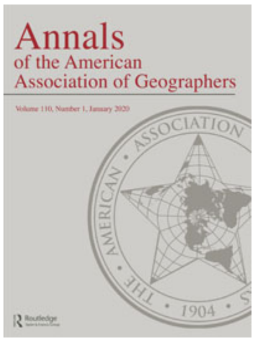

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Assessing Social Vulnerability through a Local Lens: An Integrated Geovisual Approach

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Vulnerability and resilience of coastal communities is increasingly important in the face of sea level rise and severe storms. Situated at the nexus of geographic information systems (GIS) and natural hazard vulnerability, this study compares and integrates a GIS-based approach that produces social vulnerability indexes from census data and a human subject survey-based approach that learns local perceptions of coastal hazards in the aftermath of Hurricanes Matthew and Irma. It applies statistical and geovisual analyses of data from both approaches. We find significant variations in perceptions across the vulnerability spectrum and relate these differences to theories of expert and nonexpert knowledge. It is believed that both sets of results are useful and revealing from different perspectives, although each has its own weaknesses. Integration of both can provide a fuller picture of social vulnerability. To this end, the study demonstrates several geovisualization methods for integration. *Key Words: coastal resilience, critical GIS, geovisualization, mixed methods, social vulnerability.*

面对海平面上升和剧烈的风暴，海岸社区的脆弱性和回復力日益重要。本研究座落于地理信息系统（GIS）和自然灾害脆弱性轴线的交汇处，比较并整合以GIS为基础、从人口统计数据生产社会脆弱性指标的方法，以及以人为目标、学习马修与欧玛飓风过后地方对海岸灾害的认知之调查方法。本研究运用两大方法的统计和地理视觉分析数据。我们发现认知在脆弱性光谱上的显着变异，并将这些差异连结至专家与非专家知识的理论。本研究相信，从不同的角度而言，两组结果皆有用并具启发性，仅管各自具有其弱点。整合两者能够提供社会脆弱性更充分的图像。为此，本研究展现整合的若干地理可视化方法。*关键词：海岸回復力，批判地理信息系统，地理可视化，混合方法，社会脆弱性。*

La vulnerabilidad y la resiliencia de comunidades costeras es cada vez más importante ante el ascenso del nivel del mar y la severidad de las tormentas. Situado entre el nexo de los sistemas de información geográfica (SIG) y la vulnerabilidad a las catástrofes naturales, este estudio compara e integra un enfoque basado en SIG que genera índices de vulnerabilidad social a partir de datos censales y un enfoque de estudio de campo de sujetos humanos con el que se puede aprender de las percepciones locales de traumas litorales dejados como secuelas de los huracanes Matthew e Irma. Se aplican análisis estadísticos y geovisuales de los datos de ambos enfoques. Hallamos variaciones significativas en las percepciones a través del espectro de la vulnerabilidad y relacionamos estas diferencias con teorías de conocimiento experto e inexperto. Se cree que ambos conjuntos de resultados son útiles y reveladores desde diferentes perspectivas, aunque cada cual tiene sus propias flaquezas. La integración de los dos puede suministrar un cuadro más completo de la vulnerabilidad social. Para este efecto, el estudio hace la demostración de varios métodos de geovisualización para la integración. *Palabras clave: geovisualización, métodos mixtos, resiliencia litoral, SIG crítico, vulnerabilidad social.*

Natural hazards, particularly flooding, heavy rainfall, and wind associated with hurricanes and tropical storms, are inherent to the everyday experiences of people living in coastal areas. Coastal communities are also expected to be among the first to reckon with the effects of climate change, both in the immediate future and over the next century. The Georgia coast, where the case study of this research takes place, is no exception. Although some coastal residents believe that the stretch of coastline known as the South Atlantic Bight shelters coastal Georgia due to its concave shape, the area is not physically immune to the impacts of hurricanes and tropical storms (Feng and Olabarrieta 2016; Braun et al. 2017). Historically, the region has been affected by catastrophic storms, such as the Great Sea Island Storm of 1893 and the Great Hurricane of 1898 (Garriott 1898; Ho 1974; Sandrik and Landsea 2003). More recent storms include Hurricanes Matthew and Irma in 2016 and 2017, respectively.

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In addition to severe storm events, the U.S. East Coast and the Georgia coast specifically will have to contend with sea level rise in the coming decades. Mean sea levels are rising worldwide (Nicholls 2011), and on the Georgia coast, sea levels have risen 250 to 275 mm since 1935 (National Oceanic and Atmospheric Administration 2012). One serious consequence of sea level rise is the eventual inundation of many coastal communities, resulting in displacement (Hauer, Evans, and Mishra 2016). Another related challenge is so-called nuisance flooding or sunny day flooding events that occur at high tide. Although tidal flooding is not abnormal in coastal areas, the frequency of these events has increased along the East Coast, as well as in other regions. These increasingly common events might not cause severe damage, but they interfere with everyday life by submerging roads and causeways, overwhelming stormwater drainage capacity, and contributing to the deterioration of infrastructure not intended for regular saltwater exposure (Sweet et al. 2014).

Despite these challenges, coastal regions continue to experience population growth (Crossett et al. 2013). Coastal hazards, including tidal flooding, tropical storms, and sea level rise, will be a reality for these populations in the foreseeable future. A deep body of vulnerability research in geography and related fields tells us that the impacts of these hazards will be felt unevenly, as natural hazards and disasters serve to highlight and deepen existing inequalities in the distribution of power and material resources (Wisner et al. 2004; Smith 2006). Environmental exposure is a precondition for disaster, but differences in social capital, status, power, and income dramatically affect the ability of individuals to cope, and structures put in place by the state and other actors also play a role. Overall, the social turn in hazards studies was a reaction to the overly deterministic approaches of previous decades that focused on physical vulnerability alone (Cutter 2016). In current research, the social aspects of hazards are nearly universally acknowledged.

Vulnerability research takes place in the physical sciences as well as quantitative and qualitative social sciences (Miller et al. 2010) and at intersections of those fields. Because vulnerability has historically been addressed from disparate perspectives, formal definitions are complex and sometimes contradictory. The concept can be summarized, however, as the intersection of physical exposure, population sensitivity, and adaptive or coping capacity. Vulnerability does not exist as an inherent quality of a person that can be directly measured; rather, it is a term for the net effect of a variety of social and environmental factors that constitute sensitivity and adaptive capacity.

Two approaches can be identified in the contemporary geography literature for the study of social vulnerability. Geographers have used both quantitative geographic information system (GIS) techniques and qualitative methodologies to analyze the uneven distribution of vulnerability. Products of this line of research range from numerical indexes, which compare vulnerability among different places, to finer scale qualitative studies aimed at deriving a rich body of knowledge about a specific place or community. Separately, critical geographers and critical GIScientists have argued in favor of local, nonexpert knowledge, derived from personal perceptions rather than scientific expertise. Following a similar line of thinking, some GIS scholars have integrated qualitative and mixed-methods approaches with digital mapping techniques to better represent local knowledge (e.g., Elwood 2008; Kwan and Ding 2008). Both traditional GIS methods and approaches based on local knowledge contribute to a robust understanding of vulnerability and can be complementary to each other. Few studies, though, investigate the relationship between the results of different approaches and the potential to integrate them.

We argue that an integrative use of both approaches will present a fuller picture that can enhance our understanding of the social vulnerability of specific geographical areas. This study attempts to fill the gap by comparing the results of two approaches and presenting techniques to integrate the two sets of results for a fuller representation of vulnerability, revealing where local attitudes toward vulnerability and risk overlap with or diverge from the quantitative social vulnerability index, as well as how localized data can lend social context. We do this through a case study in Chatham County, Georgia. First, we adopt a classical model of the quantitative social vulnerability index and produce values for census tracts in the study area. Then we process and analyze data collected from a human subjects survey in the study area for a representation of nonexpert knowledge. Finally, we compare the two sets of results and develop methods to visually integrate the two sets of results in a GIS environment. Our findings suggest that individuals perceive their own vulnerability and risk in ways that are not necessarily consistent with demographic predictors and that incorporating these differences can lend additional depth to an analysis of social vulnerability.

