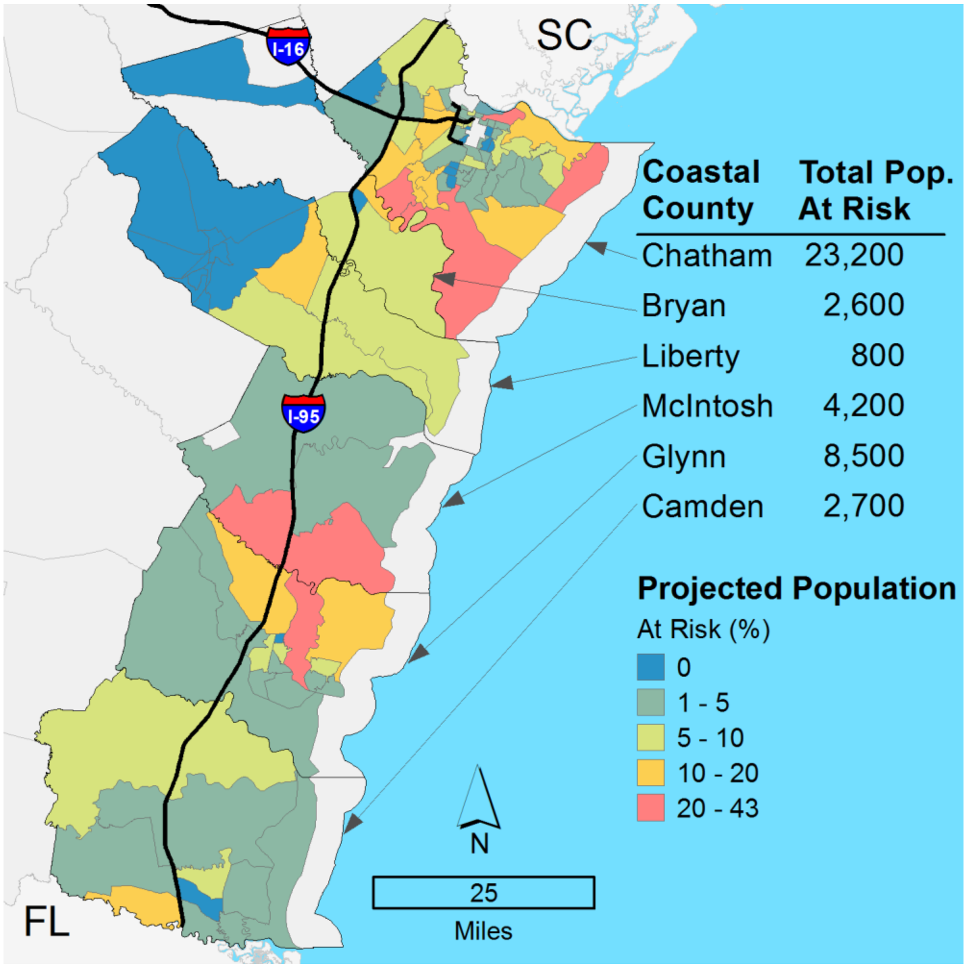

Figure C.6 The map shows the projected population predicted to be at risk to flooding from the fast scenario of sea-level rise for the year 2050 in coastal Georgia (see graph). The projected population predicted to be at risk is mapped as the population percentage for US Census Tracts and in the table as totals (rounded to hundreds) by county.