Related Work

Geospatial Approaches to Vulnerability

Working with an integrated social–physical framework, Cutter, Mitchell, and Scott (2000) developed a place-based vulnerability model and the social vulnerability index (SoVI). They generated a map that included layers for Federal Emergency Management Agency (FEMA) flood risk zones, hurricane storm surge extents, hurricane wind zones, technological hazard zones, and earthquake frequency. These factors were overlaid and quantitatively combined. The final output was a GIS map illustrating the overall vulnerability score. The SoVI formula was updated in 2010 and 2014 to account for changes in vulnerability theory, and subsequent analyses have followed similar approaches, with some extensions and modifications.

Evaluations of the quantitative mapping approach identified a need for greater contextualization and validation of findings (Rufat et al. 2015; Kwan 2018; Rufat et al. 2019). Various applications of the SoVI model have attempted to do this. In Georgia, the SoVI was adapted to include meteorological events and long-term climatic conditions (Kc, Shepherd, and Gaither 2015), revealing greater levels of climate vulnerability in coastal counties and in the Atlanta metropolitan area. In terms of validation, the SoVI output is often checked against records of mortality or property damage. At least one study, however, compared the index with qualitative measures of local expert opinion and found significant differences in the results (Oulahen et al. 2015).

Other recent work has used the integrated social–physical framework without applying the SoVI method (e.g., Cai et al. 2018; Hardy and Hauer 2018; Parry et al. 2018). Hardy and Hauer (2018) integrated sea level rise models with projections of demographic change to more accurately forecast the effects of climate change on coastal populations. Cai et al. (2018) used a Bayesian network to model physical and social aspects of resilience while accounting for uncertainty. In one of the relatively few studies to consider nonexpert opinion, Shao, Gardezi, and Xian (2018) compared "objective" risk factors to aggregated measures of risk perception, finding that greater economic and community resilience, as well as recent experience with storm surge, was related to a heightened perception of hurricane risk. We see potential for further work that incorporates local nonexperts, in line with ongoing developments in GIS theory.

Critical GIS and Nonexpert Knowledge

Critical cartography has historically emphasized the constructive, power-laden nature of maps and challenged their impartiality (Crampton 2001; Crampton and Krygier 2006). Critical GIS leveraged this thinking to interrogate the power dynamics involved in GIS practices (Harvey, Kwan, and Pavlovskaya 2005; Sheppard 2005). This viewpoint stems from objections to the purportedly impartial "view of everything from nowhere" (Haraway 1988, 581) of positivist research. Instead, feminist scholars make the case for drawing on "local" narratives and focusing on everyday practices that influence access to resources (Truelove 2011; Israel and Sachs 2013). Meanwhile, Rice, Burke, and Heynen (2015) argued in favor of increased roles for nonexpert knowledge in climate change research.

Early critiques notwithstanding, critical approaches, mixed methodologies, and nonexpert knowledge are not foreign to geospatial research. GIS scholars have considered the potential for channeling feminist epistemologies and politics through GIS (Kwan 2002), as well as for representing lived experiences through qualitative "geo-narratives" (Kwan and Knigge 2006; Kwan and Ding 2008). Similarly, Knigge and Cope (2006) suggested an integration of grounded theory and visualization in a mixed-methods framework "attuned to multiple subjectivities, truths, and meanings" (2035). Along the same lines, the field of public or participatory GIS includes a community of researchers who work to explicitly incorporate "local" nonexpert knowledge into their work (e.g., Elwood 2008; Brown, Weber, and de Bie 2014; Corbett, Cochrane, and Gill 2016). Applications range from what is often termed *citizen science* to more radical countermapping exercises by indigenous or community groups.

More recent critical GIS scholarship has reflected "a move from a more narrow set of concerns around desktop GIS software to digital mapping in the context of pervasive digital culture" (Wilson 2017, 31). Spatially referenced data are ubiquitous (Hahmann and Burghardt 2013), and Web-based geospatial technology permeates everyday life more thoroughly than desktop GIS ever has (Leszczynski and Wilson 2013). Accordingly, some scholars have directed their attention toward a critical analysis of spatial data itself, including so-called Big Data (Dalton and Thatcher 2014; Leszczynski and Crampton 2016; Burns, Dalton, and Thatcher 2018) and digital geographies more broadly. Pavlovskaya (2018) observed a trend toward decentralization of GIS technologies, which presents opportunities for new critical engagements, whereas Elwood and Leszczynski (2018) envisioned a path forward for feminist digital geographies.

An interest in nonexpert knowledge and integrated methodologies has also appeared in discussions of vulnerability and climate change adaptation. According to Heijmans (2004), vulnerability research often lacks the voice of the people presumed to be vulnerable. Gaillard (2012) made a similar point, describing a "climate gap" between international climate science and "everyday concerns of vulnerable communities" (261). The climate gap is invoked in coastal Georgia by Hardy, Milligan, and Heynen (2017), who argued for an approach to climate adaptation that considers the structural racism of uneven development. Finally, Cutter (2016), developer of the SoVI, posed the salient question, "Resilience for whom?," calling for a more nuanced understanding of resilience and its potential beneficiaries. Taken together, these bodies of work support the consideration of nonexpert forms of knowledge when developing spatial analyses of vulnerability.

Research Design

This research interfaces with two distinct yet related representations of vulnerability and risk. The first is the quantitative SoVI, which is demographically based, generalizable, and widely accepted in official contexts. The second is nonexpert or local knowledge, which in this case means understandings and perceptions of risk and sensitivity constructed by residents of a place from their individual and collective experiences, rather than from investigation by scientific experts. It is assumed that, although residents might be aware of expert opinions on vulnerability to varying extents, their perceptions are largely informed by their own experiences and needs. Thus, *local* is used here to indicate a form of knowledge constructed by nonexperts based on their own experiences. The primary goals are twofold. First, the research examines the connections or differences between results of the two types of measures. Second, the research visually integrates them for a more comprehensive representation of vulnerability and risk. Figure 1 is an illustration of the research framework, showing the flow of processes for the construction of the two types of vulnerability measures as well as their subsequent examination and integration.

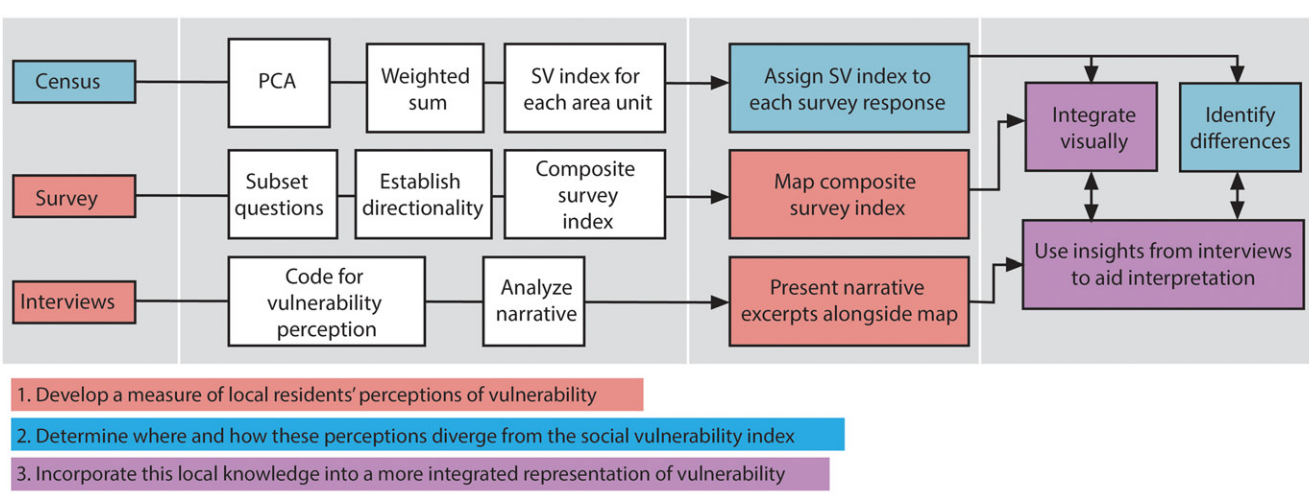

Figure 1. Schematic of research design. *Note:* PCA = principal component analysis; SV = social vulnerability.

Study Area and Data

The study area is Chatham County, the core county of the Savannah metropolitan area and the most populous Georgia county outside the Atlanta metropolitan area. The county is located along the South Atlantic Bight, a gradual curve in the North American coastline running roughly from North Carolina to the east coast of Florida. This area has been identified as a critical site for ocean research due to its recent population growth, frequent storm events and flooding, and environmental degradation (Shepard 2001). Figure 2 shows the study area.

Chatham County has a population of 136,286 (U.S. Census Bureau 2010c). The majority of the population is white, but the minority African American share (40.1 percent) is slightly higher than that of Georgia as a whole. The median household income ($44,928) and poverty rate (16.6 percent) are comparable to the state's figures (U.S. Census Bureau 2010a). The county includes rural inland communities, relatively exclusive barrier island developments, and denser urban neighborhoods of various income levels. In addition, Tybee Island, located in Chatham County, was one of the first communities in Georgia to develop a long-term plan for sea level rise (Evans et al. 2016).

This study uses demographic data from the 2016 American Community Survey 5-Year Estimates at the census tract level (U.S. Census Bureau 2016). It also makes extensive use of data derived from a subset of survey and interviews. The online survey included about eighty questions assessing attitudes, beliefs, behaviors, perceived behavioral control, community interactions, and social norms as they relate to sea level rise and severe storms, as well as basic demographics. It received approximately 800 georeferenced

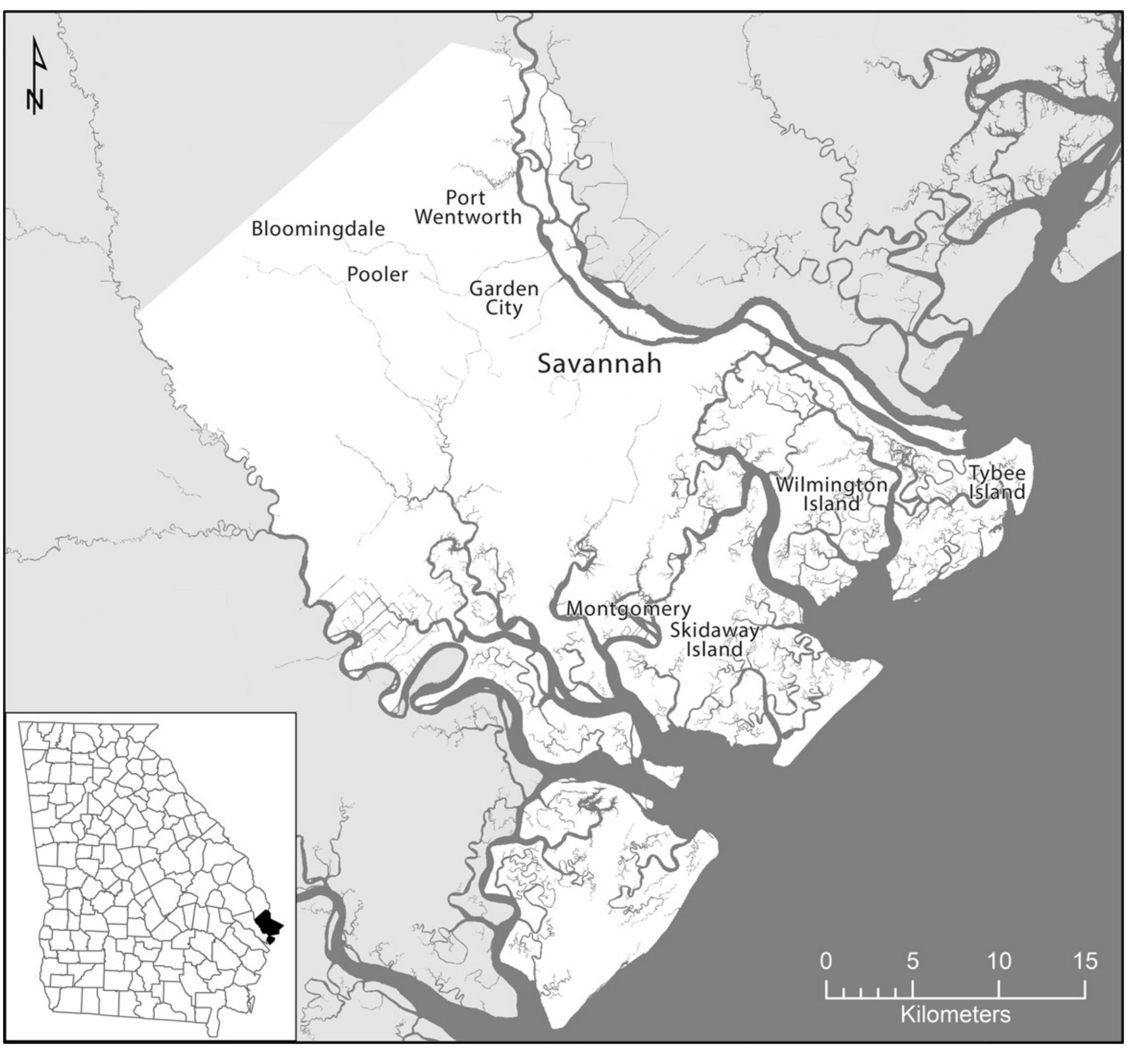

Figure 2. The study area of Chatham County, Georgia.

responses; this study examined the approximately 350 responses located in Chatham County. In addition, interviews with seventy-two informants were conducted over two time periods, one following Hurricane Matthew and another following Hurricane Irma. They covered similar topics in greater depth and, like the survey, included information about the demographic characteristics of their participants.

Methods

Organization of the Survey and Interviews

During the interview process, participants were asked a range of questions dealing with their attitudes toward severe weather, sea level rise, and adaptation in general and their experiences with Hurricanes Matthew and Irma in particular. Transcribed interviews were coded for indicators of individual and community vulnerability, community ties, interpretations of risk, expectations for the future, and attitudes toward adaptation options. Coded responses were then sorted by age, ethnicity, education, gender, and income.

The survey, designed with similar goals in mind, collected information on individual demographic characteristics and also sought to measure attitudes and behaviors with respect to migration and adaptation in the face of changing coastal conditions. These attitudes and behaviors reflect the underlying vulnerabilities behind the demographic indicators used in the SoVI. For example, age is included in the vulnerability formula because older individuals are considered to be less mobile and less able to evacuate (Wisner et al. 2004); accordingly, the survey assesses respondents' perceived abilities to relocate to avoid coastal hazards. Possible responses for the questions or prompts were *strongly agree*, *agree*, *neutral*, *disagree*, and *strongly disagree* and were coded on a 5-point Likert-style scale from -2 to 2. Responses with address information were selected and joined to GIS point features for the purpose of spatial analysis.

From the original panel of survey questions, we selected seven that were most directly comparable with the SoVI (Table 1). Values for these questions were each assigned a cardinality based on how they contribute to vulnerability (positive values represent greater perceived vulnerability and negative values represent lower vulnerability) and were combined into a single composite survey score. Higher values for this score indicated a greater overall sense of vulnerability.

Construction of the Social Vulnerability Index

The study generally follows the SoVI construction approach originally presented by Cutter et al. (2003) and updated most recently in 2014. This method employs a set of twenty-nine aggregated demographic variables understood to represent social vulnerability. These include factors that represent gender, age, race, household size, education, English proficiency, income, social status, employment, housing, and mobility. We converted counts to proportions where necessary, standardized the values using z scores, and then conducted a principal component analysis (PCA) to reduce the high-dimensional data to a set of linearly uncorrelated variables. The purpose of the PCA was to separate the data set into groups of variables (components) that represent different aspects of vulnerability and to generate a weighting for each group. Positive, negative, or neutral cardinality was assigned to each component, and the final SoVI value was calculated for each census tract as a weighted sum of the component scores, with weights based on proportion of variance explained.