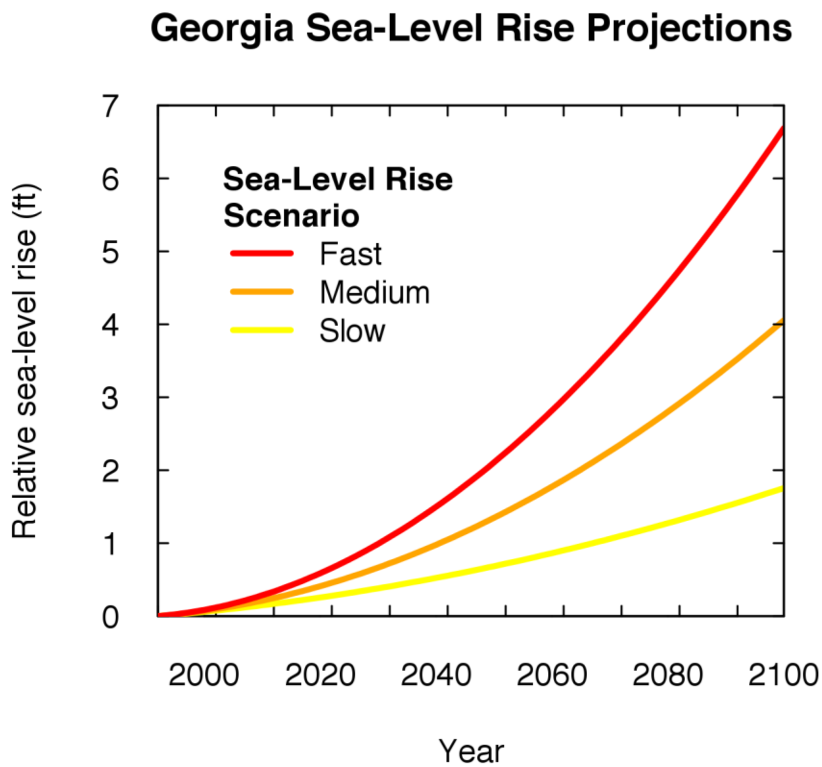

Figure C.7 The graph shows three scenarios of local sea-level rise for coastal Georgia based on the 2014 National Climate Assessment global projections for high, intermediate high, and intermediate low rates of rising seas above 1992 sea level. The projections are adjusted to local rates of sea-level rise by applying the average of historical measurements of sea-level rise recorded at the Fort Pulaski and Fernandina Beach tide gauges.

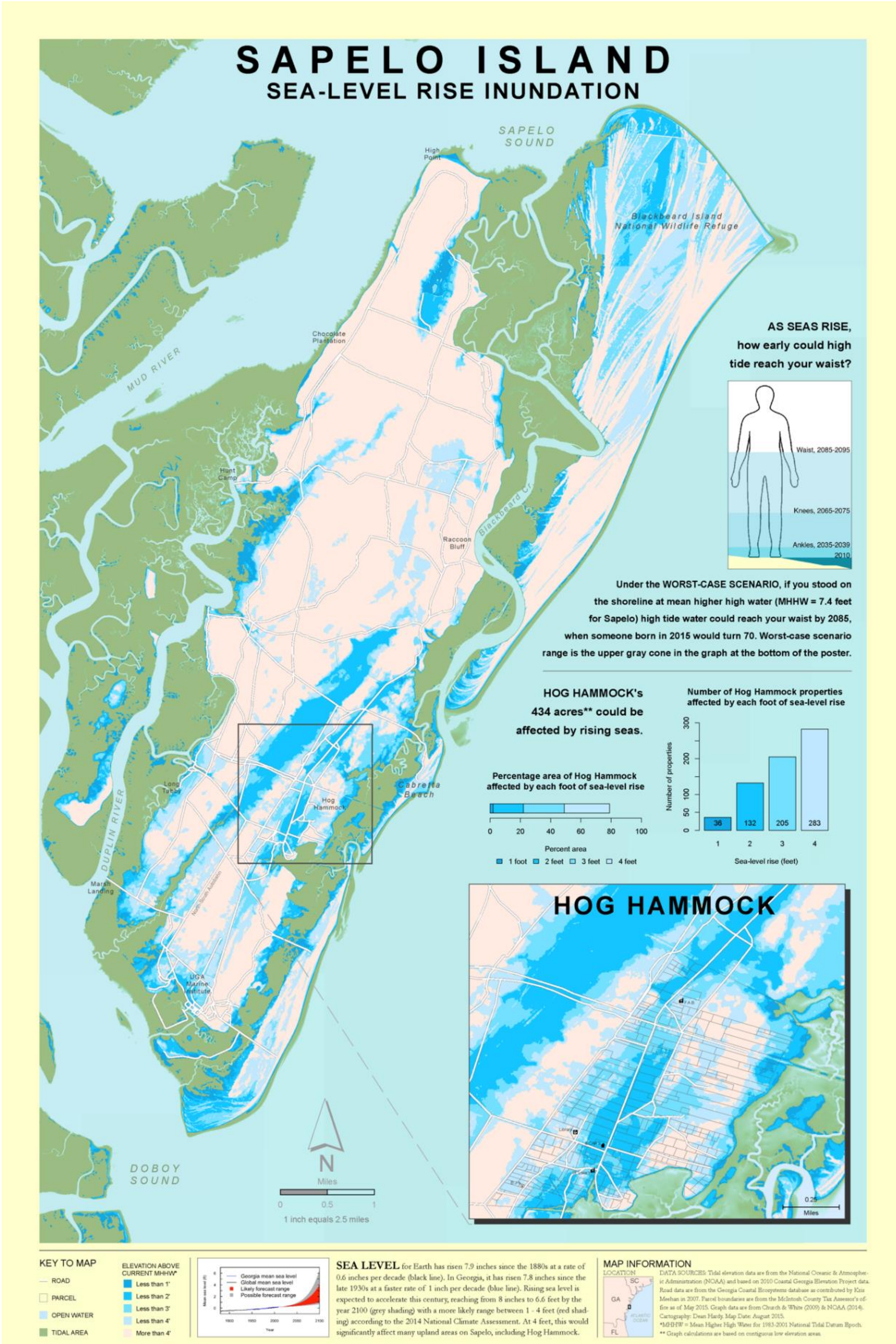

Figure C.8 Sapelo sea-level rise inundation poster presented to Hog Hammock Public Library.