Comparative Analysis and Visual Integration

With the SoVI computed and measures of local vulnerability perceptions established, we turn to the

Table 1. Questions selected from survey

Survey prompt	Cardinality
It will not be easy for me to decide to move if the time comes.	+
I am confident that I'll be able to move if that becomes necessary.	−
I'll seek advice from people important to me before deciding to move.	−
I'm concerned that I'll be forced to move by unexpected events.	+
I could recover from losses or damage to my home.	+
I will storm and flood-proof my home.	−

primary goal of the study. The first step of the comparative analysis was to compare responses across demographic categories. In the social vulnerability framework, groups such as racial minorities, low-income people, the elderly, and those with lower educational attainment contribute to a place's vulnerability in a certain direction and at various degrees. It was useful to evaluate how these individuals responded to the more specific measures of the survey. The second step was to perform a correlation analysis between responses to each survey question and the vulnerability index, as well as between the composite survey score and the vulnerability index, all at the level of individual responses.

Finally, to facilitate comparison of the two types of vulnerability measures, we developed two visual integration methods, each with advantages and disadvantages. The first, and simplest, was a bivariate choropleth map with classes indicating whether values for the vulnerability index and the composite survey score for a given tract were above or below the mean. This demonstrated overall agreement or disagreement between the two measures but did not reflect further gradation. The second visualization was a series of "radar" charts representing the SoVI value, the composite survey score, and the values for each of the selected survey questions, for each tract. This facilitated a finer look at what factors contributed to the perception of vulnerability throughout the study area.

Results

Descriptive Statistics of the Survey Responses

Survey respondents who indicated that they could not recover from losses or damage to their homes were in the minority (37 percent). A greater proportion (41 percent) of the respondents said that they would not be able to pay for protection to allow them to remain in their homes, but nearly two thirds (64 percent) said that they would be able to move if necessary. This suggests that eventual relocation might be a viable option for many residents; however, the proportion for whom recovery could be a problem was significant. These results might reflect some uncertainty, as respondents were not presented with specific costs but were instead asked about their ability to recover in general.

The results varied across racial categories. For example, a greater proportion of African Americans (36 percent) than whites (26 percent) agreed with the statement "I could not recover from losses or damage to my home" (Figure 3A). Likewise, a smaller proportion of African Americans disagreed (36 percent) compared to whites (52 percent), with the remaining respondents answering "neutral." Similarly, a greater proportion of African American respondents (42 percent) agreed with the statement "I will not be able to pay for protections to allow me to stay here" compared to whites (32 percent), and a higher proportion of African American respondents expressed interest in relocating (38 percent compared to 20 percent). For both racial categories, most respondents said that they would be able to move if necessary, although the percentages were slightly lower for African American respondents (59 percent) than they were for whites (67 percent). These findings support the framework of the SoVI, which considers racial minorities, including African Americans, to be more vulnerable than whites. They also align with recent work that foregrounds race in understanding vulnerability (Hardy, Milligan, and Heynen, 2017). It is noted that we focused on white and African American respondents in the study because other racial and ethnic identities had very small sample sizes in the survey.

For household income, the pattern was more varied (Figure 3B). Respondents in the highest income bracket expressed greater ability to invest in preventive measures than members of the lowest brackets. For instance, only 10 percent of top-earning respondents (household incomes greater than $150,000) said that they could not pay for protections against storms or sea level rise, compared to over half (54 percent) of the poorest respondents. In response to the question dealing with recovery, respondents in the $75,000 to $100,000 range seemed the most secure, with only one fourth saying that they would not be able to recover from damage. This was a smaller proportion than that of the income categories above (30 percent) and below it (41 percent). Responses to all of the selected questions were similar for male and female respondents, and only two respondents identified as another gender. Although older people are often considered to be more vulnerable, respondents sixty-five and older actually expressed greater ability to recover and greater control over their situations. Less than one fifth (17 percent) said that they could not recover from losses or damage, and just over one fourth (27

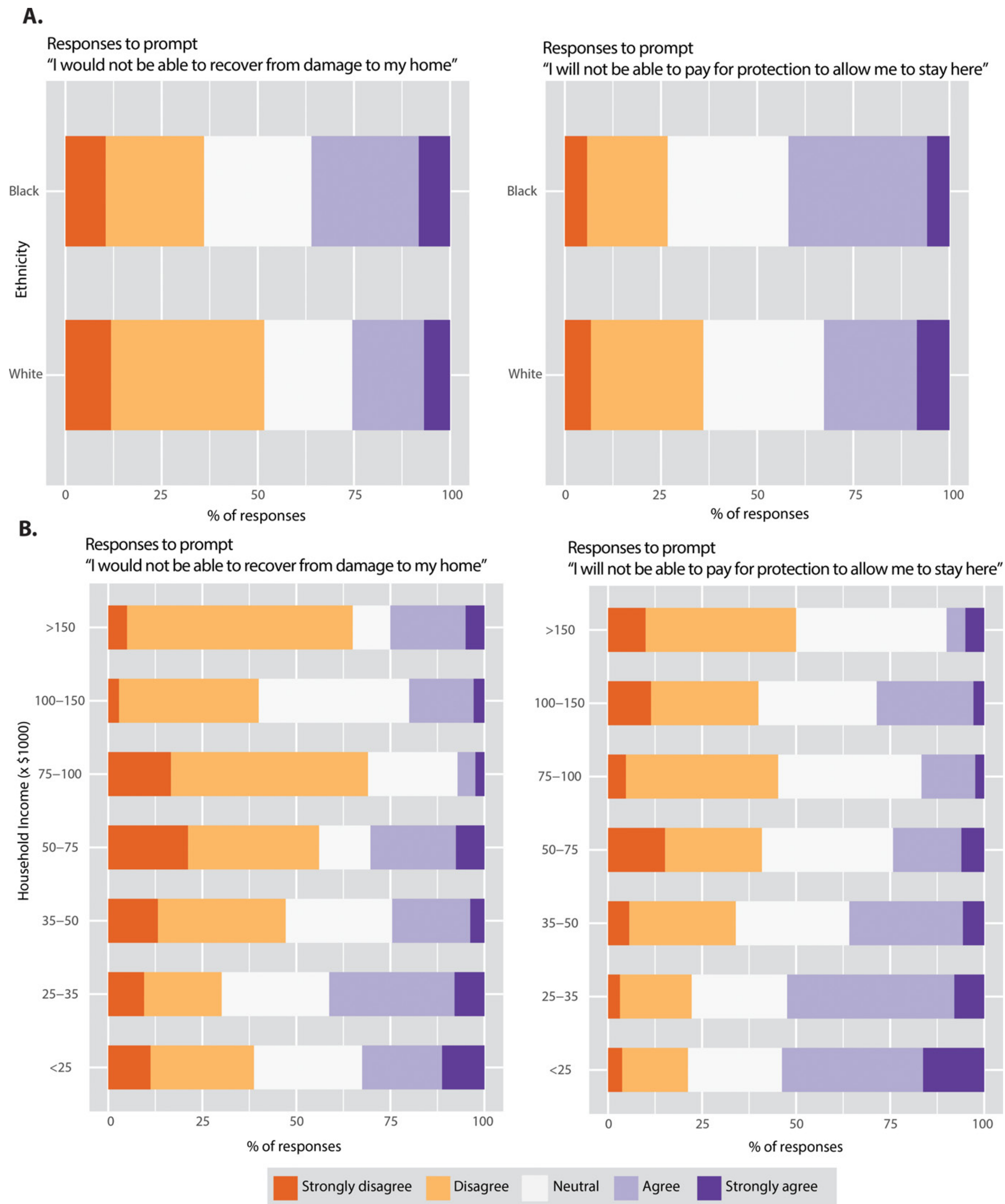

Figure 3. Responses to selected survey prompts by income or ethnicity.

percent) said that they could not pay for protections. By comparison, about a fourth of eighteen- to twenty-five-year-old respondents could not recover (26 percent), and over half (54 percent) could not pay for protective measures.

Mean values of the survey responses also varied somewhat across demographic groups, as shown in Table 2. The composite survey score, derived from a selection of survey questions that were most comparable to the SoVI, indicated that African Americans perceived greater vulnerability than whites, and the poorest respondents perceived greater vulnerability than the wealthiest. The effects of gender and age were less pronounced, however, and the effect of income was nonlinear, with respondents in the $75,000 to $100,000 range seeming to be especially resilient. At the level of individual questions, the results are more complex. Lower income, female, and African American respondents were often less secure in their ability to adapt to hazards and more interested in the option of relocation. The effect of age ran counter to typical social vulnerability thinking, however, as the oldest category gave, on average, the most optimistic responses to some questions. This could be a function of the relative financial stability of seniors in the coastal region, many of whom are retirees living there by choice. Indeed, the interview data provided examples of relatively wealthy, often white retirees who were not especially concerned about storms or sea level rise, despite owning property near the ocean. One of these participants said, regarding his decision to ignore the evacuation order during Hurricane Matthew:

> If you live in a trailer, you got to go. If you live in a shanty, you got to go. If you paid $200,000 or more for your house, and it's not in a flood zone, it's a Category 2 hurricane and you're probably going to be okay … if you paid more than $500,000 for your house and it's well-built, you're going to be fine.

For respondents like this man, financial stability, as represented by the ability to afford a "well-built" home in an exclusive community, outweighed age as a factor in vulnerability. His reference to FEMA flood zones and hurricane categories shows that he has some knowledge of physical risk factors and that his decision to shelter in place during Hurricane Matthew was not based on a lack of information. Instead, he simply did not perceive himself to be vulnerable.

Although wealth was clearly an important consideration, it is noteworthy that perceived vulnerability did not seem to increase consistently as income decreased. This is a departure from the logic of the SoVI, which assumes a more or less linear relationship between wealth and vulnerability (a lower mean income is assumed to correspond with greater vulnerability). The more complex findings shown here are not illogical. It is likely that income's effect on perceived vulnerability reflects a balance between owning material property and having the means to replace or restore it after a disaster event, such that the people with the greatest sense of security in the face of storms and sea level rise might be those in upper and middle-income brackets. The SoVI is not designed to accommodate this level of nuance. This lends credence to the supposition that aggregated demographic indicators, despite being undeniably important aspects of vulnerability, do not encompass all of the ways in which people understand their situation with regard to natural hazards.

Comparative Analysis and Visual Integration

Correlation analyses provided a starting point for exploring the relationship between survey responses and social vulnerability. Correlation coefficients and associated p values are reported in Table 3. For individual responses to the survey, the composite survey score did not correlate with the SoVI, as the p value for the respective correlation coefficient is 0.947. This suggests that respondents' beliefs and attitudes about their own vulnerability differed from the predictions based on demographic indicators. Responses to some questions were correlated with the SoVI, however, as shown in Table 3. Examining these individual questions gives some indication as to why their respective groups correlated as they did.

Higher SoVI scores were associated with greater interest in relocation and fewer community ties. As the social vulnerability of a respondent's community increased, so did that person's interest and intention to move. This makes sense, given the finding that members of more vulnerable demographic groups expressed greater interest in relocating to avoid the impacts of storms and sea level rise and less confidence in the security of their current situation. Of course, this association is not evidence that individuals planned to relocate because of their community's

Table 2. Descriptive statistics of survey responses by demographic category

	Composite survey score		Relocating will be a hard decision		Able to relocate if necessary		Will seek advice on relocating		Worried about unexpected move		Cannot recover from damage to home		Will storm and flood-proof home	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Race														
White	−1.94	2.80	0.31	1.13	0.65	0.93	0.59	0.95	−0.14	1.07	−0.31	1.11	0.55	0.91
African American	−1.41	2.62	−0.05	1.21	0.52	1.03	0.56	1.00	0.29	1.04	−0.02	1.14	0.55	0.98
Income (×$1,000)														
<25	−1.23	2.89	0.28	1.26	0.50	1.13	0.69	1.03	0.14	1.20	−0.06	1.18	0.39	1.01
25–35	−1.08	2.70	0.14	1.13	0.46	1.10	0.73	0.94	0.33	1.08	0.10	1.12	0.46	0.93
35–50	−2.21	2.43	0.26	1.08	0.66	0.85	0.58	0.89	−0.25	1.05	−0.32	1.07	0.66	0.83
50–75	−1.85	3.00	0.42	1.25	0.67	1.07	0.61	1.04	0.00	1.12	−0.39	1.26	0.61	0.91
75–100	−2.48	2.48	0.07	1.07	0.74	0.63	0.21	1.05	−0.26	0.96	−0.76	0.88	0.57	0.94
100–150	−2.31	2.36	−0.11	0.96	0.86	0.55	0.43	0.95	−0.17	0.98	−0.20	0.87	0.54	0.98
>150	−2.45	2.67	0.35	1.23	0.90	0.72	0.70	0.80	−0.05	0.89	−0.40	1.05	0.75	0.79
Gender														
Female	−1.80	2.82	1.17	1.17	0.96	0.96	0.92	0.92	1.10	1.10	1.14	1.14	0.92	0.92
Male	−1.68	2.49	1.10	1.10	0.94	0.94	1.06	1.06	1.04	1.04	1.09	1.09	0.93	0.93
Age														
18–24	−1.82	2.76	0.29	1.27	0.69	1.11	0.81	1.03	0.04	1.18	−0.25	1.23	0.41	1.08
25–54	−1.71	3.06	0.07	1.17	0.55	1.00	0.59	0.96	0.07	1.10	−0.09	1.13	0.62	0.92
55–64	−1.92	2.40	0.34	1.06	0.69	0.83	0.51	0.99	−0.03	1.05	−0.37	1.05	0.65	0.81
>65	−1.71	1.95	0.46	1.10	0.73	0.78	0.37	0.94	−0.24	0.99	−0.63	0.97	0.20	0.84

Table 3. Survey prompts significantly correlated with social vulnerability index

Prompts with significant correlations to social vulnerability score	*r*	*p*
I know most of the long-term, established families in my area	−0.03	0.02
I get more satisfaction out of being in this community than anywhere else	−0.16	<0.01
I would like to relocate elsewhere	0.18	<0.01
I think about moving to another part of my community to avoid future losses or damage	0.11	0.04
I intend to move to another home in the next five years	0.16	<0.01
I intend to move in the next five years to somewhere hurricane risk is lower	0.26	<0.01
Most people like me believe sea level rise will force us out of our homes	0.15	<0.01

social vulnerability. It should also be noted that these associations are not especially strong.

Just as important are the areas in which the survey results and the SoVI were not associated. No significant correlation was present for questions that dealt specifically with ability to recover from storm damage, ability to relocate as necessary, and ability to pay for adaptive measures. Overall, then, the survey results did not necessarily relate to the SoVI in the manner that would be expected if they were both representing the same factors. This is evidence that respondents' assessments of their own situation with regard to coastal hazards largely did not reflect their community's level of demographic vulnerability.

In the upper left of Figure 4 is a choropleth map that compares the SoVI and the composite survey score. It also shows additional patterns that might be worth noting even though they are not statistically significant. Directional agreement between the vulnerability index and the composite survey score is represented by gray (Low–Low) and indigo (High–High) classes. The other two classes reflect respondents who perceived vulnerability differently from the quantitative index. Teal indicates tracts with high (above-average) social vulnerability indexes and low (below-average) composite survey scores. This would include respondents who feel relatively mobile, able to recover from storms, and in control of their adaptation choices, despite their area's high social vulnerability score. Tracts with low social vulnerability indexes and high group scores are colored magenta. These respondents are more pessimistic about their ability to recover from damage or relocate as needed, despite living in places with below-average social vulnerability.

For below-average values, tracts exhibiting agreement between SoVI and composite survey scores were about as common as those exhibiting disagreement. For above-average values, though, a greater percentage showed agreement. This suggests that at least some residents of vulnerable communities perceived themselves to be vulnerable, a perception that might have been heightened by their recent experience with a hurricane.

Visual inspection of Figure 4 suggests a connection between survey responses and population density (lower left of Figure 4) somewhat similar to the relationship exhibited in the SoVI. Many of the tracts with low survey scores were located in less densely populated areas south and west of Savannah. Relatively higher survey scores were found in the densely populated center of Savannah, in some of the coastal tracts, and northwest of Savannah, near Pooler, a rapidly growing town of approximately 20,000 (U.S. Census Bureau, 2010b). Some demographic components of vulnerability can help explain this pattern. In particular, regions of Chatham County with higher population densities also tend to have more African American residents and more renters. As noted earlier, African Americans reported a lesser ability to recover from storm damage and to pay for protection than did whites. Meanwhile, renters might be less interested in physical protective measures than homeowners would be, because they do not have as strong of a financial interest in improving the property.

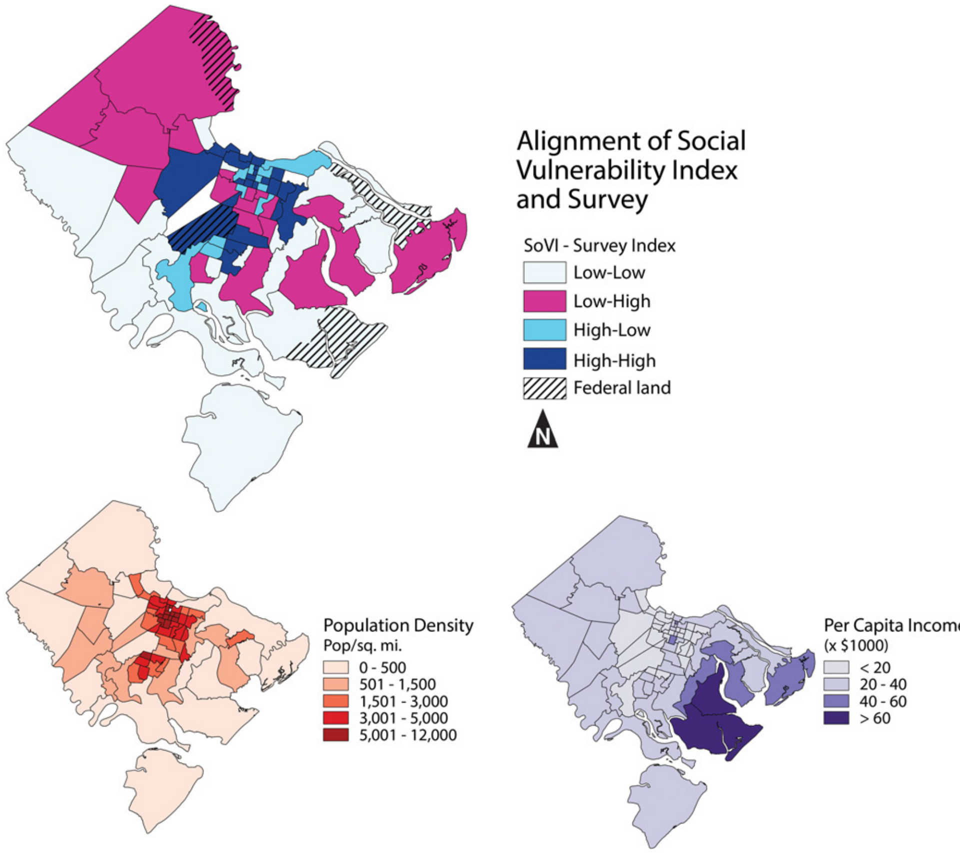

Figure 4. Comparing geographic information system–based index and composite survey scores (upper), with population density (lower left) and per capita income (lower right) by census tract. SoVI = social vulnerability index.

Examining the questions that comprise the composite score offers some further insight. In Figure 5, polygons are census tracts, and responses to individual questions are aggregated to hexagonal bins, revealing the heterogeneity within each census tract. Anytime spatial data are applied to a larger geographic unit, there is a risk of masking variation, a source of statistical bias known as the modifiable areal unit problem. This visualization uses a smaller areal unit to represent more of the variation that exists in reality without providing the locations of individual respondents. Comparing the hexbin-mapped survey results with the SoVI (shown in the lower part of Figure 5) highlights an advantage of an integrated approach to visualizing vulnerability. The survey data explore perceptions of vulnerability at a finer scale than is possible with tract-level census data alone.

Figure 5 shows that, across the county, respondents tended to be pessimistic about their ability to recover from damage to their home. Respondents were more optimistic, though, when asked about their ability to relocate, their concern about an unexpected move, and their willingness to seek advice on relocation. When high social vulnerability values overlapped with low composite survey scores, it is likely that residents' perceived inability to recover from damage was outweighed by their ability to take preventive action and avoid damage in the first place.

Although the survey results and the SoVI did not relate in a statistically significant way, there was some similarity in their spatial pattern as it related to population density. To the extent that density can be used as a proxy for urban development, many respondents in "urban" tracts perceived their vulnerability to be relatively high. The differences between the survey results and the SoVI, however, indicate that important aspects of people's experiences with coastal hazards are not fully accounted for by the SoVI based on this metric. There was some evidence in the interview data to help explain why this was the case. In particular, the interviews pointed to the importance of social connections. Participants who fell into socially vulnerable demographic categories often lived in close-knit communities in which they found mutual

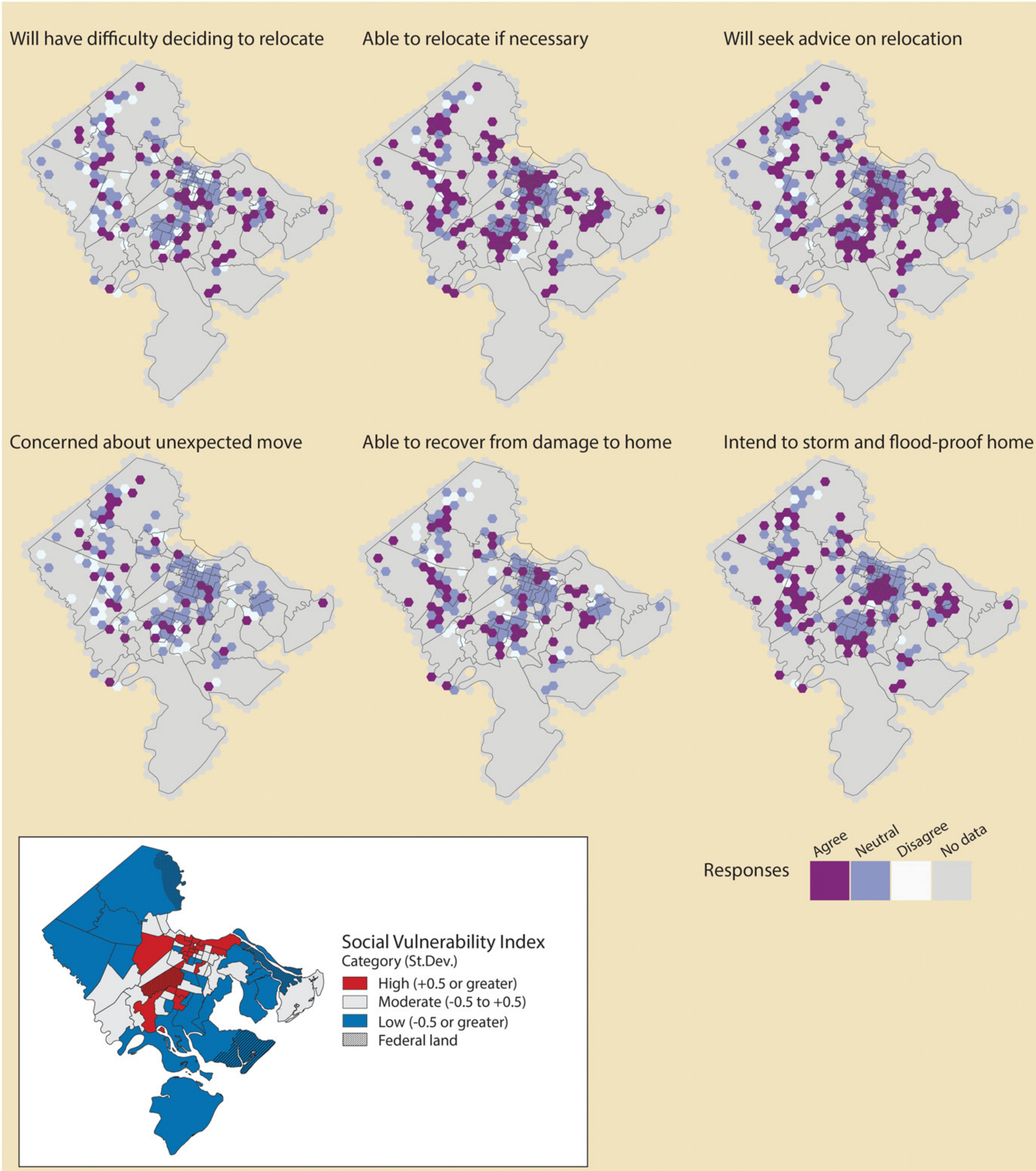

Figure 5. Spatial distribution of responses to selected questions vis-à-vis geographic information system–based vulnerability index.

support—in everyday life and presumably in times of crisis, as well. For example, one lower income participant believed her community would be prepared to recover from the effects of a hurricane in part because

We find other means and ways to maneuver around and thrive on a daily basis. And most of the time, we don't let things get us down or bother us, you know? We work. No matter how you even don't like someone

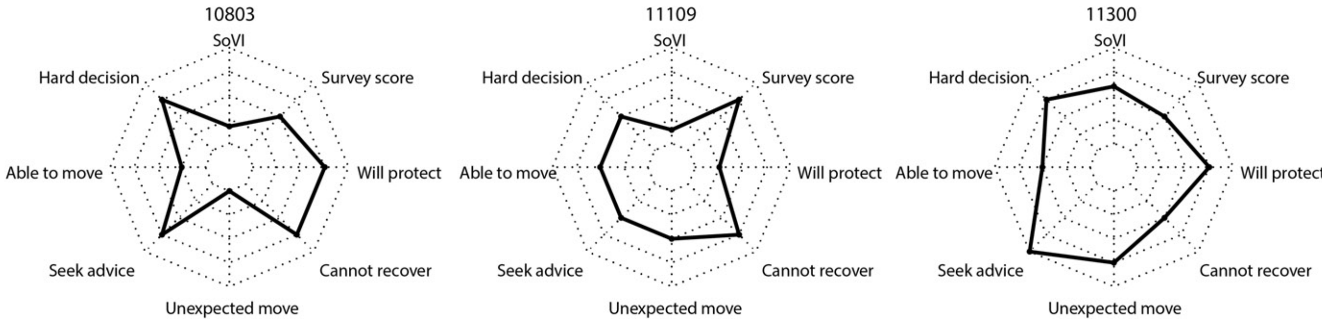

Figure 6. Integrated radar charts for three selected tracts. SoVI = social vulnerability index.

> or what have you. If you can help out, you do your part to help out.

Her reference to "[thriving] on a daily basis" suggests that she believes that the strategies she uses in everyday life would also serve her well in dealing with a natural disaster. Individuals like her did not construe resilience solely as a function of financial capital and physical infrastructure. For them, community support and self-sufficiency would be important components of the recovery process, ones that are not included in demographic indicators.

In part because of these social ties, many participants also expressed a deep sense of place and attachment to their communities, as well as to the coast in general. Although they acknowledged the reality of coastal hazards, they often saw them as inevitable "acts of God," no worse than the forces of nature in other geographic regions (tornadoes in the Midwest and snowstorms in the Northeast were commonly referenced). The combination of attachment to place and acceptance of a certain level of risk helps explain why the survey did not reveal higher levels of concern about worsening hazards or greater interest in migrating away from the coast.

Having established two distinct yet complementary types of vulnerability measures, the survey and interview approach and the SoVI, we took a visual approach to integrate them. In the radar charts (Figures 6 and 7), SoVI values, composite survey scores, and values for the questions that make up the survey score are all plotted along separate axes. The farther the point is from the center, the greater the value, and the points are connected so that the resulting polygon describes the tract's characteristics in summary. The charts in Figure 6 illustrate three distinct locations within the study area. Tract 11109 (center) is near the coast and includes Wilmington Island. Although it ranks low on the SoVI, its residents, on average, tended to say that they could not recover from damage to their homes (labeled "cannot recover" on the chart) and expressed low levels of interest in storm- and flood-proofing their residences (labeled "will protect"). As a result, the tract's composite survey score was relatively high (higher than the SoVI), suggesting that, although respondents were not vulnerable based on demographic indicators, their perceptions reflected an awareness of the physical risk associated with their proximity to the ocean.

Tract 10803 (left of Figure 6) is an area in Chatham County west of Savannah that includes the town of Pooler. It also has a low social vulnerability level, reflecting Pooler's relatively high incomes (U.S. Census Bureau 2010b). Respondents here were pessimistic, though, about their ability to recover from damage and their ability to relocate. They indicated that the decision to migrate would be a difficult one (labeled "hard decision" in the chart) but that they would take measures to protect their homes. They were not concerned about being forced to move by unexpected events (labeled "unexpected move"). Overall, this area's vulnerability based on local perceptions was greater than what was estimated by the SoVI.

Tract 11300 (right of Figure 6) had a moderately high SoVI value. Respondents here expressed concern about being forced to relocate and said that moving would be a difficult decision, although their reported ability to move or recover from damage was moderate. This was offset in the composite survey score by their strong interest in storm- and flood-proofing their homes. Overall, perceived vulnerability as represented by the survey score was in agreement with the SoVI; however, examination of the responses to individual questions revealed more nuanced attitudes.

Figure 7 includes radar charts for a large subset of tracts in Chatham County. They are sorted by SoVI,

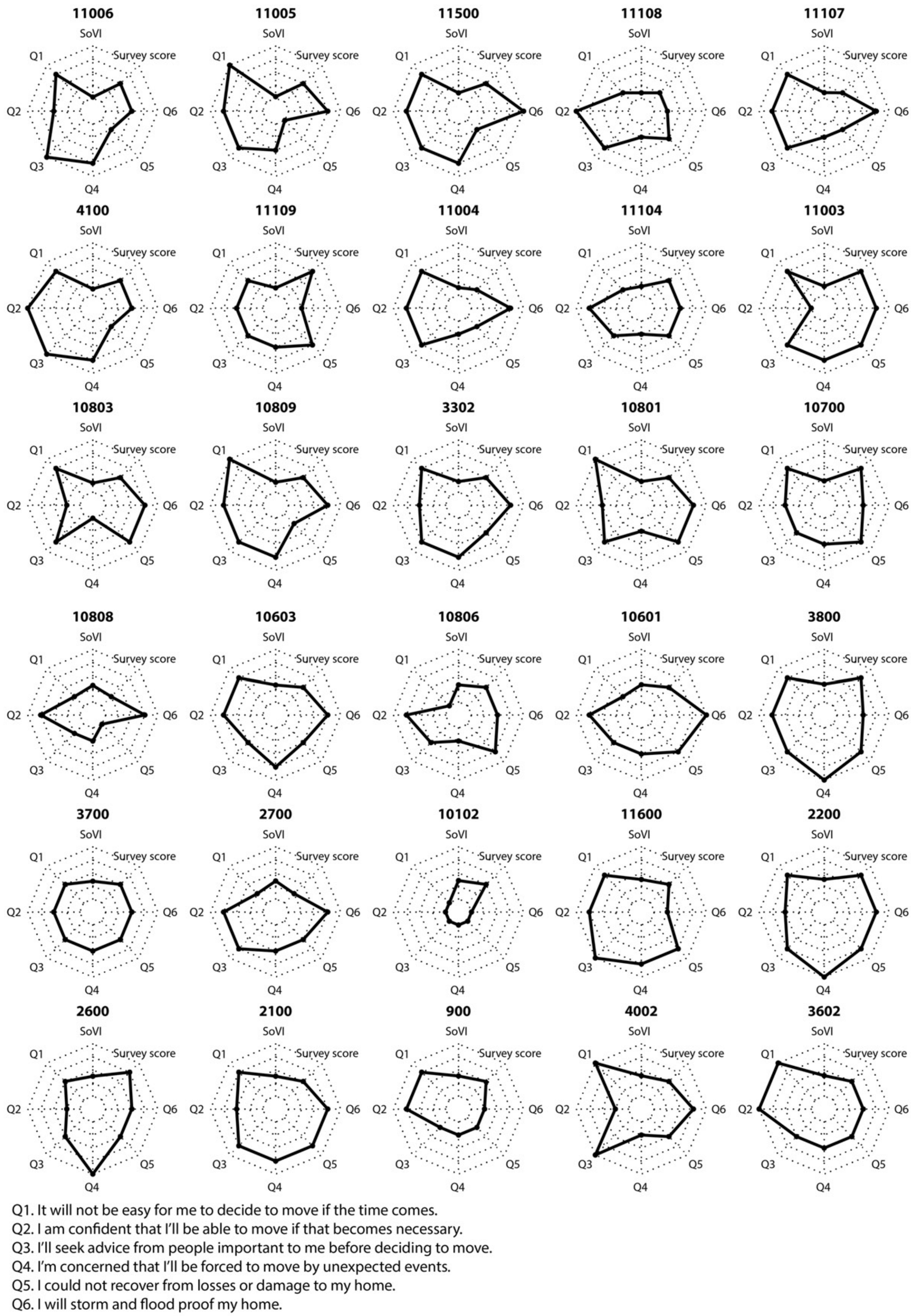

Figure 7. Integrated radar charts for thirty census tracts in study area. SoVI = social vulnerability index.

so Tract 11006, represented by the first chart in the top row, has the lowest value, and Tract 3602, the last chart in the bottom row, has the highest value. As has been demonstrated through the other visualizations, there is a wide range of variation in each measure of the survey within each SoVI level. The shape of the polygons on each chart gives some indication of what this variation looks like. It can be used to discern not only where perceptions were aligned with demographic indicators but also which survey variables contributed the most. Ultimately, this visualization reinforces the idea that local perceptions vary noticeably within any given classification of social vulnerability. When asked specific questions about vulnerability, coastal residents' attitudes vary along multiple axes, including factors such as place attachment, adaptation measures, and migration, not just a spectrum of vulnerable to resilient.

Discussion

We can offer some explanations for the differences between the SoVI and the survey results. Our findings are partially explained by the multifaceted ways in which people, including vulnerable and marginalized people, negotiate their interactions with natural hazards and everyday challenges. As previous research has shown, factors such as self-reliance, social networks, and place attachments are important for some communities' resilience in the face of disaster (Airriess et al. 2008; Xin et al. 2014). Likewise, comments by participants in this study suggest that social ties and self-reliance are important parts of their coping strategies. These factors are not fully captured by those aggregated metrics such as social vulnerability indexes and, consequently, can help explain why local perceptions differ. Specific to this study area, many participants echoed the notion that the Georgia coast is shielded from hurricanes by the physical geography of the South Atlantic Bight. For many participants, Matthew and Irma were exceptions to the norm, rather than evidence that the threat of hurricanes might be greater than previously thought. Chosen from many similar responses, one said:

> But this coast, the Georgia Bight very seldom has a hurricane. We've had two in eleven months. We were way behind on our averages, now we're ahead. We're good for 200 years.

Although the region is not physically immune, as discussed previously, the Georgia coast has seen less hurricane activity than other areas of the Atlantic coast over the last century (Keim, Muller, and Stone 2007). Therefore, many of the participants probably had not experienced a devastating hurricane in Georgia. At the community scale, experience with certain storm impacts is positively associated with risk perception and, in turn, adaptive behaviors (Shao, Gardezi, and Xian 2018). Respondents' optimism regarding coastal hazards is likely influenced by relatively calm hurricane seasons and the corresponding belief in the physical protection of the South Atlantic Bight.

Additionally, wealth remains an essential component of the vulnerability discussion. In this study, the wealthiest respondents often expressed less concern about coastal hazards and perceived less vulnerability, even when they lived in physically exposed places. The poorest respondents had fewer options for adaptation and were often less secure overall. This unevenness can be reflected in policy decisions to the extent that wealthier individuals have greater access to channels of power and greater ability to participate in local governance, as compared with the precarious working class. Affluent residents who feel comfortable with their situation (i.e., not vulnerable) might also be satisfied with government (in)action on climate change and less interested in using their political capital to support policies that would benefit the less resilient.

Taken together, our findings highlight some differences between predominant scientific perspectives and personal perceptions of coastal hazards and vulnerability, as well as climate change more broadly. On the whole, residents in Chatham County, Georgia, perceived themselves to be less vulnerable to severe storms and sea level rise than would be expected based on location and demographic indicators alone. Although some respondents in communities near the ocean were very concerned about coastal hazards, this was not the overall trend. Respondents in areas ranked highly on the SoVI were more interested in moving to avoid the hazards of a coastal location, but they did not consistently rate themselves as more vulnerable than other categories of respondents. Furthermore, the surveyed population was much more concerned about severe storms than about sea level rise, despite the documentation of sea level rise and the dire predictions of current research. The discrepancy between results of the two approaches indicates that a complete picture of a place's vulnerability should also include the perspectives of nonexperts, not just "authoritative" data sources. For researchers and practitioners using a synoptic quantitative approach, additional consideration of vulnerability and resilience at a more localized scale, perhaps using qualitative methodologies, would provide added insight. Demographic indicators should not be taken as the final word on vulnerability in a given place.

Conclusions

This study has made the case for an analysis of vulnerability that integrates quantitative vulnerability indexes based on census data and the local perspectives based on human subject surveys. It has three main findings. First and foremost, an SoVI can be supplemented by integrating local knowledge. The proposed integrative approach demonstrates some effective geovisual methods to achieve that. Second, a consideration of nonexpert knowledge reveals that local perceptions do not consistently align with a SoVI; that is, within a given level of demographic vulnerability, there is a wide range of variation in local perceptions. Third, these differences can be partially explained by the importance of general factors, such as community social ties, that are not fully captured by a demographic index, and by specific factors, such as the lack of recent hurricane activity in the study area, which could lead to lower levels of concern locally.

In terms of broader implications, the findings of this study underscore the importance of local context in vulnerability indexes, and they are also suggestive of a gap between the academic communities of hazards and climate change vulnerability and the perspectives of the nonexpert public. Where climatologists see the potential for catastrophic damage to coastal communities, and social scientists see these environmental processes working in tandem with uneven development to further marginalize certain people, local perceptions often do not reflect corresponding levels of concern. To some extent, this discrepancy points to a need for better communication between the academic community and the nonexpert public.

Our approach does come with some limitations. As discussed earlier, any geospatial analysis of social data must reckon with the modifiable areal unit problem. In our visualizations for this study, we have attempted to capture variation within geographic units without introducing a false sense of precision; however, the problem still comes into play when survey responses are aggregated to larger areas. Similarly, the spatial distribution of survey responses likely has some impact on composite survey scores, as does the percentage of different demographics represented in the survey. To control spatial distribution, future studies could choose to follow a similar approach with mailed or door-to-door surveys. Due to these limitations in scope and the inherent challenges of spatial representations, this study should not be taken as a definitive or comprehensive assessment.

Nonetheless, from the standpoint of critical GIS theory, the study made a compelling case that a critical approach to vulnerability mapping can yield a more nuanced understanding of the local situation, demonstrating the ability of GIS to be "constructively critical" (Thatcher, Bergmann, and O'Sullivan 2018). Drawing on theoretical arguments for local knowledge and using an analytical design that incorporates nonexpert perspectives, we incorporated localized perceptions into new visualizations alongside an established method of mapping vulnerability. As geospatial technologies are diffused into the wider geoweb, accessed more broadly by policymakers, and connected more closely with everyday life (Leszczynski and Crampton 2016), the underlying data and assumptions continue to be worth exploring for vulnerability research (Zou et al. 2018). Here we have shown that this research framework can be applied productively to a study of coastal vulnerability. This approach holds value as a method for integrating disparate data sources in GIS, and the findings should be of interest to researchers and practitioners whose work deals with social vulnerability indexes in particular and coastal hazard vulnerability more broadly.

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